Australian Government

Department of Infrastructure and Transport

Bureau of Infrastructure, Transport and Regional Economics

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Road

Evaluation of the National Black Spot Program

VOLUME 3: CONSULTANTS' REPORTS

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May 2012 / INFRASTRUCTURE 1189

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An appropriate citation for this report is:

Bureau of Infrastructure, Transport and Regional Economics (BITRE), 2012, Evaluation of the National Black Spot Program Volume 3 BITRE Report 126, Canberra ACT.

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Published by

Bureau of Infrastructure, Transport and Regional Economics

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December 2006

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STRATEGIC INFORMATION CONSULTANTS

DATA ANALYSIS AUSTRALIA PTY LTD

A Review of the Statistical Methodology Used in the National Black Spot Program Evaluation

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Project: BTRE/1

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1. Introduction

The National Black Spot Program (NBSP) provides funding to address road safety issues associated with identified parts of the road network. The identification of appropriate sites uses a transparent set of objective criteria, of which the past history of crashes is a key component.

For the purposes of evaluating the NSBP and to continually improve the identification criteria, it is appropriate to quantify the costs and benefits. Such an evaluation is necessarily statistical in part since it must account for the natural or random variation in the numbers of crashes over both time and sites.

This report develops the appropriate statistical methodologies to be used and makes recommendations on the best approaches.

2. Overview of Current Methods Used

The two major previous evaluations were published as Report 90 and Report 104 in 1995 and 2001 respectively. Here we review the statistical aspects of these briefly to determine where improvements might be appropriate.

For each report it is necessary to also consider the Black Spot site selection process since evaluation must account for any effects due to the selection as distinct from the treatment itself.

2.1 Report 90 – Evaluation for 1992-94

This was a thorough report with many appendices covering statistical issues.[1]

2.1.1 Identification of Black Spots

The report had an extensive discussion of methods of identifying potential Black Spots for treatment, including detailed consideration of the problem of making decisions on relatively small crash counts. Three broad approaches to identifying black spots are based on crash numbers, crash rates related to exposure to risk, and qualitative methods.

Several statistical techniques are available to identify Black Spots:

- The confidence interval technique involves comparing the crash rate at a site with the mean crash rate of similar sites to which a multiple of the standard deviation is added.

[1] Bureau of Transport and Communications Economics, *Report 90, Evaluation of the Black Spot Program*, Australian Government Publishing Service, Canberra, 1995.

- The statistical quality control technique involves calculating an upper control limit for crashes by using the normal approximation to the Poisson distribution.
- The technique of potential crash reduction employs regression analysis to estimate the expected number of crashes at particular categories of sites that is then compared with the observed number.
- Crash severity indices can be constructed using numbers of crashes corresponding to different levels of severity. These are combined into a composite index for a particular area then compared with the indices for specific sites. Bayesian methods may also be used in identifying black spots. The Bayesian approach combines sample information with other available relevant information about sites.

Overall Report 90 appears to address the issue of selection to encourage more systematic methods for the future rather than to consider their effect on evaluation.

2.1.2 Evaluation Methodology

A 'before and after' approach was adopted, which involved comparing the observed number of crashes after treatment with the expected number had there been no treatment. Because the 'expected' number cannot be known, it was estimated using the number of crashes before treatment and other appropriate data. It is assumed that the number of crashes observed before the treatment was applied is a reasonable estimate of the number of crashes that would have occurred in the after period without the treatment. This critical assumption can be subject to systematic regression- to-mean bias.

Besides the effects of the treatment itself, a range of extraneous factors can contribute to an observed decline in crashes at a site after treatment. These factors include:

- Site specific factors (events such as improvements in weather conditions at the site after treatment);
- Maturation (the process by which crash data change over time, especially the generally declining trend in crashes per unit of exposure over time);
- Regression-to-mean (the tendency of a variable such as the number of crashes which has an extreme value during a particular time period to 'regress' or move closer to its mean value in a subsequent period);
- Under reporting of crashes;
- Effects of publicity about dangerous sites on drivers;
- Statistical instability of crash data; and

- The possibility of 'migration' of crashes to alternate sites in the vicinity of treated sites.

While Report 90 had Appendix VI devoted to the regression-to-the-mean effect that could bias the evaluation to a favourable result, it is not clear to what extent this actually affected the analysis. In addition, some of the statistical procedures were unnecessarily simplistic – for example, Appendix VIII outlined a method for testing the statistical significance of changes in crash numbers that used methods from 1958 that, while correct, predate modern computerised methods such as generalised linear models. This, together with an acknowledged limitation in time for the analysis, suggests that more could have been done with better time and statistical resources.

It was not possible to control for all extraneous effects in this study. Appropriate control areas in each jurisdiction were used to calculate the 'expected' crash numbers. These control areas accounted for general community crash trends and would therefore in the process have made allowance for any changes in the weather. Having assessed available data, most other effects were considered relatively insignificant.

The benefits of Black Spot treatments were estimated in terms of crash costs avoided. Two methods of calculating crash costs were used: crash type (where crashes are costed on the basis of the type of vehicle movements just before impact) and crash severity (where crashes are costed on the basis of the highest level of injury occurring in the crash). The basis of both methods was the human capital approach, which measures the lost output or productivity of individual crash victims due to premature death or disability.

The cost-benefit analysis of the projects was carried out at a discount rate of 8% and alternative rates of 6% and 10% as recommended by the Department of Finance (1991). Project lifetimes (the periods during which crash reduction benefits were assumed to continue) were based on data provided by the states and territories. The results of the evaluation are reported in terms of the net present value (NPV) and benefits-cost ratio (BCR).

2.2 Report 104 – Evaluation for 1996-2000

The second report[2] followed a similar format to the first.

[2] Bureau of Transport Economics, *Report 104, The Black Spot Program 1996-2002, An Evaluation of the First Three Years*, AusInfo, Canberra, 2001.

2.2.1 Selection of Black Spots

The selection process is not explicitly discussed beyond recording the rules to be followed.

2.2.2 Evaluation Methodology

This study adopted a 'before and after' treatment approach, chosen because of its compatibility with the nature of the data available for analysis. A Poisson regression model was used to determine whether Black Spot treatments had a statistically significant effect. The model $\mathbf{E}\{\ln(r_{ij})\} = \mu_I + \beta z_j$ is fitted using a weighted generalised linear model technique employing a Poisson error structure, where the associated weight for each r_{ij} is the length of the observation period on which the rate r_{ij} is based. Ideally, the weight should be the annual average daily traffic (AADT), but this information is not always available.

The statistical analysis was done in SAS. The actual procedure outlined in Appendix XIII is somewhat curious, appearing to do a Poisson regression but with crash frequencies rather than crash counts. However it can be shown to be mathematically equivalent to the more logical procedure of using an offset in a generalised linear model.

No attempt seems to have been made for correcting for regression-to-the-mean or for over-dispersion that was present.

The benefits of Black Spot treatments were estimated in terms of crash costs avoided. Crash costs were estimated on the basis of crash severity. This analysis disregards other benefits and costs that might arise from treatment.

The benefit-cost analysis was done using treatment effects obtained from the sample of projects. The analysis was completed using a 5% discount rate. This rate is an approximation of the geometric mean of the Federal Government 10-year bond rate at the time the funds allocated to the Black Spot program was spent – that is the opportunity cost to the Federal Government of borrowing the funds. A sensitivity analysis was conducted at rates of 3%, 7% and 8%. Varying the discount did not significantly alter the findings of this evaluation.

3. Methodology Review

3.1 Statistical Issues

A starting point for developing the most appropriate statistical methods is to simultaneously consider the questions that need to be answered in the review and the statistical properties of the data available.

The basic question can be phrased as "when an identified Black Spot is treated, does this lead to a measurable reduction in road trauma?". This question can be asked in a number of different ways, such as "does treatment on average lead to a reduction in trauma?" or "in what circumstances does treatment of a Black Spot lead to a significant reduction in trauma?".

In each case the question has:

- a before and after context, meaning that we are looking for changes over time; and
- a need to link any apparent change (a casual relationship between treatment and trauma) to an actual mechanism for change (a causal link).

These two properties of the question tend to focus the statistical methods on what is broadly termed intervention analysis.

The data relevant to the study measures the level of road trauma. While it is possible to consider many possible measures of trauma, for example working days lost; in practice the only reliable data is in the form of crash events. Since crashes are discrete events which either do or no not occur, there is a certain unavoidable crudity to such measures.

3.2 Statistical Framework

Most of the quantitative data available is in the form of counts – counting crashes of varying types, counting persons involved and counting injuries or fatalities. This simple fact constrains much of the statistical analysis.

In this regard, counting crashes is almost always more appropriate than counting fatalities or injuries since within a crash the fatalities and injuries are not statistically independent. If it is necessary to analyse (say) fatalities, it usually requires a model of the numbers of crashes first and then a model of the number of fatalities per crash.[3] In what follows, we focus on the analysis of the number of crashes.

[3] The analysis of fatalities by a two stage model is not impossible as the *compound distribution* can be derived from the distribution of the number of fatalities per crash and the distribution of the number of crashes. A simple introduction to such compound distributions is found in N.J. Bailey, *The elements of Stochastic Processes*, Wiley, 1964, p5-10. The usual problem encountered is that there is a paucity of models for the number of fatalities per crash.

3.2.1 Poisson Models

The standard probability model for the counting of events is the Poisson distribution. This gives the probability of a random quantity N taking the value n as

$$P(N=n)=e^{-m}\frac{m^n}{n!}$$

where m is the average or expected value of N. The defining assumption behind this model is that the events being calculated are statistically independent of each other.[4]

An important property of the Poisson distribution is that the sum of two independent Poisson variables is itself a Poisson variable. Hence if the number of fatal crashes and the number of non-fatal crashes are individually Poisson variables then the total number of crashes is expected to be a Poisson variable. Hence the use of this model provides a high level of consistency in the analysis of complex events that might be categorised in a number of different ways.

The standard deviation of a Poisson variable with mean m is $\sqrt{m}$. Hence the relative standard deviation (sometimes called the coefficient of variation) is $1/\sqrt{m}$. This demonstrates that Poisson variables with a low mean value can appear to be very erratic. This is the basis of many somewhat dated statistical rules of thumb about minimum counts required for statistical analysis.

The Poisson distribution is a member of the *exponential family* and hence it is possible to use quite sophisticated statistical methods like generalised linear models as described below.[5] Exact methods are often available and should be used where possible.

A common mistake made with count data is to assume that a zero count contains no information and can hence be omitted from the data. Sometimes this mistake is made without realising it when aggregating a database of individual crashes, a process that may omit time periods with no crashes. This is incorrect since a zero count does contain valuable information, namely that

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[4] A classic discussion of where the model has worked surprisingly well is found in W. Feller, *Introduction to Probability Theory and its Applications*, Wiley, 1950-68.

[5] Exponential families of distributions can be thought of as generalisations of the normal distribution in that they have a relatively simple relationship between their mean values and their full probability distributions. This simplicity permits simplified statistical inference and a common computational framework. See for example O.E. Bandorff-Nielsen, *Information and Exponential Families in Statistical Theory*, Wiley, 1978.

the expected count cannot be too large. Failure to include the zeros in the analysis will create biases. Hence it is essential to include the zero count records.

3.2.2 Crash Frequencies

It is commonly appropriate to consider crash rates, or the number of crashes of a certain type per unit time. For example, at a particular site it may be appropriate to consider the number of serious crashes per year. Reducing the measures to this form makes it possible to compare rates before and after treatment even when time periods of different length are used.

A crash rate is essentially a count divided by the length of the time period. The statistical properties derive from the random nature of the numerator and as discussed above, this can usually be assumed to be Poisson. The rate itself is not a simple count (it in unlikely to even be an integer) and hence is generally *not* Poisson.

3.2.3 Generalised Linear Models

Generalised linear models[6] extend the concepts of classical linear regression models in two ways:

- 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.
- Instead of assuming that the mean value of the distribution is a linear function of the parameters, it assumes that the mean value is possibly a non-linear function of the parameters. (The term for this non-linear function or its inverse is the *link function*.)

Generalised linear models are often associated with a standard way of specifying models using a model formula. While this is particularly convenient in the context of interactive modelling, it is independent of the concept of generalised linear models. This is implemented in standard programs such as GLIM, S Plus, R and Stata.

For each distribution used with generalised linear models there is a canonical link function, one for which certain mathematical properties such as sufficiency are particularly convenient. The canonical link should not always

[6] The models were originally introduced by J.A. Nelder and R.W.M Wedderburn, *J. R. Statist. Soc A* **135** 370-384, 1972. A readable standard text is P. McCullagh and J.A. Nelder *Generalized Linear Models 2nd. ed.*, Chapman and Hall, 1989.

be used as sometimes it does not make much structural sense.[7] In the case of the Poisson distribution the canonical link is the logarithmic function. Fortunately this is statistically well behaved and is often the preferred link.

The treatment of crash frequencies or rates requires special attention in the generalised linear model context. As discussed above, the rate itself cannot be expected to be a Poisson variable but the numerator in its calculation can be. The denominator in the rate is usually known and is non-random – for example, the number of days in the month. This situation is usually handled by modelling the Poisson numerator, using a logarithmic link and including a fixed *offset*[8] term in the linear component equal to the logarithm of the denominator. This procedure only works with a logarithmic link. Most software for generalised linear models allows the use of an offset term.

There are two measures that can be used to test the goodness of fit of a generalised linear model:

- The deviance relates closely to the likelihood and for a Poisson model is of the form:

$$D = \sum_{i=1}^{n} d_i = \sum_{i=1}^{n} 2n_i \log(n_i / e_i) - (n_i - e_i)$$

  where n_i is the ith data value and e_i is the expected value for this under the model.

- A Pearson residual more closely parallels the traditional sum of squares and is closely related to the Pearson χ^2 test for tables. For the Poisson distribution it is given by

[7] An example of a poor canonical link is the reciprocal function that is associated with the Gamma distribution. In practice the logarithmic link is the most commonly useful link, followed by the linear link. The reciprocal link is virtually never used.

[8] The offset term in generalised linear modelling is an explicit term added to the regression equation. In the case of standard linear regression this is normally handled by subtracting the term from the variable being modelled. However this simple approach is not suitable in the generalised linear modelling context due to both the non-linearity and the distributional assumptions.

$$R = \sum_{i=1}^{n} r_i^2 = \sum_{i=1}^{n} (n_i - e_i)^2 / e_i$$

where $r_i = (n_i - e_i)/\sqrt{e_i}$ is sometimes called a standardised residual. The standardised residual is a useful quantity when investigating possible shortcomings of a model – it is discussed later.

The choice of these two measures is somewhat arbitrary. Generally the deviance measure has superior mathematical properties but the Pearson measure is more readily interpreted.

3.2.4 Weighting

Weights are used for two distinct purposes in statistics:

- Making a sample data set reflect the proportions of respondent types actually in the population. These are best described as *expansion weights* since they are often factors used to scale up from the sample to the population, effectively giving for each unit in the sample the number of population members they represent. Expansion weights are commonly used with survey data so that simple tabulation procedures can then be used.
- Making units in a data set contribute to an estimation procedure in a way that reflects their accuracy or reliability. For example, in linear regression the weights should be inversely proportional to the error variance. While there is no commonly used term for such weights, they may be called *variance weights*.

There are two tasks in an evaluation which require different approaches to the weights:

- The testing whether the effects of intervention are real and then the estimation of the change parameters together with the testing of their significance requires the best possible estimation. For this testing the variance weights should be used. Where the data is in the form of Poisson counts, the generalised linear model procedure automatically calculates these weights and *no further weighting should be used*.
- In calculating the total effects of the intervention, it may be appropriate to account for factors such as traffic counts to determine just how important each type of intervention is. For this step some form of the expansion weight may be appropriate, which is generally applied in a simple mathematical model for the effects based upon the estimated parameters.

3.2.5 Time Series

Road crash data is often thought of as a time series, or a sequence of measures over time. A typical example of a time series is daily or monthly crash numbers.

The times series structure is only important if it affects the statistical properties and hence the analysis. For example, if a higher than expected number of crashes in one month is likely to be followed by a high number the next month, this suggests a lack of independence. The key term here is “than expected” – only the unpredictable or random component is relevant. Predictable components such as seasonal variation can and should be modelled to eliminate their effect from the analysis.

Usually the term “time series models” refers to situations where the models directly account for dependence of the random component at one time on the random component at nearby times. This dependence is often described as autocorrelation – a series being correlated with itself – although once the distributions are no longer normal it is necessary to consider other forms of dependence beyond correlation.

Road crash counts are known to be affected by a number of time dependent factors that can be modelled. These include:

- **Season or time of year**. The time of year affects road crashes in a complex manner, since so many mechanisms have a time of year relation. These include the weather, hours of daylight, school and other holidays, public transport patronage and levels of travel. Some of these effects change gradually through the year while some such as long weekends are highly specific. In general adequate modelling of the time of year effect is critical.
- **Day of the week**. It is well known that certain types of crashes are strongly influenced by the day of the week – for example, drink driving is a major issue on Friday and Saturday nights. If modelling using calendar months it is necessary to allow in the analysis for the numbers of each day of the week. Alternatively the analysis should use time units that are multiples of a week.
- **Time of day**. Time of day is a major issue but is rarely of concern from a time series viewpoint as it is common to look at (say) separate series for daytime and night-time crashes. The correlation between these is only of concern when considering joint inference for two such series.
- **Weather, particularly rainfall**. Weather is obviously strongly seasonal and hence medium term weather effects are often indistinguishable from other time of year effects. On a shorter timescale it is possible to observe a strong relationship. The most plausible mechanisms contributing to crashes are reduced visibility and wet roads. The latter is directly

measured on a daily basis at many places in Australia while the former is not. Temperature is not thought to be a major direct contributor to crashes (it does affect tyre failure but that is relevant to only a small component of crashes) but it may relate to conditions that affect visibility.

Ideally the modelling of such factors eliminates any time series statistical structure. If some remains, the statistical analysis is potentially very complex. While some theory exists for Poisson valued time series, it is not easily applied and has many constraints, and is usually best avoided. In addition, time series models usually are poor at handling gaps in the series, such as might be the case if the period of construction work is excluded.

The easiest way to explore whether a time series model is necessary is to examine the standardised residuals and to test for autocorrelation.

3.2.6 Time Periods for Data Aggregation

Count data raises the issue of the time periods over which counts are taken. For road crash data it is rare to consider counts for less than a day, but the question is raised as to whether they should be aggregated to a week, a month, a year or some other period. Several points need to be considered:

- Hence using the properties of the Poisson distribution the relative standard deviation will be less, giving more readily interpreted data.
- The shorter the period the easier it is to relate the counts to explanatory factors. For example, if daily data is used it is easy to model the effects of the day of the week, holidays and the weather.

If a Poisson model with a logarithmic link is used, it can be shown that using a shorter than necessary period does not change the result of the analysis – this is due to the sufficiency property associated with this combination of distribution and link function.

3.3 Over-Dispersion

The Poisson model implies a direct relationship between the mean (or expected value) and the variance – they must be equal. This means that the goodness of fit of a model as measured by the deviance can be directly gauged against this criterion and a decision made as to whether the fit is adequate.[9] The deviance D is expected to have a *Chi Square* distribution with the degrees

[9] The same situation arises with the Binomial distribution where again the variance is directly determined from the expected or mean value. We do not discuss that here since firstly most road crash analysis uses Poisson type models and secondly most Binomial models can be also posed as a Poisson model.

of freedom given by the number of data values less the number of model parameters. A formal test of this is easy.[10]

In practice it is not unusual for the goodness of fit measure (the deviance) to be greater than expected. This is termed over-dispersion.[11] This can be due to 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 structure is not precisely correct and the lack of fit appears as additional variance.
- There is a dependency between events being counted (crashes) that inflates the variance. This attacks the basic assumption of the Poisson distribution.

The first two of these possible causes are generally manageable provided that the relevant data is available. They suggest that poorly fitting models should receive special attention to determine whether they can be improved to eliminate the over-dispersion.

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.)

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 can lead to an understatement of the standard errors associated with the estimates, giving false levels of significance. Hence it is important to obtain realistic values for these standard errors. There are three distinct approaches to this – the use of the negative binomial model, through approximate techniques, or through resampling methods.

3.3.1 Negative Binomial Methods

It is possible to add variability to a Poisson variable by considering its mean value is itself random with an appropriate distribution. That is,

[10] This is a simple test suitable when the number of parameters in the model is not too large and no single data values have too greater influence on the fit – a more precise one should take into account the structure of the explanatory variables in the model.

[11] A good discussion of this is found in the *Encyclopedia of Biostatistics*, ed. P. Armitage and T. Colton, Wiley 1998, 4, 3226-3232. (Despite its title this encyclopaedia has an exceptionally good coverage of most modern statistics, not just biostatistics.)

$$P(N = n \mid M = m) = e^{-m} \frac{m^n}{n!}$$

and M has a prescribed distribution. Most commonly M is assumed to have a Gamma distribution, and the result is called a Gamma-Poisson mixture. The Gamma distribution may be assumed to have a probability density function

$$g(m) = \frac{m^{\alpha-1} e^{-m/\beta}}{\beta^{\alpha}\Gamma(\alpha)}.$$

This gives the unconditional distribution for N as

$$P(N = n) = \binom{n+\alpha-1}{n} \left(\frac{\beta}{\beta+1}\right)^{n} \left(\frac{1}{\beta+1}\right)^{\alpha},$$

which is known as the negative binomial distribution. While the mathematics is not particularly difficult, this result is of limited application since:

- The negative binomial distribution does not have particularly good properties for estimation; and
- The assumption of the Gamma distribution for the mean parameter of the Poisson is usually based more upon mathematical convenience rather than any underlying reason for believing that this might be true.

The mathematics of how to fit models with negative binomial distributions is too complex to present here. The computations can be organised as a variation on the standard generalised linear model algorithm and are available in several software packages.

3.3.2 Approximate Techniques

The most common method is to adjust the standard errors by a factor representing the over-dispersion. This is usually $\sqrt{\frac{D}{n-p}}$ or $\sqrt{\frac{R}{n-p}}$ where p is the number of parameters in the model. This is sometimes caller the quasi-likelihood approach. It is simpler to implement than the negative binomial approach and in practice is just as attractive since the assumptions of the negative binomial distribution are hard to justify.

3.3.3 Bootstrap Techniques

In essence bootstrap techniques repeats the estimation procedure many times with different data sets, each derived by sampling with replacement from the original data. Hence it can be applied wherever such resampling does not conflict with the assumptions of the model and it cannot be applied in its simple form to time series data where the sequencing must be maintained.

The statistical properties of the estimates can be derived from the manner in which the estimates from the different samples vary. The standard errors calculated by the base estimation method are ignored and hence the bootstrap standard errors do not depend upon model assumptions, making them very attractive. Today the computer power available makes these methods feasible even for reasonable sized data sets.

Relatively few statistical software packages implement the bootstrap directly. However some make it possible for the user to readily implement it through their programming language. For example the program R (and the earlier program S that it copies in many respects) makes this very easy through the sample function and its basic looping constructs. Stata v9 documentation also indicates that it can do bootstrapping[12].

Where the treatment of over-dispersion is critical, the extra effort involved with the bootstrap is recommended.

3.4 Selection Bias

The Black Spot treatment sites were chosen in part on the basis of their crash statistics – the same statistics that are then being used in their evaluation. This means that the data itself is influencing the questions being asked for it, which conflicts with one of the basis principles of inference. Furthermore, it introduces a potential bias into the analysis that will show the NBSP in a misleadingly favourable light.

The reason for this is simple. Some of the sites would have been chosen due to *chance* fluctuations in crash levels that gave the appearance of high crash rates. For these, even in the absence of any treatment, the future crash rates would be expected to be lower, in line with their long-term values. This reduction may however be falsely ascribed to the treatment. The effect has been frequently discussed under the name of *regression-to-the-mean*.

Regression-to-the-mean can be minimised by ensuring that selection is made on the basis of as much information as is possible. This typically means:

- Using a number of years crash data to minimise the random fluctuations; and
- Using non-crash assessments such as engineering evaluations that are not directly dependent upon crash numbers.

However we recognise that the Black Spots currently being evaluated have already been chosen and the problem of regression-to-the-mean must be

[12] See http://www.stata.com/capabilities/boot.html for more information.

handled *post hoc*. The major tools for this are the proper use of crash data between that used in the selection and the implementation of the treatment and the proper use of control sites.

There is also some potential for a more subtle form of selection bias – the specific treatments applied to a Black Spot may reflect the circumstances of the most recent crashes. To the extent that the composition of this set of crashes is random and may not reflect the average composition in the longer term, the treatments targeting that composition may appear to be particularly effective.

Other factors include:

- The selection of Black Spot treatment sites varies by state. For example, Queensland sites are selected by local government, while other states have a more centralised selection process. (In Queensland local governments are much larger than in other states.) It is not clear what the effect of this might be.
- Up to 20% of sites were selected based on a road safety audit, which is likely to reduce the number of sites chosen due to random fluctuations in crash numbers. Others were chosen using criteria such as the number of fatalities within a certain number of years must have been greater than a chosen threshold. In general the audit based selection will introduce less of a selection bias to the analysis and thus can be used to quantify the selection bias. This suggests that type of selection should be included in the analysis.

3.5 Control Sites

It is suggested that control sites be compared with the chosen Black Spot sites, in order to gain an understanding of random variation in the absence of treatments and, more importantly, overall trends.

Ideally control sites should be as similar to treatment sites as is possible. In the extreme case each treatment site should have a matched control site against which it can be compared.[13] Matching can be done on the basis of a number of variables, with the general aim of having sites that would follow the same

[13] This is somewhat different from the use of controls in the widely used clinical case-control methodology. For this, when studying a condition that is relatively uncommon the first step is to identify cases. For each case one or more control is then selected from the same population at random but in some sense matched. For example in the classic study of smoking and lung cancer, Doll identified as cases admissions of people with lung cancer in certain London hospitals. For each case a control was selected by randomly selecting someone admitted on the same day at the same hospital and in the same age-gender group. If smoking had no relation to lung cancer then the cases and controls would have been expected to have the same level of smoking.

pattern of crashes as the treatment site if the treatment had not been applied. Typical variables might be:

- Geographical location – physical closeness of treatment and control sites is likely to mean that they are subject to similar weather conditions, similar enforcement and similar drivers.
- Type of site – if the treatment site is an intersection it makes sense that the control site also is. In addition it is sensible to ensure that the road types match.
- Traffic volumes – the sites should have similar traffic levels.
- Similar safety level – this is difficult to achieve as the treatments are in many cases applied to sites that have the worse crash history. However there are two statistical reasons for trying to achieve this. First is the simple issue of comparing like with like. The second is one of efficiency – if the control sites do not have enough crashes then they add little statistical information.

This raises an issue of control site selection bias. In the same way that the selection of Black Spots for treatment can lead to apparent post treatment reductions in crashes through regression-to-the-mean, control sites may show apparent increases in crashes if they are heavily affected by not being selected for treatment, thus showing an increase in crashes as they regress to their mean.[14] To overcome this it is best to choose control sites that if anything have a selection bias similar to the treatment sites.

Sites that *could* be used as control sites include those that were considered but not selected for Black Spot treatment (ideally those with high crash rates but only missing for other reasons) or sites that were selected but treated at a much later date. These are ideal since they can match treatments on the last criterion – similar safety levels.

3.6 Censored Information

Some of the information collected about crashes is problematic because it is *only* collected for crashes. This includes road and weather conditions, factors that can be expected to have a significant impact. The trouble is that this information might not be available for times when there are no crashes.

This is a form of censoring of the data. Unfortunately the censoring is related to the response variable, whether or not there is a crash. Hence any attempt to

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[14] This effect of control sites adjacent to treatment sites showing increases in crashes can also be due to crash migration. In many situations it is not possible to distinguish between the two effects as selection bias is not quantified. Much of the discussion about this lacks real evidence.

use the data through a statistical model has the potential to introduce bias unless the model is absolutely correct.

Where this information is available in an uncensored form – for example weather data from the Bureau of Meteorology – it can be valuable in understanding crash rates.

4. Data Management and Software Issues

4.1 General Principles

The outcome of any analysis is influenced by the assumptions of the models and the data itself. While the model assumptions are often explicitly stated, there is frequently a danger that further assumptions are implicitly introduced by the way the data is prepared.

A general principle in preparing data that to the greatest extent reasonable the full information content should be retained where possible and that where data needs to be extracted and summarised for analysis, this step should be done through programs (usually short scripts) so that there is no artificial limit on the analysis. These programs also provide an audit trail of the data manipulation and coding processes.

This can be a challenge where data is sourced from different systems that collect different subsets of possible variables and may also use slightly different definitions.

4.2 Data Management Format

Our general advice is that data is best managed by database software. While some statistical programs claim data management capabilities, this is usually quite limited.

There are a variety of database products available. Almost all adopt the standard relational structure and have varying levels of support for the SQL language. Examples on the PC under Windows are FoxPro, Access and SQL Server. There are also PC versions of mainframe products such as Oracle and DB2. Under the Linux operating system there are two commonly used products, MySQL and PostgreSQL. The practical differences between these products are their ease of use (FoxPro and Access are easy to set up databases) and their support for more complex SQL queries (FoxPro and Access are limited). The SQL issues tend not to be so important for statistical data.

As a general rule we advise caution in making databases too complex. Access in particular has many features that can make a database difficult to debug unless used by a very experienced programmer.

Most statistical packages including Stata function very effectively with a data matrix with the rows corresponding to observations and the columns variables. (Some packages such as SPSS have this as their only data structure.) This corresponds to a single database table. Hence good practice is to use the database software to manage the data to the point of creating the data matrix.

Many statistical packages including Stata have the ability to import data from ODBC (Open Database Connect) sources, a standard originally used on Microsoft operating systems. This permits the retrieval of data by SQL statements issued through the statistical package. In general this approach is useful when it works but sometimes introduces a level of complexity and even an additional invisible stage of data conversion (from the database format to ODBC conventions and then to the statistical package). Alternative methods are to export from the database as a text file (such as CSV format) or in the DBF format used by the older dBase packages.

Conversion of dates and times through these stages is often most problematic, especially where date-time data types are used. It is often best to store dates and time in a numeric format.

As mentioned earlier, zero crashes for a site in a time interval is valuable information so such records must be maintained.

4.3 Data Structure

In general data that represents counts of events is often best thought of as a large but sparse multidimensional table. This table might be indexed by:

- Site, using the Site ID; and
- Time period, the smallest unit that is used in the data, such as "between midnight and 6.00AM on Friday 13th February, 2004".

For each cell of the table there are only a few data values:

- The number of serious crashes, *most of which will be zero;*
- The number of fatal crashes, *even more of which will be zero;*
- The length of the time period, measured in hours or days; and
- Treatment status: before, under construction, after or control.

This data means that it is possible to estimate rates of crashes – typically crashes per day. However it also permits aggregation so that the rates can be computed at a higher level while still preserving the knowledge of the actual number of crashes so that the statistical significance can be determined.

Auxiliary information can be attached to this, related to either the site or the time period:

- Site related:
    - Site type – treatment or control;
    - Intersection/mid-block;
    - State;
    - Metropolitan/country; and
    - Treatment type (improvements if applicable).
- Time period related:
    - Year;
    - Month;
    - Day of the week;
    - Time of day;
    - Lighting conditions (perhaps); and
    - Weather conditions (perhaps).

As lighting conditions are intrinsically related to the time of day, any models developed cannot use both fields. It may therefore not be necessary to include information on lighting conditions, except perhaps for sites where street lighting is switched on for part of the night. Weather conditions are likely to be unavailable for many sites except for times when crashes occurred and it therefore may not be practicable to use this information in any analysis.

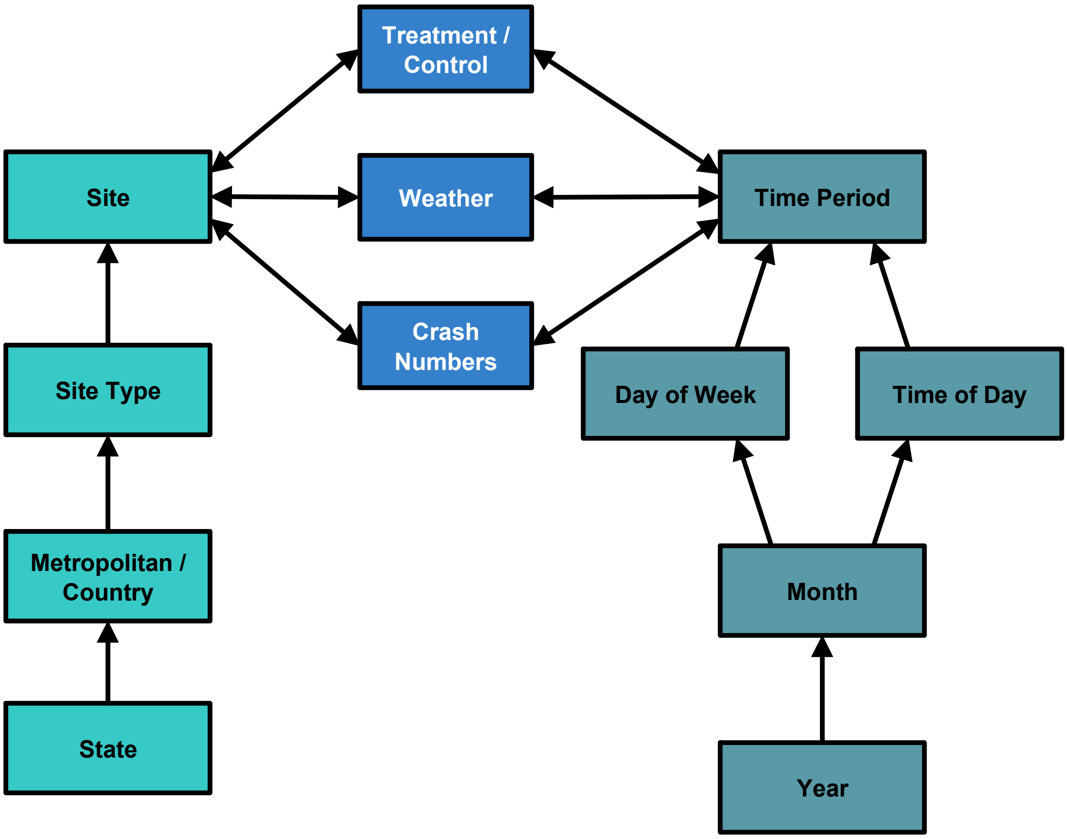

Figure 1. Relationship between variables in recommended data structure.

This structure is illustrated in Figure 1. Whether the auxiliary information is attached to the basic data table or whether it is held in separate but linked tables is a database management issue.

- The hypercube or data mining approach – often used, although not under that name, by most statistical packages – will store all the information in a single table. This is wasteful of storage since the data becomes highly repetitive with, for example, the same site details being repeated in each of the hundreds of records for that site. However it means that aggregating the data is very simple.
- The relational data approach will keep them as separate tables. This is efficient in storage but requires greater care in aggregating data. Few statistical programs directly support this although many can access data held in an external relational database system with this structure.

The size of this data structure is considerable – if we consider seven years of data, 100 sites (including controls and three time periods each day then the basic table will have approximately 800,000 records, with perhaps all but 1000 having zero crashes. A highly efficient normalised structure might use 8 to 10 bytes per record, giving a table size of up to 8 Mbytes. A less efficient hypercube structure might use around 120 bytes per record, giving a file size of about 100 Mbytes. Both these sizes are easily manageable in database systems and many statistical systems that are designed for survey type data, including SPSS, SAS and Stata.

4.4 Data Used/Available

In general the analysis should look at both serious and fatal crashes. While the individual importance of a fatal crash is generally greater, the relatively small number of such crashes limits the statistical inferences that can be drawn.

When counting the crashes associated with a site, it is important to objectively define the boundaries of the site so that they can be applied uniformly before and after a treatment. In general it is appropriate to have the boundaries defined generously rather than too closely – generous boundaries might add some irrelevant crashes reducing the power of the analysis but boundaries that are too close may generate biases if the effect of a treatment is to displace crash locations slightly.

Experience in road safety analysis consistently shows a major metropolitan versus country difference, reflecting different people, different driving styles, different road conditions and many other factors. To a lesser extent there are differences between states. This suggests that at the exploratory stage the data should be looked at separately for these issues.

4.5 Missing Data

Missing data is a perpetual issue with practical statistics. In this case it might take several forms:

- Not all crashes will be counted. This mainly affects the less serious crashes where there is some discretion in reporting. It is difficult to quantify and correct for such errors. The usual approach in road crash data is to be wary of analysing “all crashes” and to restrict the scope to accidents that have a very high probability of being reported. Typically this means fatal and serious crashes.
- Crash count data is missing or not considered reliable for a site. This is likely to be rare in this study. Where it occurs the *site* usually will be omitted.
- Auxiliary information such as traffic counts or weather is not available. It is sometimes possible to impute these missing values – if so, the imputation procedure *should not* use the crash count data in its algorithm otherwise it will upset the analysis. On some occasions where auxiliary information is missing the imputation will be relatively crude leading to a need to simplify the coding used. For example actual traffic counts might be replaced by high, medium and low.

In general it is best to avoid omitting data due to missing data wherever possible since it is not known whether the factors that lead to it being missing relate to safety.[15]

We have considered some more sophisticated methods where the missing data may partially relate to the crash counts – for example weather might be available for all occasions when crashes occurred but not all other times. While in theory it might be possible for methods based upon the Expectation Maximisation (EM) algorithm to be used in such circumstances to give unbiased analysis and still use all the data, it will not be generally feasible. On occasions where it is it feasible, the EM algorithm is likely to introduce model assumptions that will be hard to justify. Hence we recommend against following this path.

4.6 Coding Field Variables and Other Data Issues

Some general guidelines for coding the data are:

- Where possible record data in the initial database with as much precision as is possible. For example, this might mean recording rainfall in millimetres. If it is necessary to have a simpler coding scheme for analysis, the data can be transformed to this at a later stage.
- This is made complicated by inconsistent coding frames used by the different road authorities for categorical data. In many cases the inconsistencies are the result of frames being optimised for state conditions, particularly for lighting and road conditions. There is no perfect solution to this problem but there are methods that can sometimes be used:
  - If there is a courser classification that is consistent with the individual classifications. Using this courser classification loses information but does not introduce biases or assumptions.
  - If it is possible to use a numeric coding (not just ordinal) that largely reflects the categorical codes, representing midpoints of each category. This minimises the information loss at the risk of introducing an incorrect metric.
  - Conduct separate analyses using the classification for each state and use a meta-analysis to combine inference across states. This can be complex but if a simple set of questions are being asked then it is feasible.

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[15] This concern is termed non-ignorable non-response. See for example Chambers R.L. and Welsh A.H., Loglinear models for survey data with non-ignorable non-response, *J. R. Statist. Soc B*, **55**, 157-170, 1993.

- NSW doesn't separate major and minor injury and it is generally recognised that minor injuries have a much lower reporting rate. This makes their data different from all other states. However the size of the data set for New South Wales suggests that a separate analysis may be reasonable for that state.
- It is recognised that traffic count data may be difficult to obtain. The critical aspect will be to identify sites where traffic volumes have changed substantially. Where this change is a result of a treatment it will raise the question of whether the change in crashes at that site is a real change to total numbers or simply a shifting of location of crashes.

Evaluation of the National Black Spot Program: Analysis Report

December 2009

CONTENTS

TABLES

CHAPTER 1 SCOPE OF ANALYSIS

The National Black Spot Program (NBSP) provides funding to address road safety issues associated with identified parts of the road network. The identification of appropriate sites uses a transparent set of objective criteria, of which the past history of crashes is a key component. Each identified Black Spot was assessed by a safety engineer and a recommendation for a treatment, or number of treatments, aimed at addressing the safety issues were given. According to the AusLink database, during the seven-year period from 1996/97 until 2002/03 a total of 2,577 projects were approved and completed under the program.

To evaluate the effectiveness of the NBSP, the Bureau of Infrastructure Transport and Regional Economics (BITRE) is undertaking a cost–benefit analysis. A component of this work is to conduct a statistical analysis of crash data at Black Spots to determine the effectiveness of the various treatments that were administered under the program. This report is a summary of the statistical methodology and results of this analysis.

CHAPTER 2 STATISTICAL METHODOLOGY

CHOICE OF STATISTICAL METHODOLOGY

The choice of statistical methodology was governed primarily by the questions of interest, but also by consideration of the data available for analysis.

The primary question of importance is:

- when an identified Black Spot is treated, does this lead to a measurable reduction in road trauma?

However, to compare the benefits of the program against costs and to improve the effectiveness of the program in the future it is also important to consider:

- how large is the reduction?
- what circumstances govern the reduction in road trauma (e.g. type of treatment, site)?

Thus there is a need to investigate changes over time and to link these changes to a cause.

The crash data consists of counts of crashes. Counts of people killed and injured in the crashes were also available, however it is more appropriate to model crash numbers as once a crash has occurred there are additional factors that determine numbers of fatalities and injuries.

The standard probability model for the counting of events is the Poisson distribution. Using Poisson regression analysis it is possible to investigate the relationships between crash data and the treatments applied and other variables likely to effect crash rates.

POISSON REGRESSION ANALYSIS

Poisson Probability Model

The standard probability model for the counting of events is the Poisson distribution. This gives the probability of a random quantity N taking the value n as

$$p(N = n) = \frac{e^{-m} m^n}{n!}, n = 0,1,2,\ldots$$

where m is the average or expected value of N, and e is Euler's number, the base for natural logarithms. The defining assumption behind the model is that the events being calculated are statistically independent of each other.[1]

[1] A classic discussion of where the model has worked surprisingly well is found in W. Feller, Introduction to Probability Theory and its Applications, Wiley, 1950-68.

The standard deviation of a Poisson variable with mean m is $\sqrt{m}$. Hence the relative standard deviation (sometimes called the coefficient of variation) is $1/\sqrt{m}$. This demonstrates that Poisson variables with a low mean value, and consequently a high coefficient of variation, can appear to be very erratic.

An important property of the Poisson distribution is that the sum of two independent Poisson variables is itself a Poisson variable. For example, if the number of fatal crashes and the number of non-fatal crashes are individually Poisson variables then the total number of crashes is expected to be a Poisson variable. Hence the use of this model provides a high level of consistency in the analysis of complex events that might be categorised in a number of different ways.

A final feature of the Poisson model is that it fully utilises the data from periods where no crashes occur. Such zeros in count data, contrary to what is sometimes thought, contain important information that provides an upper bound to the likely rates of crashes.

Generalised Linear Models

Generalised linear models[2] extend the concepts of classical linear regression models in two ways:

- 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).
- 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. The term for the inverse of this non-linear function is the 'link function'. That is, a random variable Y is modelled against independent variables $X_1, X_2, \cdots, X_k$ as

  $$g(\mathrm{E}(Y)) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k$$

  where $\beta_0, \beta_1, \beta_2, \cdots, \beta_k$ are regression coefficients, $\mathrm{E}(Y)$ is the expected value of Y and g is the link function.

For each distribution used with generalised linear models there is a canonical (natural) link function, one for which certain mathematical properties such as sufficiency are particularly convenient. The canonical link should not always be used, as sometimes it does not make much structural sense.[3] The canonical link for the Poisson distribution is the logarithmic function, which is statistically well behaved, and in this case is the preferred link.

CHOICE OF TIME PERIOD

In modelling crash data a decision must be made on the time periods over which counts should be taken. As 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 provided that the effect of the explanatory variables can still be modelled.

2 A readable standard text is P. McCullagh and J.A. Nelder Generalized Linear Models 2nd. ed., Chapman and Hall, 1989.

3 An example of a poor canonical link is the reciprocal function that is associated with the Gamma distribution. For this distribution the logarithmic link is the most commonly useful link, followed by the linear link. The reciprocal link is virtually never used.

While it is possible to model the counts of crashes in a day, and this would be useful if a day of week effect is likely to be present, the data set is likely to be extremely large and the calculations needed in modelling the data may be outside the capabilities of many software packages. Thus it is important to consider whether this level of detail is necessary.

In addition one must also consider if the time series structure of the data will affect its statistical properties and hence the analysis. For example, if a higher than expected number of crashes in one month is likely to be followed by a high number the next month there is a lack of independence. The key term here is “than expected” – only the unpredictable or random component is relevant. Predictable components such as seasonal variation can be modelled to eliminate their effect on the analysis.

Road crash counts are known to be affected by a number of time dependent factors such as season or time of year, day of the week, time of day and weather. However, as the purpose of this analysis is not so much to model crashes, but to model the change in crashes before and after treatments, the question is which of these factors are likely to affect the effectiveness of a treatment.

In relation to the treatments applied in the Black Spot program it is unlikely that any are affected by the day of the week. While weather may have some effect on some of the treatments, the lack of weather data makes it impossible to include this. (For some recorded crashes data is available on weather conditions at the site at the time of the crash, however weather information is not available for time periods when there were no crashes.) Season or time of year is unlikely to provide a substitute for weather due to seasonal variation between the states, and indeed within some states (such as WA).

For this reason, it was decided that modelling crash counts over a year should be sufficient to determine if the Black Spot treatments have a real effect on crash numbers. Therefore data was aggregated by year for each site. Calendar years were used as the aggregation period for all sites.

Where the data is aggregated in such as manner that not all time periods are of equal length, it is necessary to account for these differences in the modelling. The standard (and most effective) method in generalised linear modelling is to specify an “offset” [4] variable. When a logarithmic link function is used (as is common with Poisson data) then the offset is the natural logarithm of the length of the time interval.

The result of using an offset in this form is that the rate of crashes per unit time is being modelled. This can be extended to more general concepts of exposure than simple time. For example, it is possible that other measures of exposure (such as vehicle kilometres driven) may also be available and these may be critical where they display a trend over the period of study. In such cases the appropriate offset is the logarithm of the aggregated exposure.

RANDOM EFFECTS AND FIXED EFFECTS MODELS

A key feature of the dataset is that each site is unique, particularly in regard to its long-term prior crash rates. The variation is rarely of interest in itself, but it must be accounted for in the modelling if substantial biases are to be avoided.

[4] The offset term in generalised linear modelling is an explicit term added to the linear predictor equation. This approach is required since to adjust the dependent variable (as is done with standard linear regression by subtracting the term from the variable being modelled) would upset the distributional assumptions. A good example of the use of an offset term is provided in McCullagh and Nelder, p 204-208.

There are two distinct approaches to this modelling:

- The fixed effects approach assumes that each site has a specific parameter associated with it, effectively the prior crash rate. Such parameters can then be directly estimated together with all the other parameters – in many cases there will be a large number of such parameters but this is a numerical rather than a statistical issue.
- The 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 then estimated, as well as the other parameters.

Each of these approaches has advantages and disadvantages. The fixed effects model ignores the fact that some of the apparent variation between sites is just random. The random effects model has to assume that the variation follows some distributional form, without in this case a good argument as to what this should be and the 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 while this may be interesting, it is not the point of this evaluation.

In this study initial, investigative models were fitted by both methods. The resulting differences in the relevant parameters (those measuring the effect of road treatments) were 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 (i.e. models with more interactions) to be fitted.

GOODNESS OF FIT

To test the goodness of fit of the Poisson regression models the deviance was used. The deviance relates closely to the likelihood and for a Poisson model is of the form:

$$D = \sum_{i=1}^{n} d_i = \sum_{i=1}^{n} 2n_i \log(n_i / e_i) - (n_i - e_i)$$

where n_i is the i^{th} data value and e_i is the expected value for this under the model.

In practice, it is often difficult to distinguish between poor goodness of fit and overdispersion. In many cases, if the deviance remains significantly high when all reasonable model terms have been included and there are plausible causes for overdispersion, such as unobservable factors affecting multiple crashes, it is reasonable to then assume an overdispersed model as is discussed in the following section.

In road safety, it is not uncommon for overdispersion to be limited to the more common data types, and not observed for the least frequent such as fatal crashes. This is not surprising since less frequent events will be more separated in time and hence less likely to have common contributing factors.

OVERDISPERSION

The Poisson model implies a direct relationship between the mean (or expected value) and the variance – they must be equal. This means that the goodness of fit of a model as measured by the deviance can be directly gauged against this criterion and a decision made as to whether the fit is adequate. The deviance D is expected to have a Chi Square distribution with the degrees of freedom given by the number of data values minus the number of model parameters.

In practice, it is not unusual for the goodness of fit measure (the deviance) to be greater than expected. This is termed overdispersion and can be due to 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 structure is not precisely correct and the lack of fit appears as additional variance.
- There is a dependency between events being counted (crashes) that inflates the variance. This attacks the basic assumption of the Poisson distribution.

The first two of these possible causes are generally manageable provided that the relevant data is available. They suggest that poorly fitting models should receive special attention to determine whether they can be improved to eliminate the overdispersion.

The third reason is true overdispersion 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.)

True overdispersion rarely leads to biased estimates provided that the mechanism causing overdispersion is not related to the factors in the model. However, it does lead to an understatement of the standard errors associated with the estimates, giving false levels of significance. Hence, it is important to obtain realistic values for these standard errors. To do this, a dispersion parameter c is calculated as

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

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 overdispersion and is used to adjust the standard errors.

Note that we have *not* used the negative binomial distribution approach to overdispersion, basically because there is no reason to believe that such a distribution is likely to better fit the data and the computational issues it creates are significant.

SELECTION BIAS

The Black Spot treatment sites were chosen in part on the basis of their crash statistics – the same statistics that are then being used in their evaluation. This means that the data itself influences the questions being asked of it, which conflicts one of the basic principles of inference. Some of the sites would have been chosen due to chance fluctuations in crash levels that gave the appearance of high crash rates. For these, even in the absence of any treatment, the future crash rates would be expected to be lower, in line with their long-term values. This reduction may however be falsely ascribed to the treatment, a bias into the analysis that may show the NBSP in a misleadingly favourable light. The effect has been frequently discussed under the name of “regression-to-the-mean”.

To allow for this effect, we note that there is a period of time between the date a site was selected for the NBSP and the commencement of the project to treat the site. Crashes during this period were compared to those in the period prior to selection to investigate regression to the mean. As the exact selection date was not available the application date was used as a substitute.

There is also some potential for a more subtle form of selection bias – the specific treatments applied to a Black Spot may reflect the circumstances of the most recent crashes. To the extent that the composition of this set of crashes is random and may not reflect the average composition in the longer term, the treatments targeting that composition may appear to be particularly effective. However, such an effect is only likely to be apparent if the analysis considers individual crash types, for example, head on collisions. In general, the number of observed crashes in any such category is not sufficient to provide a meaningful statistical analysis and in any event, the total crash number by severity level is more important since some treatments may change the mixture of crash types while not necessarily changing the total numbers.

CHAPTER 3 DATA AND MODELS

The data used in this analysis consists of two main components: site data and crash data. Data was provided by BITRE who had collected and collated the data from each State/Territory and from the Department of Infrastructure, Transport, Regional Development and Local Government (DITRDLG) Black Spot Program database.

SITE DATA

The data used in the analysis is given in TABLE 3.1.

TABLE 3.1 SITE DATA USED IN THE ANALYSIS

Data	Explanation
Federal Reference	DOTARS reference code used to identify the site
Jurisdiction	State/Territory in which the site is located
Urban/Rural	Urban or rural site
BCA or RSA	Whether the site was approved on a BCA or RSA basis (see below for details)
State or Local	State or local government road
Primary Treatment Code	Main treatment, determined by BITRE
Secondary Treatment Codes	List of other treatments also applied at the site
AusLink Received Date	Date application received by DOTARS
Construction Start Date	Start date for implementation of the project
Construction End Date	Completion date for implementation of the project

Sites were selected for treatment under the Black Spot Program in one of two ways:

- Benefit Cost Ratio (BCA) - a standardised calculation that compared the potential benefit as predicted from past crashes with the projected costs of the proposed treatments); or
- Road Safety Audit Project (RSA) – an assessment of crash risk based on road design elements rather than on crash history.

As the treatment classification system used to administer the NBSP was not well suited to analysis of effectiveness of different treatment types, BITRE developed a new classification system. Under this system treatments are classified by one of 29 different codes. As projects at some sites consisted of more than one treatment, a primary treatment code was assigned to each site by BITRE. All other treatments applied at the sites are considered secondary treatments.

There are many different characteristics of sites that may affect crash levels such as layout of an intersection, traffic flow, number of traffic lanes, weather and lighting conditions. If these factors do not change over the period of the Black Spot Program, then they will not affect the analysis, however when a characteristic changes over time it may have an affect on the number of crashes that is not related to any treatment. Of those suggested above, traffic flow, weather and lighting conditions are likely to change and could affect crash rates independently of the Black Spot treatment.

For this reason, BITRE attempted to gather traffic flow data, however a lack of available data for many sites made it impossible to include this data in the analysis. It was not practical to try to include weather conditions, as the information would be needed for times when no crashes occurred as well as at the time of a crash. Each day was divided into two time periods for the analysis – day and night – and it was therefore unnecessary to add an extra term for lighting conditions, as this term contained similar information.

An additional variable provided was whether the treatment was considered to be for a "spot" or "length". A treatment that was implemented at a single location would be considered a "spot" treatment, whereas a "length" treatment could involve a stretch of road and possibly even multiple intersections along that stretch of road. This variable was included in initial models, however BITRE identified some inconsistencies in the manner in which this variable was recorded leading to significant problems in interpretation. It was therefore not included in the final models.

CRASH DATA

Crash data was provided by each State and Territory to BITRE. An outline of the data that was provided is given in TABLE 3.2. Only crashes that occurred within seven years of the implementation of the treatment were analysed because it was considered that, outside this range, it was likely that other changes (not related to the Black Spot Program) would have occurred that could affect the crash rate.

TABLE 3.2 CRASH DATA USED IN THE ANALYSIS

Field name	Explanation
Federal reference	DOTARS reference code for site
Jurisdiction	State or territory in which the crash occurred
Date	Date of occurrence
Year	Derived from date
Month	Derived from date
Day of week	Derived from date
Time of day	Time of day of occurrence
Severity	Severity of crash, based on the most serious injury level of all road users involved in the crash.

The two time periods into which crashes were categorised for the analysis, based on the actual time the crash occurred, were as follows:

- Day - 6:00 am to before 6:00 pm; and
- Night - 6:00 pm to before 6:00 am

Crash severity is not recorded in a consistent manner across all jurisdictions, with the major difference being that in New South Wales there is no separation of injuries into serious injuries or minor injuries. Victoria was unable to provide any data on property damage only crashes. The severity levels provided by each jurisdiction are shown in the table below. For modelling purposes, the number of injury crashes was calculated for jurisdictions other than NSW by summing the serious injury crashes and minor injury crashes. For completeness, the number of casualty crashes was also calculated as the sum of fatal crashes and injury crashes.

TABLE 3.3 CRASH SEVERITY LEVELS PROVIDED BY JURISDICTION

Severity Level	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
Fatal	✓	✓	✓	✓	✓	✓	✓	✓
Serious injury		✓	✓	✓	✓	✓	✓	✓
Minor injury		✓	✓	✓	✓	✓	✓	✓
Injury	✓							
Property damage only	✓		✓	✓	✓	✓	✓	✓

OBSERVATION PERIODS

The raw data provided by each jurisdiction consisted of records of crashes for each site. In order to correctly represent crash rates, the raw datasets were expanded to include all 'observed' time periods for each site, with the assumption that if no crash of a particular severity was recorded for any given time period then no crash (of that severity) occurred during that time period. To undertake this expansion of the datasets, it was necessary to determine the observation period for each site and this was done separately for each jurisdiction.

Each jurisdiction was asked to provide all crash records for each Black Spot site that occurred between seven years before the treatment and seven years after. Therefore in theory, the observation period should match these dates. However due to the length of time covered by the data requests, it was considered possible that changes in recording procedures could have resulted in crashes at some sites not being provided for at least some of the time. Analyses conducted by BITRE determined that for most jurisdictions there was a clear start date and end date across all sites. Therefore, for these jurisdictions, all time periods between the start and end date that had no crash records for a given site were recorded as having zero crashes at that site (for each crash severity).

For jurisdictions where it was not possible to establish a clear start and end date for the observation period based on the analyses conducted by BITRE, the observation period was determined for each site based on the first and last recorded crashes for each site. In order to avoid creating a bias for these sites by always having the first and last observed time periods containing a crash, the observation period was truncated to remove this first and last time period. The Markov property says that the distribution of the time to the next crash is not affected by whether a crash occurs today or not. Therefore truncating the data by excluding this first crash at a site and then only considering the data from the next time period on is appropriate. Effectively this just uses the first crash to mark the date where you are certain you have data coverage.

After determination of the observation period for each site and expanding the datasets to include all time periods during the observation period, the data for each site were then truncated (if necessary) to a maximum of seven years prior to treatment and seven years after treatment.

SITE REMOVAL

For each model it was necessary to remove some sites from the analysis. Sites were removed for a particular model if there was a lack of data or no crashes of that severity. A lack of data does not simply refer to a lack of crashes, but means that the site was not observed for a particular time period, so it is not known whether or not there were any crashes. If data was unavailable for a site for the whole of at least one of the relevant time periods described by the crash treatment status variable the site was removed from the analysis. That is, there was no data prior to application for treatment, or after application but before treatment starting, or after treatment.

If no crashes of a certain severity occurred at a site, the site was removed from the analysis for that crash severity. Appendix G contains a list of all the sites and indicates for each model whether the site was included and if not, the reason for its exclusion, while the table below shows the number of sites and crashes used for each model by jurisdiction.

TABLE 3.4 NUMBERS OF SITES AND CRASHES USED IN REGRESSION ANALYSIS

	Fatal		Serious Injury		Minor Injury		Injury		Property Damage Only	
Jurisdiction	**Sites**	**Crashes**	**Sites**	**Crashes**	**Sites**	**Crashes**	**Sites**	**Crashes**	**Sites**	**Crashes**
ACT	3	3	11	34	12	84	13	118	13	2,161
NSW	70	122	NA	NA	NA	NA	349	4,064	345	5,423
NT	11	26	24	176	26	314	26	490	26	1,252
QLD	45	59	199	916	220	2,442	229	3,358	211	2,631
SA	26	36	80	305	95	2,250	99	2,555	90	7,287
TAS	12	18	27	87	39	341	39	428	39	885
VIC	168	301	481	3,685	512	9,279	513	12,964	NA	NA
WA	59	110	271	1,398	301	5,472	310	6,870	316	20,663
TOTAL	**394**	**675**	**1,093**	**6,601**	**1,205**	**20,182**	**1,578**	**30,847**	**1,040**	**40,302**

TREATMENTS

Some treatments were not applied frequently enough to derive a meaningful estimate of the effect of these treatments. Therefore, such treatments were combined into an 'unspecified' category (TUnsp) for analysis. These treatments were:

- Cycling treatments (treatment 9);
- Overtaking lane/s (treatment 13);
- Ban turns (treatment 21);
- Speed limits (treatment 24);
- Parking (treatment 25);
- Railway crossing modification (treatment 26);

- Channelisation (treatment 28); and
- Other (treatment 29).

TIME TREND

Crash statistics are often affected by many competing trends. Population and vehicle numbers are increasing, cars are becoming safer and enforcement levels are constantly changing. In addition, many other road safety initiatives are likely to be operating over the time span of a project such as this. Hence it is often difficult to distinguish an improvement due to a particular measure (such as Black Spot treatments) and the general trend.

Fortunately in this study the treatments are localised so it is possible to use other areas as a measure of trend. After detailed consideration of alternatives the measure used here was the state or territory wide number of crashes in that year. While this included the Black Spot locations, it is overwhelmingly the non-Black Spot crashes. To a good approximation this is equivalent to using the rest of the state or territory as a control site.

In the generalised linear model context, this measure was introduced by setting its natural logarithm as the *offset* in the model (see discussion of offsets on page 10).

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 time period of interest, it was not possible to obtain consistent information (i.e. 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 shown in TABLE 3.5.

As the model measures relative changes in the rate of crashes before and after treatment, the use of different measures, while not ideal, is acceptable. For the same reason, the number of persons injured is an acceptable alternative where the number of crashes is unavailable.

TABLE 3.5 NUMBERS OF SITES AND CRASHES USED IN REGRESSION ANALYSIS

Jurisdiction	Measure Used
ACT	Total persons injured*
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

*Estimated for calendar years from financial year data.

VARIABLES USED IN REGRESSION ANALYSIS

Dependent Variables

Separate regression models were fitted for each crash severity level, using the number of crashes as the dependent variable. As some severity levels were not recorded for some jurisdictions, each model is only valid for jurisdictions for which data was provided at that severity level. Although a model of casualty crashes was not needed for the cost-benefit analyses, a model at this level is included for completeness. The resulting model is not discussed in the body of this report, however is included in Appendix F.

Explanatory Variables

The explanatory variables that were used in the modelling process were:

Crash Treatment Status – This variable was introduced to describe whether a treatment had yet to be applied at an intersection. There are four possible values for this variable:

- “0”-Prior to when the application for acceptance into the Black Spot Program was received by DOTARS
- “1”- After the application was received but before construction work on the treatment project commenced.
- “2”- Within two years of the completion of the project.
- “3”- More than two years after the project was completed.

No value was included for the construction period as data from this time period was not used. Distinguishing between the period before and after the application date was done in order to measure any regression to the mean, as discussed in more detail on page 12. The inclusion of period 2 enabled testing of whether the signage erected at Black Spot sites and retained for two years after completion of the project had any impact on crashes. This variable was found not to be significant in any of the models.

Treatment Implementation Year – The year that the treatment commenced was included to determine if the effectiveness of a treatment may be related to the time it was applied. It was suggested that as the “most dangerous” Black Spots were likely to be treated earlier by the Black Spot Program, treatments that were applied in later years may appear to be less effective.

BCA/RSA – Sites were selected as Black Spot in one of two different ways: Benefit Cost Ratio or Road Safety Audit Project. (see page 14 for further information.)

Jurisdiction – This is the name of the state/territory where the Black Spot site was located.

Urban/Rural – This is used to indicate if the Black Spot site was located in an urban or rural area. The urban/rural classifications of sites are taken from the AusLink database. It uses the definition from the NBSP’s Notes on Administration. Metropolitan areas are defined on the basis of Australian Bureau of Statistic’s ‘statistical divisions’, as cities and towns with a population in excess of 100,000. Many sites in towns will be classed as rural but have urban characteristics. While this limits the usefulness of the variable in distinguishing between town and country roads, the variable also recognises that rural black spot projects may be chosen with a lower warrant compared with urban projects. The Notes on Administration provides that ‘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’.

Legal speed limits could be used to distinguish between town and country roads, but some jurisdictions were unable to provide speed limit data.

State/Local – This is used to indicate whether the site is on a state or local government road.

Time Trend – As there were no useable control sites in the data, it was important to include a variable that would measure the change in crashes over time that would be expected regardless of whether a treatment had been applied at a Black Spot. To do this, a term that reflected the expected number of crashes was included as an offset in the model.

Treatments – All treatments applied to a site were included in the analysis. No separation was made between the primary and secondary treatments at the sites. The treatments are given in TABLE 3.6.

TABLE 3.6 TREATMENT CODES AND MEANING

Code	Treatment	Code	Treatment
T01	Roundabout	T16	Realign intersection
T02	Medians	T17	Clear obstacles or hazards
T03	New signals	T18	Warning signs
T04	Modify existing signals/change phase	T19	Line marking
T05	Traffic calming measures	T20	Priority sign treatments
T06	Lighting treatments	T21	Ban turns
T07	Turning lane	T22	Alter direction of traffic flow
T08	Pedestrian treatments	T23	Cameras
T09	Cycling treatments	T24	Speed limits
T10	Sealing and resealing	T25	Parking
T11	Non-skid treatment	T26	Railway crossing modification
T12	Alter road width	T27	Grade separation
T13	Overtaking lane/s	T28	Channelisation
T14	Barriers/guardrails	T29	Other
T15	Realign road length – horizontal and vertical		

This measures the individual treatment effect on crash rates, however some treatments are commonly applied with other treatments. For instance, sealing/resealing (T10) the road also requires line markings (T19). To measure this combined effect, pairwise treatments were also included in the analysis where the pair occurred at ten or more sites. If two separate treatments of the same type were applied, this was also considered a pair of treatments. Descriptions of these pairs are provided in TABLE 3.7. The labelling of treatment 1 in this table is *not* based on which treatment was most likely to be the primary treatment.

TABLE 3.7 PAIRS OF TREATMENTS INCLUDED IN ANALYSIS

Code	Treatment 1	Code	Treatment 2
T10	Sealing and resealing	T19	Line marking
T04	Modify existing signals/change phase	T07	Turning lane
T18	Warning signs	T19	Line marking
T12	Alter road width	T19	Line marking
T02	Medians	T07	Turning lane
T10	Sealing and resealing	T14	Barriers/guardrails
T12	Alter road width	T15	Realign road length – horizontal and vertical
T10	Sealing and resealing	T12	Alter road width
T10	Sealing and resealing	T15	Realign road length – horizontal and vertical
T14	Barriers/guardrails	T19	Line marking
T04	Modify existing signals/change phase	T04	Modify existing signals/change phase
T02	Medians	T20	Priority sign treatments
T02	Medians	T19	Line marking
T19	Line marking	T19	Line marking
T07	Turning lane	T07	Turning lane
T14	Barriers/guardrails	T18	Warning signs
T10	Sealing and resealing	T17	Clear obstacles or hazards
T15	Realign road length – horizontal and vertical	T19	Line marking
T07	Turning lane	T08	Pedestrian treatments
T19	Line marking	T20	Priority sign treatments
T17	Clear obstacles or hazards	T19	Line marking

Interactions

A number of interactions were included in the modelling, with the key interactions involving the crash treatment status and other variables. A full list of variables interacted with crash treatment status is provided in TABLE 3.8.

As lighting conditions are likely to impact on the effectiveness of some treatments, such as T06 (lighting treatments), which will only be effective at night, interactions between the time of day variable and five treatment types were also included. The treatment types that were interacted with time of day are listed in TABLE 3.9. The treatments were chosen on the basis that effectiveness might vary with visibility.

Pre-application bias was interacted with time-of-day to test whether, in selecting sites with light-sensitive treatments, crashes at night were given greater weight. This was not found to be statistically significant in any of the models

For sites with light-sensitive treatments, time-of-day was interacted with the site variable to enable the models to distinguish between the daytime and nighttime crash rate at each site. The interaction term between treatment type and after-treatment provides the effectiveness of the treatment on daytime crashes. A three-way interaction term between treatment type, after-treatment and time-of-day provides the effectiveness of the treatment for reducing nighttime crashes.

The only other interactions included were those between treatment implementation year and all treatment types.

TABLE 3.8 VARIABLES INCLUDED IN INTERACTION TERMS WITH CRASH TREATMENT STATUS

Variable (description used in appendices)	**Reason for Inclusion**
Two Way Interactions with Crash treatment status	
Treatment type (T##, TUnsp)	Does the effectiveness vary by treatment type?
Treatment implementation year (ImpYear)	Has the treatment effectiveness changed over time?
BCR/RSA (RSA)	Does the method of selection impact on treatment effectiveness?
Urban/Rural (Rural)	Is there a difference in treatment effectiveness between urban and rural sites?
Jurisdiction (ACT/NT/QLD/SA/Tas/VIC/WA)	Does the effectiveness of treatments vary between jurisdictions?
State/Local (State)	Does the effectiveness of treatments vary between state and local government roads?
Three Way Interactions with Crash treatment status	
Treatment type by treatment type	Does the effectiveness of the different treatments vary when applied with other treatments?
Treatment type by time of day	Does the effectiveness of the different treatments vary by night?
Treatment type by Treatment implementation year	Has the effectiveness of the different treatments changed over time?
Treatment type by Urban/Rural	Does the effectiveness of the different treatments vary if the site is located in an urban or rural area?
Treatment type by Jurisdiction	Does the effectiveness of the different treatments vary by jurisdiction?
BCR/RSA by Urban/Rural	Does the treatment effectiveness vary by method of selection and whether the site is located in an urban or rural area?

TABLE 3.9 TREATMENT TYPES INCLUDED IN INTERACTION TERMS WITH TIME OF DAY

Treatment Type Code	Treatment Description
T03	New signals
T06	Lighting treatments
T18	Warning signs
T19	Line marking
T20	Priority sign treatments

MODEL SELECTION

Statistical model selection is always a difficult process, with the aim being to find a model that is as simple as is possible while still capturing all the significant detail. In addition, the model must “make sense”. The process is invariably iterative and requires consideration of both formal statistical measures and the context.

Simplicity is often interpreted as parsimony, having as few parameters as possible. However that alone does not give sensible models since logical interdependence between parameters means groups of parameters must often be included or excluded as a whole. The principles of marginality are critical here – if a complex term is included then it rarely makes sense to exclude the corresponding simpler terms.

The iterative process ideally starts with the “full model”, one with all reasonable terms included. This ensures that the starting point is sufficiently flexible to avoid introducing biases to the following steps. Terms that are not statistically significant and are able to be dropped while keeping a sensible model are then progressively dropped, usually as groups. When no further terms can be dropped, the resulting model is considered a good description of the data.

The actual process often requires making some judgments since sometimes several different terms in the model may each describe certain features. Not all of them may be needed, but some are - which are needed is not always so clear from the statistics alone without reference to the interpretation.

The first model fitted for each crash type was the “full model” made up of all the terms discussed above. The output from these models was reviewed and terms or groups of terms removed based on the Akaike information criterion (AIC). After removing terms, the model was checked for overdispersion and, if necessary, the standard errors were adjusted accordingly. This adjustment caused terms in the overdispersed models to become less significant. Additional groups of variables that appeared to be borderline significant (using a level of significance of $\alpha=0.05$) following the overdispersion adjustment were explored further to determine whether to retain them in the model, either by testing a model without the variable group or by assessing whether the collection of p-values was consistent with randomness.

In some cases, the principles of marginality (including main effect terms corresponding to interactions) and factor coding (considering all the terms coding a factor as a single group) meant that some non-significant terms have been retained. For factors, in some cases the factor and hence its individual coefficients was retained since the factor was significant even when no individual coefficient was significant. While this may seem counterintuitive, the parameter estimate for each level of a factor variable is relative to the base level and therefore the model provides information on whether each individual level is different to the base level. It is therefore possible for a factor variable as a whole to add significantly to a model without any of the individual levels being significantly different from the base level.

CHAPTER 4 RESULTS

In this section results tables are provided showing the effect of each model term relative to the baseline level. For all models the baseline time period was set as the period after the application was received but before construction work on the treatment project commenced. A negative effect indicates a crash rate lower than this baseline, while a positive effect indicates a crash rate higher than the baseline. Parameter estimates, standard errors (adjusted for overdispersion) and confidence intervals for each model are provided in the Appendices.

FATAL CRASHES

TABLE 4.1 summarises the results from the model for fatal crashes and Appendix A contains the actual model output. In addition, TABLE 4.2 shows the overall effectiveness of light-dependent treatments separately for day and night.

The effect for one treatment type (T05 traffic calming) has been marked as NE, signifying "not estimable". This results from zero counts in the data preventing estimation – typically giving rather large but not significant parameter estimates, a sign that a parameter is iterating to infinity.

The pre-application bias was large (in fact, the largest across all the crash type models) at 25%, although only just reaching the standard level of statistical significance (one-sided p-value = 0.046). Thus the model is suggestive that a large part of the apparent drop in the rate of fatalities was due to the selection process for Black Spot sites choosing sites where there had *by chance* been a number of fatalities, and the subsequent regression to the mean.

Three treatments were found to be statistically significant with roundabouts (T01), new signals (T03) and turning lanes (T07) reducing fatal crashes by 79%, 93% and 60% respectively. Although signals (T03) decreased fatal crashes during the day, the effect was reversed during the night. In fact, the overall nighttime effect of signals (T03) was not found to be significantly different from zero. No other treatments were found to have a statistically significant effect on fatalities.

In general, very few of the variables in the model were shown to have a statistically significant effect on fatal crashes. This is likely to have occurred because of a lack of data – fatal crashes are rare and sites were only included in the model if a fatal crash had occurred.

TABLE 4.1 SUMMARY OF THE PARAMETERS USED IN THE FATAL CRASH MODEL

Term	Effect	p-value	Term	Effect	p-value
Pre-Application Bias	24.7%	0.046	T15 - Realign len	-20.0%	0.620
T01 - R/bout	-79.2%	0.005	T16 - Realign int	-74.6%	0.093
T02 – Median	-10.8%	0.777	T17 - Clear haz	-14.4%	0.690
T03 - New sig	-93.1%	0.010	T18 - Warn signs	41.7%	0.425
T04 - Mod sig	-34.0%	0.216	T19 - Lines	-20.1%	0.324
T05 - Traff calm	NE	NE	T20 - Priority signs	155.1%	0.107
T06 – Lighting	16.2%	0.780	T22 - Alter dir	20.7%	0.836
T07 - Turn lane	-60.4%	0.024	TUnsp	65.9%	0.424
T08 - Ped treat	-58.6%	0.125	T03 * Night	3836.7%	0.004
T10 - Seal/reseal	-25.5%	0.145	T06 * Night	39.3%	0.618
T11 - Non-skid	61.0%	0.208	T18 * Night	-53.7%	0.240
T12 - Alter width	-7.6%	0.832	T19 * Night	7.9%	0.819
T14 – Barriers	-6.0%	0.816	T20 * Night	-84.1%	0.147

TABLE 4.2 TIME OF DAY TREATMENT EFFECT IN THE FATAL CRASH MODEL

Treatment	Day Effect	Day p-value	Night Effect	Night p-value
T03 - New sig	-93.1%	0.010	173.1%	0.184
T06 – Lighting	16.2%	0.780	61.9%	0.260
T18 - Warn signs	41.7%	0.240	-34.4%	0.424
T19 – Lines	-20.1%	0.819	-13.9%	0.586
T20 - Priority signs	155.1%	0.147	-59.4%	0.533

SERIOUS INJURY CRASHES

TABLE 4.3 summarises the results from the model for serious injury crashes and Appendix B contains the actual model output. In addition, TABLE 4.4 shows the effectiveness of some treatments separately for day and night. As these treatments were thought to be more likely to be effective at night, the model included interaction terms for these treatments with time of day.

There was a statistically significant pre-application bias for serious injury crashes. The result suggested that the number of serious injury crashes was 17% higher in the period prior to application for treatment compared to other time periods.

Six of the treatments were found to significantly reduce the rate of serious injury crashes with roundabouts (T01), new signals (T03), modifying/changing the phase of existing signals (T04), sealing and resealing roads (T10), priority signs (T20) and altering the direction of traffic flow (T22) reducing serious injury crashes by 70%, 55%, 28%, 14% 48% and 76% respectively. The effect of new signals (T03) on serious injury crashes was reversed in the nighttime and it was found that overall new signals had no effect on nighttime serious injury crashes. Likewise, the treatment priority signs (T20), was found to have no significant effect on nighttime serious injury crashes.

There was a statistically significant difference in treatment effectiveness for serious injury crashes at rural sites after treatment compared to urban sites. The number of serious injury crashes was 12% lower at rural sites after treatment than in urban areas. This could be due to several reasons: a qualitative difference in how Black Spot sites are chosen in rural areas, the treatments themselves, higher speed environments in rural areas, or a possibly greater scope for reducing crashes in rural areas because safety is generally lower. Whatever the case, the results suggest significantly higher effectiveness in rural areas.

For the serious crash model, Victoria was chosen as the baseline level for comparisons. South Australia was the only jurisdiction to show a significant difference in effect when compared to Victoria, with a 31% relative reduction in serious injury crashes.

TABLE 4.3 SUMMARY OF THE PARAMETERS USED IN THE SERIOUS CRASH MODEL

Term	Effect	p-value	Term	Effect	p-value
Pre-Application Bias	16.9%	0.000	T19 – Lines	-4.5%	0.586
T01 - R/bout	-69.8%	0.000	T20 - Priority signs	-48.4%	0.011
T02 - Median	1.4%	0.896	T22 - Alter dir	-75.8%	0.000
T03 - New sig	-55.3%	0.000	Tunsp	6.6%	0.589
T04 - Mod sig	-27.6%	0.000	T03 * Night	100.5%	0.006
T05 - Traff calm	-6.4%	0.795	T06 * Night	-11.0%	0.535
T06 - Lighting	11.1%	0.401	T18 * Night	13.8%	0.605
T07 - Turn lane	-4.6%	0.562	T19* Night	-9.7%	0.395
T08 - Ped treat	-2.1%	0.858	T20 * Night	110.4%	0.117
T10 - Seal/reseal	-14.1%	0.042	Rural * After Treatment	-12.5%	0.043
T11 - Non-skid	6.5%	0.556	ACT * After Treatment	-36.0%	0.303
T12 - Alter width	0.7%	0.957	NT * After Treatment	29.9%	0.147
T14 - Barriers	23.0%	0.111	QLD * After Treatment	-1.6%	0.848
T15 - Realign len	-5.3%	0.762	SA * After Treatment	-30.6%	0.010
T16 - Realign int	9.0%	0.554	TAS * After Treatment	-32.2%	0.152
T17 - Clear haz	-18.4%	0.140	WA * After Treatment	11.5%	0.126
T18 - Warn signs	-1.2%	0.945			

TABLE 4.4 TIME OF DAY TREATMENT EFFECT IN THE SERIOUS CRASH MODEL

Treatment	Day Effect	Day p-value	Night Effect	Night p-value
T03 - New sig	-55.3%	0.000	-10.5%	0.600
T06 – Lighting	11.1%	0.401	-1.1%	0.941
T18 - Warn signs	-1.2%	0.945	12.5%	0.564
T19 – Lines	-4.5%	0.586	-13.7%	0.140
T20 - Priority signs	-48.4%	0.011	8.6%	0.837

MINOR INJURY CRASHES

There was slight evidence of overdispersion ($\hat{c}$ = 1.27) for the minor injury crash model and the standard errors of the parameter estimates were adjusted accordingly, as discussed in Chapter 2.

TABLE 4.5 summarises the results from the model for minor injury crashes and Appendix C contains the actual model output, adjusted for overdispersion. In addition, the effect of some treatments are shown separately for day and night in TABLE 4.6 and the effect of individual treatments for urban and rural areas is provided in TABLE 4.7.

The pre-application bias was not statistically significant unlike for fatal and serious injury crashes. This may be due to an emphasis on the number of fatal and serious injury crashes in determining whether a site should be treated under the Black Spot program.

In urban sites, roundabouts (T01), medians (T02), new signals (T03), modifying/changing the phase of existing signals (T04), clearing obstacles and hazards (T17) and altering the direction of traffic flow (T22), reduced minor injury crashes by 62%, 20%, 49%, 23%, 31% and 58% respectively. However, sealing and resealing (T10) increased minor injury crashes by 30%. On average, treatments at rural sites were 46% more effective at reducing accidents than at urban sites. However a number of the interactions between the individual treatment types and whether a site was urban or rural were found to significantly modify this effect. In rural sites, roundabouts (T01), medians (T02), new signals (T03), modifying/changing the phase of existing signals (T04), sealing or resealing (T10), altering road width (T12), realigning intersection (T16), line markings (T19), priority sign treatments (T20) and altering the direction of traffic flow (T22) all reduced minor injury crashes by 77%, 47%, 40%, 39%, 30%, 46%, 47%, 29%, 63% and 67% respectively.

The overall effect of new signals (T03) reduced nighttime serious injury crashes by 40%, a slightly lower reduction in crash rates than seen during the day.

For minor injury crashes, the model included interaction terms to measure any additional effect due to the use of multiple treatments at a site. While for most treatment pairs the additional effect was not significant, two pairs were found to be significant. When line marking (T19) was applied with sealing or resealing the road (T10) there was an additional 39% reduction in minor injury crashes compared to when these were applied individually. The combination of a turning lane (T07) with an addition or modification of a median (T02) was found to be 45% less effective when compared to the individual treatments.

The interaction between the treatment implementation year and the period after treatment was statistically significant and indicates that, on average, treatments have become 6% more effective at reducing minor injury crashes each year since 1996. That is, for a particular treatment type implemented in 2001, the effect on the minor injury crash rate would be a reduction of 30% compared to the same treatment type implemented in 1996. This could be due to either the improved selection of sites or the better selection of treatments to be applied at particular sites. Either way, it suggests that the Black Spot program has improved over the years.

There was evidence that the relative number of minor injury crashes was 20% higher at sites on state roads after treatment compared to those on local government roads. This suggests that Black Spot treatments were more likely to be effective when applied to the smaller local government roads, in itself suggestive of a selection effect where there were fewer opportunities for large improvements with state government administered roads.

For the minor injury model, Victoria was chosen as the baseline level for comparisons. Treatments seemed to be more effective in reducing minor injury crashes in the ACT with a 64% reduction in minor injury crashes above that of Victoria. On the other hand treatments in WA were around 20% less effective when compared to Victoria.

TABLE 4.5 SUMMARY OF THE PARAMETERS USED IN THE MINOR CRASH MODEL

Term	Effect	p-value	Term	Effect	p-value
Pre-Application Bias	2.8%	0.183	T15 * T19	-18.2%	0.722
T01 - R/bout	-62.0%	0.000	T07 * T08	-24.3%	0.279
T02 – Median	-20.5%	0.029	T19 * T20	23.1%	0.512
T03 - New sig	-48.6%	0.000	T17 * T19	-42.0%	0.169
T04 - Mod sig	-22.7%	0.000	T03 * Night	17.0%	0.399
T05 - Traff calm	-21.9%	0.657	T06 * Night	-9.2%	0.544
T06 – Lighting	14.3%	0.171	T18 * Night	39.8%	0.158
T07 - Turn lane	-12.4%	0.106	T19 * Night	-0.6%	0.961
T08 - Ped treat	-3.6%	0.737	T20 * Night	13.9%	0.703
T10 - Seal/reseal	30.0%	0.005	T01 * Rural	13.3%	0.576
T11 - Non-skid	-12.5%	0.138	T02 * Rural	22.7%	0.276
T12 - Alter width	-20.0%	0.165	T03 * Rural	115.7%	0.001
T14 – Barriers	-12.9%	0.413	T04 * Rural	44.8%	0.076
T15 - Realign len	-38.0%	0.445	T05 * Rural	77.0%	0.350
T16 - Realign int	-18.8%	0.062	T06 * Rural	19.5%	0.399
T17 - Clear haz	-31.4%	0.037	T07 * Rural	58.4%	0.009
T18 - Warn signs	4.4%	0.845	T08 * Rural	29.4%	0.288
T19 – Lines	3.9%	0.700	T10 * Rural	-1.4%	0.936
T20 - Priority signs	3.4%	0.895	T11 * Rural	61.4%	0.019
T22 - Alter dir	-58.0%	0.003	T12 * Rural	24.9%	0.447
TUnsp	-3.1%	0.782	T14 * Rural	43.2%	0.226
T10 * T19	-38.6%	0.007	T15 * Rural	85.6%	0.257
T04 * T07	8.3%	0.549	T16 * Rural	19.4%	0.603
T18 * T19	-7.4%	0.766	T17 * Rural	75.5%	0.048
T12 * T19	-29.8%	0.234	T18 * Rural	26.9%	0.375
T02 * T07	44.9%	0.042	T19 * Rural	25.0%	0.140
T10 * T14	-13.6%	0.584	T20 * Rural	-33.5%	0.307
T12 * T15	-24.5%	0.633	T22 * Rural	45.1%	0.503
T10 * T12	-14.7%	0.656	TUnsp * Rural	57.3%	0.038
T10 * T15	-55.2%	0.146	ImpYear * After Treatment	-6.0%	0.000
T14 * T19	14.3%	0.725	State * After Treatment	19.7%	0.000
T04 * T04	-8.6%	0.585	Rural*After Ttreatment	-45.6%	0.000
T02 * T20	-6.2%	0.896	ACT * After Treatment	-64.4%	0.008
T02 * T19	39.6%	0.131	NT * After Treatment	16.6%	0.418
T19 * T19	19.7%	0.278	QLD * After Treatment	7.5%	0.302
T07 * T07	31.5%	0.204	SA * After Treatment	5.6%	0.472
T14 * T18	-6.0%	0.883	Tas * After Treatment	3.3%	0.854
T10 * T17	-2.5%	0.947	WA * After Treatment	20.3%	0.001

TABLE 4.6 TIME OF THE DAY TREATMENT EFFECT IN THE MINOR CRASH MODEL

Treatment	Day Effect	Day p-value	Night Effect	Night p-value
T03 - New sig	-48.6%	0.000	-39.9%	0.004
T06 - Lighting	14.3%	0.171	3.9%	0.791
T18 - Warn signs	4.4%	0.845	45.9%	0.169
T19 - Lines	3.9%	0.700	3.3%	0.787
T20 - Priority signs	3.4%	0.895	17.8%	0.645

TABLE 4.7 URBAN/RURAL TREATMENT EFFECT IN THE MINOR CRASH MODEL

Treatment	Urban	Urban p-value	Rural	Rural p-value
T01 - R/bout	-62.0%	0.000	-76.6%	0.000
T02 - Median	-20.5%	0.029	-47.0%	0.001
T03 - New sig	-48.6%	0.000	-39.7%	0.004
T04 - Mod sig	-22.7%	0.000	-39.1%	0.007
T05 - Traff calm	-21.9%	0.657	-24.8%	0.257
T06 - Lighting	14.3%	0.171	-25.6%	0.097
T07 - Turn lane	-12.4%	0.106	-24.5%	0.141
T08 - Ped treat	-3.6%	0.737	-32.1%	0.129
T10 - Seal/reseal	30.0%	0.005	-30.2%	0.008
T11 - Non-skid	-12.5%	0.138	-23.1%	0.146
T12 - Alter width	-20.0%	0.165	-45.6%	0.037
T14 - Barriers	-12.9%	0.413	-32.2%	0.261
T15 - Realign len	-38.0%	0.445	-37.3%	0.328
T16 - Realign int	-18.8%	0.062	-47.2%	0.039
T17 - Clear haz	-31.4%	0.037	-34.5%	0.098
T18 - Warn signs	4.4%	0.845	-27.9%	0.294
T19 - Lines	3.9%	0.700	-29.3%	0.010
T20 - Priority signs	3.4%	0.895	-62.6%	0.037
T22 - Alter dir	-58.0%	0.003	-66.8%	0.017
TUnsp	-3.1%	0.782	-17.0%	0.214

INJURY CRASHES

TABLE 4.8 summarises the results from the model for injury crashes and Appendix D contains the actual model output, adjusted for overdispersion. There was slight evidence of overdispersion ($\hat{c}$ = 1.31) and the standard errors of the parameter estimates were adjusted accordingly, as discussed in Chapter 2.

Overall, the results were similar between the models for injury crashes and minor injury crashes because injury crashes are made up of serious injury crashes and minor injury crashes. Since there are more minor injury crashes than serious injury crashes, the model results are heavily influenced by the minor injury crashes. However, the injury crash model was developed from a larger dataset that included sites in New South Wales, which were not included in either the serious or minor injury crash models.

There was a statistically significant pre-application bias for injury crashes. The result suggested that the number of injury crashes was 6.0% higher in the period prior to application for treatment compared to other time periods.

In urban sites, roundabouts (T01), new signals (T03), modifying/changing the phase of existing signals (T04), and altering the direction of traffic flow (T22) reduced injury crashes by 61%, 46%, 20% and 63% respectively. Sites with lighting treatments (T06) were found to increase daytime urban injury crashes by 21%. Sealing/resealing (T10) resulted in a statistically significant increase in urban injury crash rates of 24%, however when this treatment was combined with either realigning road lengths (T15) or lines (T19) urban injury crashes were reduced by an additional 49% and 36% respectively.

A number of other treatment interactions were found to be significant. Combining medians (T02) with turning lanes (T07) saw an additional 37% increase in injury crashes than when these were applied individually, while combining medians (T02) with priority signs (T20) saw around 51% less crashes than what would be expected should these be applied separately. The effect of altering the width (T12) while realigning a length of road (T15) was found to decrease injury crashes by 49% more than their individual effects.

On average, treatments at rural sites were 37% more effective at reducing injury crashes than at urban sites. However a number of the interactions between the individual treatment types and whether a site was urban or rural were found to significantly modify this effect. In rural sites, roundabouts (T01), medians (T02), new signals (T03), modifying/changing the phase of existing signals (T04), lighting treatments (T06), sealing or resealing (T10), altering road width (T12), realigning intersection (T16), clearing obstacles or hazards (T17), warning signs (T18), line markings (T19) and priority sign treatments (T20) all reduced minor injury crashes by 69%, 47%, 38%, 28%, 29%, 20%, 39%, 41%, 35%, 36%, 24% and 38% respectively. The overall estimates for the effect of each treatment at a rural site compared with the same treatment at an urban site are given in TABLE 4.10.

The interaction between the treatment implementation year and the period after treatment was statistically significant and indicates that, on average, treatments have become 4% more effective at reducing injury crashes each year since 1996. Again, whether this is due to improved selection of sites or improved implementation of treatments it is not possible to tell from the data alone, but it does suggest an improvement in the program.

The interaction between jurisdiction and the period after treatment was statistically significant, with the relative number of injury crashes in the Australian Capital Territory and Victoria being 62% and 11% lower respectively after treatment, compared to New South Wales. The ACT result is, however, based upon very few sites and these may have specific conditions that led to this result.

As was observed with minor injury crashes, the interaction between state and local government sites and the period after treatment was statistically significant, with the relative number of injury crashes at state government run sites 15% higher after treatment compared to local government run sites.

TABLE 4.8 SUMMARY OF THE PARAMETERS USED IN THE INJURY CRASH MODEL

Term	Effect	p-value	Term	Effect	p-value
Pre-Application Bias	6.1%	0.012	T15 * T19	-5.5%	0.859
T01 - R/bout	-61.2%	0.000	T07 * T08	-32.9%	0.066
T02 – Median	-13.8%	0.114	T19 * T20	-6.0%	0.808
T03 - New sig	-46.3%	0.000	T17 * T19	-34.5%	0.172
T04 - Mod sig	-19.9%	0.000	T03 * Night	32.2%	0.066
T05 - Traff calm	-36.9%	0.156	T06 * Night	-8.6%	0.499
T06 – Lighting	21.2%	0.031	T18 * Night	26.1%	0.176
T07 - Turn lane	-10.3%	0.136	T19 * Night	-6.8%	0.438
T08 - Ped treat	1.6%	0.854	T20 * Night	37.5%	0.193
T10 - Seal/reseal	24.0%	0.007	T01 * Rural	26.8%	0.135
T11 - Non-skid	-7.0%	0.362	T02 * Rural	-1.7%	0.909
T12 - Alter width	-17.7%	0.155	T03 * Rural	83.1%	0.000
T14 – Barriers	-1.5%	0.893	T04 * Rural	43.1%	0.026
T15 - Realign len	-47.0%	0.075	T05 * Rural	148.2%	0.015
T16 - Realign int	-11.3%	0.234	T06 * Rural	-7.1%	0.657
T17 - Clear haz	-25.3%	0.058	T07 * Rural	55.0%	0.001
T18 - Warn signs	-12.8%	0.435	T08 * Rural	22.7%	0.257
T19 – Lines	15.0%	0.106	T10 * Rural	2.3%	0.858
T20 - Priority signs	7.2%	0.746	T11 * Rural	50.4%	0.014
T22 - Alter dir	-63.4%	0.000	T12 * Rural	18.1%	0.446
TUnsp	-0.3%	0.975	T14 * Rural	18.3%	0.324
T10 * T19	-35.9%	0.002	T15 * Rural	181.5%	0.003
T04 * T07	6.2%	0.605	T16 * Rural	6.4%	0.795
T18 * T19	5.4%	0.787	T17 * Rural	37.4%	0.160
T12 * T19	-29.3%	0.147	T18 * Rural	15.8%	0.468
T02 * T07	37.1%	0.040	T19 * Rural	5.0%	0.667
T10 * T14	-12.2%	0.497	T20 * Rural	-8.7%	0.707
T12 * T15	-49.4%	0.034	T22 * Rural	181.4%	0.006
T10 * T12	36.7%	0.191	TUnsp * Rural	43.2%	0.033
T10 * T15	-49.5%	0.025	ImpYear * After Treatment	-3.8%	0.000
T14 * T19	0.8%	0.972	Rural*After Ttreatment	-37.0%	0.000
T04 * T04	2.4%	0.848	ACT*After Treatment	-61.9%	0.003
T02 * T20	-51.3%	0.040	NT*After Treatment	25.1%	0.146
T02 * T19	16.0%	0.419	QLD*After Treatment	-6.5%	0.315
T19 * T19	18.1%	0.189	SA*After Treatment	-8.8%	0.226
T07 * T07	36.8%	0.070	Tas*After Treatment	-11.5%	0.445
T14 * T18	-1.4%	0.954	VIC*After Treatment	-11.1%	0.016
T10 * T17	0.7%	0.980	WA*After Treatment	7.9%	0.180
			State*After Treatment	15.3%	0.000

TABLE 4.9 TIME OF DAY TREATMENT EFFECT IN THE INJURY CRASH MODEL

Treatment	Day	Day p-value	Night	Night p-value
T03 - New sig	-46.3%	0.000	-29.0%	0.018
T06 - Lighting	21.2%	0.031	10.7%	0.405
T18 - Warn signs	-12.8%	0.435	9.9%	0.649
T19 - Lines	15.0%	0.106	7.1%	0.489
T20 - Priority signs	7.2%	0.746	47.4%	0.161

TABLE 4.10 URBAN/RURAL TREATMENT EFFECT IN THE INJURY CRASH MODEL

Treatment	Urban	Urban p-value	Rural	Rural p-value
T01 - R/bout	-61.2%	0.000	-69.0%	0.000
T02 - Median	-13.8%	0.114	-46.6%	0.000
T03 - New sig	-46.3%	0.000	-38.1%	0.001
T04 - Mod sig	-19.9%	0.000	-27.8%	0.027
T05 - Traff calm	-36.9%	0.156	-1.4%	0.943
T06 - Lighting	21.2%	0.031	-29.1%	0.023
T07 - Turn lane	-10.3%	0.136	-12.5%	0.323
T08 - Ped treat	1.6%	0.854	-21.4%	0.182
T10 - Seal/reseal	24.0%	0.007	-20.1%	0.050
T11 - Non-skid	-7.0%	0.362	-11.9%	0.411
T12 - Alter width	-17.7%	0.155	-38.8%	0.019
T14 - Barriers	-1.5%	0.893	-26.6%	0.059
T15 - Realign len	-47.0%	0.075	-5.9%	0.767
T16 - Realign int	-11.3%	0.234	-40.6%	0.015
T17 - Clear haz	-25.3%	0.058	-35.3%	0.024
T18 - Warn signs	-12.8%	0.435	-36.4%	0.039
T19 - Lines	15.0%	0.106	-23.9%	0.012
T20 - Priority signs	7.2%	0.746	-38.4%	0.018
T22 - Alter dir	-63.4%	0.000	-35.2%	0.101
TUnsp	-0.3%	0.975	-10.1%	0.392

PROPERTY DAMAGE ONLY CRASHES

TABLE 4.11 summarises the results from the model for property damage only (PDO) crashes and Appendix E contains the actual model output, adjusted for overdispersion. There was evidence of overdispersion ($\hat{c}$ = 1.49) and the standard errors of the parameter estimates were adjusted accordingly, as discussed in Chapter 2.

There was no statistically significant pre-application bias for property damage only crashes. Most treatment types were effective at reducing the number of urban PDO crashes, however lighting (T06) saw a 22% increase in the rate of urban daytime crashes. Overall, treatments at rural sites were 32% more effective than at urban sites, however a number of individual treatments were found to differ significantly from this baseline. In particular, lighting (T06) was found to reduce property damage accidents by 44% at rural sites. TABLE 4.13 shows the effect of treatments at urban and rural sites.

For property damage only crashes, a number of interaction terms measuring the additional effect due to the use of multiple treatments at a site were found to be significant. Of these, only one pairing (T04 with itself - multiple modifications of signals) was found to reduce the PDO crash rate. The others were all found to increase the number of crashes compared to when they were used alone.

The interaction between the treatment implementation year and the period after treatment was statistically significant and indicates that, on average, treatments have become 4% more effective at reducing PDO crashes each year since 1996.

The means of selecting sites for the Black Spot Program was related to the treatment effectiveness, with the relative number of PDO crashes 25% higher for RSA selected sites after treatment compared to BCR selected sites. This suggests that the RSA procedure was less likely to select sites where larger reductions in property damage only crashes could be achieved.

A number of jurisdictions were found to be significantly different to New South Wales, which was used as the reference class. In ACT and Queensland, the relative number of PDO crashes were 33% and 25% lower after treatment compared to New South Wales. In contrast, the relative number of crashes was 32% and 38% higher in Western Australia and Tasmania, respectively, after treatment compared to New South Wales. The relative number of PDO crashes at state government-run sites was 29% higher after treatment compared to local government-run sites.

TABLE 4.11 SUMMARY OF THE PARAMETERS USED IN THE PROPERTY DAMAGE ONLY CRASH MODEL

Term	Effect	p-value	Term	Effect	p-value
Pre-Application Bias	3.7%	0.080	T15 * T19	6.7%	0.920
T01 - R/bout	-28.5%	0.000	T07 * T08	-11.3%	0.517
T02 – Median	-37.6%	0.000	T19 * T20	31.7%	0.364
T03 - New sig	-49.2%	0.000	T17 * T19	55.3%	0.309
T04 - Mod sig	-29.0%	0.000	T03 * Night	47.1%	0.013
T05 - Traff calm	-40.1%	0.206	T06 * Night	11.7%	0.483
T06 – Lighting	21.6%	0.049	T18 * Night	-26.4%	0.098
T07 - Turn lane	-26.0%	0.000	T19 * Night	4.5%	0.708
T08 - Ped treat	-21.3%	0.012	T20 * Night	-6.8%	0.759
T10 - Seal/reseal	23.2%	0.051	T01 * Rural	-22.8%	0.093
T11 - Non-skid	-16.8%	0.031	T02 * Rural	14.5%	0.388
T12 - Alter width	-39.1%	0.008	T03 * Rural	73.7%	0.001
T14 – Barriers	-34.5%	0.012	T04 * Rural	60.3%	0.002
T15 - Realign len	-28.0%	0.601	T05 * Rural	-5.2%	0.922
T16 - Realign int	-22.5%	0.002	T06 * Rural	-32.2%	0.021
T17 - Clear haz	-19.9%	0.245	T07 * Rural	52.6%	0.001
T18 - Warn signs	10.3%	0.565	T08 * Rural	75.8%	0.001
T19 – Lines	-30.4%	0.002	T10 * Rural	-14.9%	0.434
T20 - Priority signs	19.1%	0.300	T11 * Rural	110.3%	0.000
T22 - Alter dir	-67.0%	0.000	T12 * Rural	69.8%	0.064
TUnsp	12.9%	0.174	T14 * Rural	34.7%	0.195
T10 * T19	-40.8%	0.125	T15 * Rural	61.5%	0.512
T04 * T07	31.8%	0.026	T16 * Rural	39.0%	0.294
T18 * T19	39.8%	0.112	T17 * Rural	8.1%	0.772
T12 * T19	-11.0%	0.775	T18 * Rural	-27.6%	0.224
T02 * T07	86.8%	0.000	T19 * Rural	39.5%	0.030
T10 * T14	15.8%	0.510	T20 * Rural	-24.1%	0.269
T12 * T15	-49.6%	0.126	T22 * Rural	239.7%	0.001
T10 * T12	13.7%	0.674	TUnsp * Rural	-29.6%	0.090
T10 * T15	-61.8%	0.054	ImpYear * After Treatment	-4.1%	0.000
T14 * T19	8.8%	0.771	RSA * After Treatment	25.0%	0.000
T04 * T04	-55.8%	0.000	Rural*After Ttreatment	-32.2%	0.001
T02 * T20	18.1%	0.597	ACT * After Treatment	-32.8%	0.002
T02 * T19	36.5%	0.173	NT * After Treatment	19.2%	0.173
T19 * T19	38.8%	0.007	QLD * After Treatment	-25.2%	0.000
T07 * T07	35.9%	0.047	SA * After Treatment	-10.4%	0.086
T14 * T18	61.1%	0.140	Tas * After Treatment	37.9%	0.014
T10 * T17	4.6%	0.943	WA * After Treatment	31.8%	0.000
			State * After Treatment	29.1%	0.000

TABLE 4.12 TIME OF DAY TREATMENT EFFECT IN THE PROPERTY DAMAGE ONLY CRASH MODEL

Treatment	Day (Effect)	Day p-value	Night (Effect)	Night p-value
T03 - New sig	-49.2%	0.000	-25.2%	0.055
T06 - Lighting	21.6%	0.049	35.9%	0.058
T18 - Warn signs	10.3%	0.565	-18.8%	0.353
T19 - Lines	-30.4%	0.002	-27.3%	0.026
T20 - Priority signs	19.1%	0.300	11.0%	0.674

TABLE 4.13 URBAN /RURAL TREATMENT EFFECT IN THE PROPERTY DAMAGE ONLY CRASH MODEL

Treatment	Urban	Urban p-value	Rural	Rural p-value
T01 - R/bout	-28.5%	0.000	-62.5%	0.000
T02 - Median	-37.6%	0.000	-51.5%	0.000
T03 - New sig	-49.2%	0.000	-40.1%	0.000
T04 - Mod sig	-29.0%	0.000	-22.8%	0.094
T05 - Traff calm	-40.1%	0.206	-61.5%	0.010
T06 - Lighting	21.6%	0.049	-44.1%	0.000
T07 - Turn lane	-26.0%	0.000	-23.4%	0.062
T08 - Ped treat	-21.3%	0.012	-6.2%	0.721
T10 - Seal/reseal	23.2%	0.051	-28.9%	0.056
T11 - Non-skid	-16.8%	0.031	18.7%	0.191
T12 - Alter width	-39.1%	0.008	-29.9%	0.161
T14 - Barriers	-34.5%	0.012	-40.2%	0.012
T15 - Realign len	-28.0%	0.601	-21.1%	0.521
T16 - Realign int	-22.5%	0.002	-26.9%	0.299
T17 - Clear haz	-19.9%	0.245	-41.3%	0.017
T18 - Warn signs	10.3%	0.565	-45.9%	0.021
T19 - Lines	-30.4%	0.002	-34.1%	0.000
T20 - Priority signs	19.1%	0.300	-38.7%	0.031
T22 - Alter dir	-67.0%	0.000	-23.9%	0.201
TUnsp	12.9%	0.174	-46.1%	0.001

Treatment	Urban	Rural	Treatment	Urban	Rural
T01 - R/bout	-28.5%	-62.5%	T12 - Alter width	-39.1%	-29.9%
T02 - Median	-37.6%	-51.5%	T14 - Barriers	-34.5%	-40.2%
T03 - New sig	-49.2%	-40.1%	T15 - Realign len	-28.0%	-21.1%
T04 - Mod sig	-29.0%	-22.8%	T16 - Realign int	-22.5%	-26.9%
T05 - Traff calm	-40.1%	-61.5%	T17 - Clear haz	-19.9%	-41.3%
T06 - Lighting	21.6%	-44.1%	T18 - Warn signs	10.3%	-45.9%
T07 - Turn lane	-26.0%	-23.4%	T19 - Lines	-30.4%	-34.1%
T08 - Ped treat	-21.3%	-6.2%	T20 - Priority signs	19.1%	-38.7%
T10 - Seal/reseal	23.2%	-28.9%	T22 - Alter dir	-67.0%	-23.9%
T11 - Non-skid	-16.8%	18.7%	TUnsp	12.9%	-46.1%

APPENDIX A MODEL OUTPUT - FATAL CRASHES

Term	Meaning	Coef.	Std. Err.	z value	p-value	ll95%CI	ul95%CI
sel_bias_1	Pre-Application Bias	0.221	0.131	1.684	0.046	-0.036	0.478
trt_cts1_2	T01*After treatment	-1.570	0.553	-2.838	0.005	-2.655	-0.486
trt_cts2_2	T02*After treatment	-0.114	0.403	-0.284	0.777	-0.904	0.675
trt_cts3_2	T03*After treatment	-2.668	1.039	-2.569	0.010	-4.704	-0.632
trt_cts4_2	T04*After treatment	-0.416	0.336	-1.237	0.216	-1.075	0.243
trt_cts5_2	T05*After treatment	-12.889	658.180	-0.020	0.984	-1302.921	1277.143
trt_cts6_2	T06*After treatment	0.150	0.537	0.279	0.780	-0.903	1.203
trt_cts7_2	T07*After treatment	-0.926	0.409	-2.262	0.024	-1.729	-0.124
trt_cts8_2	T08*After treatment	-0.881	0.574	-1.535	0.125	-2.006	0.244
trt_cts9_2	T10*After treatment	-0.294	0.202	-1.458	0.145	-0.690	0.101
trt_c~10_2	T11*After treatment	0.476	0.378	1.260	0.208	-0.264	1.217
trt_c~11_2	T12*After treatment	-0.079	0.373	-0.212	0.832	-0.811	0.652
trt_c~12_2	T14*After treatment	-0.062	0.264	-0.233	0.816	-0.580	0.457
trt_c~13_2	T15*After treatment	-0.223	0.451	-0.496	0.620	-1.106	0.660
trt_c~14_2	T16*After treatment	-1.371	0.817	-1.679	0.093	-2.972	0.229
trt_c~15_2	T17*After treatment	-0.156	0.391	-0.399	0.690	-0.922	0.610
trt_c~16_2	T18*After treatment	0.349	0.437	0.798	0.425	-0.507	1.205
trt_c~17_2	T19*After treatment	-0.225	0.228	-0.987	0.324	-0.671	0.222
trt_c~18_2	T20*After treatment	0.937	0.581	1.612	0.107	-0.202	2.075
trt_c~19_2	T22*After treatment	0.188	0.908	0.208	0.836	-1.591	1.968
trt_c~20_2	Unsp*After Treatment	0.506	0.633	0.799	0.424	-0.735	1.747
trt3_cts~2	T03*After treatment*night	3.673	1.274	2.883	0.004	1.176	6.170
trt6_cts~2	T06*After treatment*night	0.332	0.666	0.498	0.618	-0.973	1.637
trt18_ct~2	T18*After treatment*night	-0.770	0.654	-1.176	0.240	-2.052	0.513
trt19_ct~2	T19*After treatment*night	0.076	0.332	0.228	0.819	-0.574	0.726
trt20_ct~2	T20*After treatment*night	-1.838	1.267	-1.451	0.147	-4.320	0.645

APPENDIX B MODEL OUTPUT – SERIOUS INJURY CRASHES

Term	Meaning	Coef.	Std. Err.	z value	p-value	ll95%CI	ul95%CI
sel_bias_1	Pre-Application Bias	0.156	0.041	3.773	0.000	0.075	0.237
trt_cts1_2	T01*After treatment	-1.196	0.136	-8.810	0.000	-1.462	-0.930
trt_cts2_2	T02*After treatment	0.014	0.108	0.130	0.896	-0.198	0.226
trt_cts3_2	T03*After treatment	-0.806	0.149	-5.419	0.000	-1.098	-0.515
trt_cts4_2	T04*After treatment	-0.323	0.072	-4.465	0.000	-0.464	-0.181
trt_cts5_2	T05*After treatment	-0.066	0.255	-0.260	0.795	-0.565	0.433
trt_cts6_2	T06*After treatment	0.106	0.126	0.840	0.401	-0.141	0.352
trt_cts7_2	T07*After treatment	-0.047	0.082	-0.579	0.562	-0.207	0.113
trt_cts8_2	T08*After treatment	-0.022	0.122	-0.179	0.858	-0.260	0.217
trt_cts9_2	T10*After treatment	-0.152	0.075	-2.030	0.042	-0.298	-0.005
trt_c~10_2	T11*After treatment	0.063	0.108	0.589	0.556	-0.147	0.274
trt_c~11_2	T12*After treatment	0.007	0.133	0.054	0.957	-0.253	0.267
trt_c~12_2	T14*After treatment	0.207	0.130	1.592	0.111	-0.048	0.463
trt_c~13_2	T15*After treatment	-0.055	0.180	-0.303	0.762	-0.408	0.299
trt_c~14_2	T16*After treatment	0.086	0.146	0.592	0.554	-0.200	0.373
trt_c~15_2	T17*After treatment	-0.204	0.138	-1.476	0.140	-0.474	0.067
trt_c~16_2	T18*After treatment	-0.012	0.173	-0.069	0.945	-0.352	0.328
trt_c~17_2	T19*After treatment	-0.046	0.084	-0.545	0.586	-0.210	0.119
trt_c~18_2	T20*After treatment	-0.662	0.261	-2.538	0.011	-1.173	-0.151
trt_c~19_2	T22*After treatment	-1.418	0.394	-3.597	0.000	-2.191	-0.645
trt_c~20_2	Unsp*After Treatment	0.064	0.119	0.541	0.589	-0.168	0.297
urorrur_~2	Rural*After Treatment	-0.134	0.066	-2.028	0.043	-0.264	-0.004
jur_cts_1	ACT*After Treatment	-0.446	0.433	-1.030	0.303	-1.296	0.403
jur_cts_2	NT*After Treatment	0.262	0.181	1.449	0.147	-0.092	0.616
jur_cts_3	QLD*After Treatment	-0.016	0.084	-0.191	0.848	-0.182	0.149
jur_cts_4	SA*After Treatment	-0.365	0.142	-2.570	0.010	-0.643	-0.087
jur_cts_5	Tas*After Treatment	-0.388	0.271	-1.432	0.152	-0.920	0.143
jur_cts_7	WA*After Treatment	0.109	0.071	1.529	0.126	-0.031	0.248
trt3_cts~2	T03*After treatment*night	0.696	0.251	2.773	0.006	0.204	1.187
trt6_cts~2	T06*After treatment*night	-0.117	0.188	-0.620	0.535	-0.486	0.252
trt18_ct~2	T18*After treatment*night	0.129	0.250	0.518	0.605	-0.361	0.620
trt19_ct~2	T19*After treatment*night	-0.102	0.120	-0.851	0.395	-0.336	0.133
trt20_ct~2	T20*After treatment*night	0.744	0.474	1.569	0.117	-0.185	1.673

APPENDIX C MODEL OUTPUT – MINOR INJURY CRASHES

Term	Meaning	Coef.	Std. Err.	z value	p-value	ll95%CI	ul95%CI
sel_bias_1	Pre-Application Bias	0.027	0.030	0.905	0.183	-0.032	0.087
trt_cts1_2	T01*After treatment	-0.968	0.122	-7.959	0.000	-1.207	-0.730
trt_cts2_2	T02*After treatment	-0.230	0.105	-2.179	0.029	-0.437	-0.023
trt_cts3_2	T03*After treatment	-0.666	0.114	-5.845	0.000	-0.889	-0.443
trt_cts4_2	T04*After treatment	-0.257	0.070	-3.673	0.000	-0.395	-0.120
trt_cts5_2	T05*After treatment	-0.247	0.557	-0.444	0.657	-1.339	0.844
trt_cts6_2	T06*After treatment	0.134	0.098	1.370	0.171	-0.058	0.326
trt_cts7_2	T07*After treatment	-0.133	0.082	-1.617	0.106	-0.293	0.028
trt_cts8_2	T08*After treatment	-0.037	0.109	-0.336	0.737	-0.251	0.177
trt_cts9_2	T10*After treatment	0.263	0.093	2.828	0.005	0.081	0.445
trt_c~10_2	T11*After treatment	-0.133	0.090	-1.482	0.138	-0.309	0.043
trt_c~11_2	T12*After treatment	-0.223	0.160	-1.389	0.165	-0.537	0.092
trt_c~12_2	T14*After treatment	-0.139	0.169	-0.819	0.413	-0.470	0.193
trt_c~13_2	T15*After treatment	-0.478	0.625	-0.764	0.445	-1.703	0.747
trt_c~14_2	T16*After treatment	-0.208	0.112	-1.865	0.062	-0.427	0.011
trt_c~15_2	T17*After treatment	-0.377	0.181	-2.084	0.037	-0.732	-0.022
trt_c~16_2	T18*After treatment	0.043	0.220	0.195	0.845	-0.388	0.474
trt_c~17_2	T19*After treatment	0.038	0.100	0.386	0.700	-0.157	0.234
trt_c~18_2	T20*After treatment	0.034	0.253	0.132	0.895	-0.463	0.530
trt_c~19_2	T22*After treatment	-0.867	0.289	-3.003	0.003	-1.432	-0.301
trt_c~20_2	Unsp*After Treatment	-0.031	0.112	-0.277	0.782	-0.250	0.188
trt_c~21_2	T10*T19*After Treatment	-0.488	0.180	-2.718	0.007	-0.840	-0.136
trt_c~22_2	T04*T07*After Treatment	0.079	0.133	0.599	0.549	-0.181	0.339
trt_c~23_2	T18*T19*After Treatment	-0.077	0.258	-0.298	0.766	-0.582	0.428
trt_c~24_2	T12*T19*After Treatment	-0.354	0.297	-1.190	0.234	-0.937	0.229
trt_c~25_2	T02*T07*After Treatment	0.371	0.182	2.036	0.042	0.014	0.728
trt_c~26_2	T10*T14*After Treatment	-0.147	0.268	-0.547	0.584	-0.672	0.379
trt_c~27_2	T12*T15*After Treatment	-0.281	0.589	-0.477	0.633	-1.436	0.874
trt_c~28_2	T10*T12*After Treatment	-0.158	0.355	-0.446	0.656	-0.855	0.538
trt_c~29_2	T10*T15*After Treatment	-0.804	0.553	-1.454	0.146	-1.888	0.280
trt_c~30_2	T14*T19*After Treatment	0.133	0.379	0.351	0.725	-0.610	0.877
trt_c~31_2	T04*T04*After Treatment	-0.090	0.165	-0.547	0.585	-0.414	0.233
trt_c~32_2	T02*T20*After Treatment	-0.064	0.493	-0.130	0.896	-1.030	0.902
trt_c~33_2	T02*T19*After Treatment	0.333	0.221	1.509	0.131	-0.100	0.766
trt_c~34_2	T19*T19*After Treatment	0.180	0.166	1.084	0.278	-0.145	0.505
trt_c~35_2	T07*T07*After Treatment	0.274	0.216	1.270	0.204	-0.149	0.697
trt_c~36_2	T14*T18*After Treatment	-0.062	0.417	-0.148	0.883	-0.879	0.756

Term	Meaning	Coef.	Std. Err.	z value	p-value	ll95%CI	ul95%CI
trt_c~37_2	T10*T17*After Treatment	-0.025	0.377	-0.066	0.947	-0.763	0.713
trt_c~38_2	T15*T19*After Treatment	-0.201	0.565	-0.356	0.722	-1.308	0.906
trt_c~39_2	T07*T08*After Treatment	-0.278	0.257	-1.083	0.279	-0.782	0.225
trt_c~40_2	T19*T20*After Treatment	0.208	0.317	0.655	0.512	-0.414	0.830
trt_c~41_2	T17*T19*After Treatment	-0.544	0.395	-1.377	0.169	-1.319	0.230
trt_ct~u_2	T01*After treatment*Rural	0.124	0.222	0.559	0.576	-0.312	0.561
trt_cts~a2	T02*After treatment*Rural	0.204	0.188	1.088	0.276	-0.164	0.572
trt_cts~b2	T03*After treatment*Rural	0.769	0.224	3.436	0.001	0.330	1.207
trt_cts~c2	T04*After treatment*Rural	0.370	0.208	1.777	0.076	-0.038	0.778
trt_cts~d2	T05*After treatment*Rural	0.571	0.611	0.935	0.350	-0.626	1.768
trt_cts~e2	T06*After treatment*Rural	0.178	0.211	0.844	0.399	-0.235	0.591
trt_cts~f2	T07*After treatment*Rural	0.460	0.177	2.599	0.009	0.113	0.807
trt_cts~g2	T08*After treatment*Rural	0.258	0.243	1.062	0.288	-0.218	0.734
trt_cts~h2	T10*After treatment*Rural	-0.014	0.169	-0.080	0.936	-0.345	0.318
trt_cts~i2	T11*After treatment*Rural	0.479	0.204	2.352	0.019	0.080	0.878
trt_cts~j2	T12*After treatment*Rural	0.222	0.292	0.761	0.447	-0.351	0.796
trt_cts~k2	T14*After treatment*Rural	0.359	0.296	1.211	0.226	-0.222	0.940
trt_cts~l2	T15*After treatment*Rural	0.619	0.546	1.133	0.257	-0.452	1.689
trt_cts~m2	T16*After treatment*Rural	0.177	0.341	0.520	0.603	-0.491	0.846
trt_cts~n2	T17*After treatment*Rural	0.563	0.285	1.977	0.048	0.005	1.120
trt_cts~o2	T18*After treatment*Rural	0.238	0.268	0.887	0.375	-0.288	0.764
trt_cts~p2	T19*After treatment*Rural	0.223	0.151	1.477	0.140	-0.073	0.520
trt_cts~q2	T20*After treatment*Rural	-0.408	0.400	-1.021	0.307	-1.192	0.376
trt_cts~r2	T22*After treatment*Rural	0.373	0.556	0.670	0.503	-0.717	1.462
trt_cts~s2	Unsp*After treatment*Rural	0.453	0.218	2.076	0.038	0.025	0.881
craXtrea~2	ImpYear*After Treatment	-0.062	0.012	-5.296	0.000	-0.085	-0.039
storloc_~2	State*After Treatment	0.180	0.044	4.110	0.000	0.094	0.265
urorrur_~2	Rural*After Treatment	-0.608	0.140	-4.334	0.000	-0.884	-0.333
jur_cts_1	ACT*After Treatment	-1.032	0.387	-2.666	0.008	-1.791	-0.273
jur_cts_2	NT*After Treatment	0.154	0.190	0.811	0.418	-0.218	0.526
jur_cts_3	QLD*After Treatment	0.073	0.070	1.033	0.302	-0.065	0.211
jur_cts_4	SA*After Treatment	0.054	0.075	0.719	0.472	-0.093	0.202
jur_cts_5	Tas*After Treatment	0.033	0.177	0.184	0.854	-0.314	0.379
jur_cts_7	WA*After Treatment	0.185	0.055	3.335	0.001	0.076	0.294
trt3_cts~2	T03*After treatment*night	0.157	0.186	0.843	0.399	-0.208	0.522
trt6_cts~2	T06*After treatment*night	-0.096	0.159	-0.606	0.544	-0.407	0.215
trt18_ct~2	T18*After treatment*night	0.335	0.237	1.413	0.158	-0.130	0.799
trt19_ct~2	T19*After treatment*night	-0.006	0.116	-0.049	0.961	-0.232	0.221
trt20_ct~2	T20*After treatment*night	0.130	0.341	0.381	0.703	-0.539	0.799

APPENDIX D MODEL OUTPUT – INJURY CRASHES

Term	Meaning	Coef.	Std. Err.	z value	p-value	ll95%CI	ul95%CI
sel_bias_1	Pre-Application Bias	0.059	0.026	2.259	0.012	0.008	0.110
trt_cts1_2	T01*After treatment	-0.947	0.096	-9.836	0.000	-1.135	-0.758
trt_cts2_2	T02*After treatment	-0.148	0.094	-1.579	0.114	-0.332	0.036
trt_cts3_2	T03*After treatment	-0.621	0.097	-6.438	0.000	-0.811	-0.432
trt_cts4_2	T04*After treatment	-0.221	0.061	-3.633	0.000	-0.341	-0.102
trt_cts5_2	T05*After treatment	-0.460	0.325	-1.418	0.156	-1.097	0.176
trt_cts6_2	T06*After treatment	0.192	0.089	2.154	0.031	0.017	0.367
trt_cts7_2	T07*After treatment	-0.109	0.073	-1.491	0.136	-0.252	0.034
trt_cts8_2	T08*After treatment	0.016	0.089	0.184	0.854	-0.157	0.190
trt_cts9_2	T10*After treatment	0.215	0.080	2.674	0.007	0.057	0.373
trt_c~10_2	T11*After treatment	-0.073	0.080	-0.911	0.362	-0.229	0.084
trt_c~11_2	T12*After treatment	-0.195	0.137	-1.422	0.155	-0.465	0.074
trt_c~12_2	T14*After treatment	-0.015	0.112	-0.134	0.893	-0.234	0.204
trt_c~13_2	T15*After treatment	-0.634	0.356	-1.781	0.075	-1.332	0.064
trt_c~14_2	T16*After treatment	-0.120	0.101	-1.189	0.234	-0.317	0.078
trt_c~15_2	T17*After treatment	-0.292	0.154	-1.897	0.058	-0.593	0.010
trt_c~16_2	T18*After treatment	-0.137	0.175	-0.781	0.435	-0.481	0.207
trt_c~17_2	T19*After treatment	0.140	0.087	1.616	0.106	-0.030	0.309
trt_c~18_2	T20*After treatment	0.070	0.216	0.323	0.746	-0.353	0.493
trt_c~19_2	T22*After treatment	-1.006	0.258	-3.904	0.000	-1.511	-0.501
trt_c~20_2	Unsp*After Treatment	-0.003	0.098	-0.032	0.975	-0.195	0.189
trt_c~21_2	T10*T19*After Treatment	-0.445	0.145	-3.071	0.002	-0.730	-0.161
trt_c~22_2	T04*T07*After Treatment	0.060	0.116	0.517	0.605	-0.167	0.287
trt_c~23_2	T18*T19*After Treatment	0.052	0.194	0.270	0.787	-0.328	0.433
trt_c~24_2	T12*T19*After Treatment	-0.347	0.239	-1.450	0.147	-0.816	0.122
trt_c~25_2	T02*T07*After Treatment	0.316	0.154	2.052	0.040	0.014	0.617
trt_c~26_2	T10*T14*After Treatment	-0.130	0.191	-0.678	0.497	-0.504	0.245
trt_c~27_2	T12*T15*After Treatment	-0.681	0.322	-2.116	0.034	-1.312	-0.050
trt_c~28_2	T10*T12*After Treatment	0.312	0.239	1.307	0.191	-0.156	0.781
trt_c~29_2	T10*T15*After Treatment	-0.684	0.306	-2.238	0.025	-1.283	-0.085
trt_c~30_2	T14*T19*After Treatment	0.008	0.229	0.035	0.972	-0.441	0.457
trt_c~31_2	T04*T04*After Treatment	0.024	0.125	0.192	0.848	-0.221	0.269
trt_c~32_2	T02*T20*After Treatment	-0.719	0.350	-2.054	0.040	-1.405	-0.033
trt_c~33_2	T02*T19*After Treatment	0.148	0.183	0.808	0.419	-0.211	0.507
trt_c~34_2	T19*T19*After Treatment	0.166	0.126	1.313	0.189	-0.082	0.414
trt_c~35_2	T07*T07*After Treatment	0.314	0.173	1.813	0.070	-0.025	0.653
trt_c~36_2	T14*T18*After Treatment	-0.014	0.237	-0.057	0.954	-0.479	0.452

Term	Meaning	Coef.	Std. Err.	z value	p-value	ll95%CI	ul95%CI
trt_c~37_2	T10*T17*After Treatment	0.007	0.284	0.024	0.980	-0.551	0.564
trt_c~38_2	T15*T19*After Treatment	-0.057	0.322	-0.177	0.859	-0.689	0.575
trt_c~39_2	T07*T08*After Treatment	-0.399	0.217	-1.837	0.066	-0.824	0.027
trt_c~40_2	T19*T20*After Treatment	-0.062	0.255	-0.243	0.808	-0.562	0.438
trt_c~41_2	T17*T19*After Treatment	-0.423	0.310	-1.365	0.172	-1.031	0.185
trt_ct~u_2	T01*After treatment*Rural	0.237	0.159	1.496	0.135	-0.074	0.549
trt_cts~a2	T02*After treatment*Rural	-0.017	0.149	-0.115	0.909	-0.308	0.274
trt_cts~b2	T03*After treatment*Rural	0.605	0.172	3.526	0.000	0.269	0.941
trt_cts~c2	T04*After treatment*Rural	0.358	0.161	2.230	0.026	0.043	0.673
trt_cts~d2	T05*After treatment*Rural	0.909	0.374	2.434	0.015	0.177	1.641
trt_cts~e2	T06*After treatment*Rural	-0.073	0.165	-0.444	0.657	-0.396	0.250
trt_cts~f2	T07*After treatment*Rural	0.438	0.132	3.319	0.001	0.179	0.697
trt_cts~g2	T08*After treatment*Rural	0.205	0.180	1.135	0.257	-0.149	0.559
trt_cts~h2	T10*After treatment*Rural	0.023	0.128	0.178	0.858	-0.228	0.274
trt_cts~i2	T11*After treatment*Rural	0.408	0.167	2.447	0.014	0.081	0.735
trt_cts~j2	T12*After treatment*Rural	0.166	0.218	0.762	0.446	-0.262	0.594
trt_cts~k2	T14*After treatment*Rural	0.168	0.170	0.986	0.324	-0.166	0.501
trt_cts~l2	T15*After treatment*Rural	1.035	0.348	2.972	0.003	0.352	1.718
trt_cts~m2	T16*After treatment*Rural	0.062	0.237	0.260	0.795	-0.403	0.526
trt_cts~n2	T17*After treatment*Rural	0.318	0.226	1.406	0.160	-0.125	0.761
trt_cts~o2	T18*After treatment*Rural	0.147	0.203	0.726	0.468	-0.250	0.544
trt_cts~p2	T19*After treatment*Rural	0.049	0.114	0.430	0.667	-0.175	0.273
trt_cts~q2	T20*After treatment*Rural	-0.092	0.244	-0.375	0.707	-0.570	0.387
trt_cts~r2	T22*After treatment*Rural	1.035	0.376	2.754	0.006	0.298	1.771
trt_cts~s2	Unsp*After treatment*Rural	0.359	0.168	2.136	0.033	0.030	0.689
craXtrea~2	ImpYear*After Treatment	-0.039	0.010	-4.045	0.000	-0.057	-0.020
urorrur_~2	Rural*After Treatment	-0.462	0.099	-4.656	0.000	-0.657	-0.268
jur_cts_1	ACT*After Treatment	-0.966	0.329	-2.938	0.003	-1.610	-0.322
jur_cts_3	NT*After Treatment	0.224	0.154	1.455	0.146	-0.078	0.525
jur_cts_4	QLD*After Treatment	-0.067	0.067	-1.005	0.315	-0.198	0.064
jur_cts_5	SA*After Treatment	-0.092	0.076	-1.212	0.226	-0.241	0.057
jur_cts_6	Tas*After Treatment	-0.123	0.160	-0.765	0.445	-0.437	0.192
jur_cts_7	VIC*After Treatment	-0.118	0.049	-2.419	0.016	-0.213	-0.022
jur_cts_8	WA*After Treatment	0.076	0.057	1.340	0.180	-0.035	0.187
storloc_~2	State*After Treatment	0.143	0.037	3.857	0.000	0.070	0.215
trt3_cts~2	T03*After treatment*night	0.279	0.152	1.840	0.066	-0.018	0.577
trt6_cts~2	T06*After treatment*night	-0.090	0.133	-0.676	0.499	-0.352	0.171
trt18_ct~2	T18*After treatment*night	0.232	0.171	1.354	0.176	-0.104	0.567
trt19_ct~2	T19*After treatment*night	-0.071	0.091	-0.776	0.438	-0.250	0.108
trt20_ct~2	T20*After treatment*night	0.318	0.245	1.301	0.193	-0.161	0.797

APPENDIX E MODEL OUTPUT – PDO CRASHES

Term	Meaning	Coef.	Std. Err.	z value	p-value	ll95%CI	ul95%CI
sel_bias_1	Pre-Application Bias	0.036	0.026	1.403	0.080	-0.014	0.087
trt_cts1_2	T01*After treatment	-0.335	0.080	-4.183	0.000	-0.492	-0.178
trt_cts2_2	T02*After treatment	-0.472	0.079	-5.958	0.000	-0.627	-0.316
trt_cts3_2	T03*After treatment	-0.677	0.093	-7.270	0.000	-0.860	-0.494
trt_cts4_2	T04*After treatment	-0.343	0.064	-5.328	0.000	-0.469	-0.217
trt_cts5_2	T05*After treatment	-0.513	0.405	-1.266	0.206	-1.307	0.281
trt_cts6_2	T06*After treatment	0.196	0.099	1.973	0.049	0.001	0.391
trt_cts7_2	T07*After treatment	-0.301	0.068	-4.415	0.000	-0.435	-0.167
trt_cts8_2	T08*After treatment	-0.240	0.095	-2.514	0.012	-0.427	-0.053
trt_cts9_2	T10*After treatment	0.209	0.107	1.951	0.051	-0.001	0.418
trt_c~10_2	T11*After treatment	-0.184	0.085	-2.156	0.031	-0.351	-0.017
trt_c~11_2	T12*After treatment	-0.496	0.186	-2.665	0.008	-0.861	-0.131
trt_c~12_2	T14*After treatment	-0.423	0.169	-2.502	0.012	-0.755	-0.092
trt_c~13_2	T15*After treatment	-0.329	0.628	-0.523	0.601	-1.560	0.903
trt_c~14_2	T16*After treatment	-0.255	0.083	-3.058	0.002	-0.418	-0.091
trt_c~15_2	T17*After treatment	-0.222	0.191	-1.162	0.245	-0.596	0.152
trt_c~16_2	T18*After treatment	0.098	0.170	0.576	0.565	-0.235	0.431
trt_c~17_2	T19*After treatment	-0.363	0.118	-3.068	0.002	-0.594	-0.131
trt_c~18_2	T20*After treatment	0.175	0.169	1.036	0.300	-0.156	0.506
trt_c~19_2	T22*After treatment	-1.108	0.276	-4.014	0.000	-1.649	-0.567
trt_c~20_2	Unsp*After Treatment	0.122	0.089	1.361	0.174	-0.054	0.297
trt_c~21_2	T10*T19*After Treatment	-0.524	0.342	-1.534	0.125	-1.194	0.146
trt_c~22_2	T04*T07*After Treatment	0.276	0.124	2.222	0.026	0.033	0.520
trt_c~23_2	T18*T19*After Treatment	0.335	0.211	1.590	0.112	-0.078	0.749
trt_c~24_2	T12*T19*After Treatment	-0.117	0.408	-0.286	0.775	-0.917	0.683
trt_c~25_2	T02*T07*After Treatment	0.625	0.165	3.799	0.000	0.303	0.947
trt_c~26_2	T10*T14*After Treatment	0.146	0.222	0.659	0.510	-0.289	0.582
trt_c~27_2	T12*T15*After Treatment	-0.685	0.448	-1.528	0.126	-1.563	0.193
trt_c~28_2	T10*T12*After Treatment	0.129	0.307	0.420	0.674	-0.472	0.730
trt_c~29_2	T10*T15*After Treatment	-0.963	0.500	-1.926	0.054	-1.942	0.017
trt_c~30_2	T14*T19*After Treatment	0.085	0.291	0.291	0.771	-0.486	0.655
trt_c~31_2	T04*T04*After Treatment	-0.816	0.214	-3.811	0.000	-1.236	-0.396
trt_c~32_2	T02*T20*After Treatment	0.167	0.315	0.529	0.597	-0.451	0.784
trt_c~33_2	T02*T19*After Treatment	0.311	0.228	1.362	0.173	-0.137	0.759
trt_c~34_2	T19*T19*After Treatment	0.328	0.122	2.679	0.007	0.088	0.568
trt_c~35_2	T07*T07*After Treatment	0.307	0.155	1.984	0.047	0.004	0.609
trt_c~36_2	T14*T18*After Treatment	0.477	0.323	1.475	0.140	-0.157	1.111

Term	Meaning	Coef.	Std. Err.	z value	p-value	ll95%CI	ul95%CI
trt_c~37_2	T10*T17*After Treatment	0.045	0.630	0.071	0.943	-1.191	1.281
trt_c~38_2	T15*T19*After Treatment	0.065	0.643	0.100	0.920	-1.195	1.324
trt_c~39_2	T07*T08*After Treatment	-0.120	0.185	-0.648	0.517	-0.482	0.243
trt_c~40_2	T19*T20*After Treatment	0.275	0.303	0.907	0.364	-0.319	0.870
trt_c~41_2	T17*T19*After Treatment	0.440	0.432	1.018	0.309	-0.407	1.287
trt_ct~u_2	T01*After treatment*Rural	-0.258	0.154	-1.680	0.093	-0.560	0.043
trt_cts~a2	T02*After treatment*Rural	0.135	0.157	0.862	0.388	-0.172	0.443
trt_cts~b2	T03*After treatment*Rural	0.552	0.173	3.188	0.001	0.213	0.892
trt_cts~c2	T04*After treatment*Rural	0.472	0.156	3.029	0.002	0.167	0.777
trt_cts~d2	T05*After treatment*Rural	-0.053	0.547	-0.097	0.922	-1.125	1.018
trt_cts~e2	T06*After treatment*Rural	-0.389	0.168	-2.317	0.021	-0.718	-0.060
trt_cts~f2	T07*After treatment*Rural	0.423	0.131	3.231	0.001	0.166	0.679
trt_cts~g2	T08*After treatment*Rural	0.564	0.165	3.427	0.001	0.242	0.887
trt_cts~h2	T10*After treatment*Rural	-0.161	0.206	-0.782	0.434	-0.565	0.243
trt_cts~i2	T11*After treatment*Rural	0.743	0.163	4.574	0.000	0.425	1.062
trt_cts~j2	T12*After treatment*Rural	0.530	0.286	1.854	0.064	-0.030	1.089
trt_cts~k2	T14*After treatment*Rural	0.298	0.230	1.297	0.195	-0.152	0.748
trt_cts~l2	T15*After treatment*Rural	0.479	0.732	0.655	0.512	-0.954	1.913
trt_cts~m2	T16*After treatment*Rural	0.330	0.314	1.049	0.294	-0.286	0.946
trt_cts~n2	T17*After treatment*Rural	0.078	0.269	0.289	0.772	-0.449	0.604
trt_cts~o2	T18*After treatment*Rural	-0.323	0.266	-1.217	0.224	-0.845	0.198
trt_cts~p2	T19*After treatment*Rural	0.333	0.154	2.167	0.030	0.032	0.634
trt_cts~q2	T20*After treatment*Rural	-0.276	0.250	-1.104	0.269	-0.766	0.214
trt_cts~r2	T22*After treatment*Rural	1.223	0.362	3.383	0.001	0.514	1.932
trt_cts~s2	Unsp*After treatment*Rural	-0.351	0.207	-1.697	0.090	-0.757	0.055
craXtrea~2	ImpYear*After Treatment	-0.042	0.010	-4.069	0.000	-0.062	-0.022
borr_cts_2	RSA*After Treatment	0.223	0.060	3.697	0.000	0.105	0.341
urorrur_~2	Rural*After Treatment	-0.388	0.118	-3.295	0.001	-0.619	-0.157
jur_cts_1	ACT*After Treatment	-0.398	0.131	-3.047	0.002	-0.654	-0.142
jur_cts_3	NT*After Treatment	0.175	0.129	1.364	0.173	-0.077	0.427
jur_cts_4	QLD*After Treatment	-0.290	0.080	-3.607	0.000	-0.448	-0.133
jur_cts_5	SA*After Treatment	-0.110	0.064	-1.715	0.086	-0.236	0.016
jur_cts_6	Tas*After Treatment	0.321	0.131	2.446	0.014	0.064	0.579
jur_cts_7	WA*After Treatment	0.276	0.051	5.379	0.000	0.176	0.377
storloc_~2	State*After Treatment	0.256	0.040	6.338	0.000	0.177	0.335
trt3_cts~2	T03*After treatment*night	0.386	0.156	2.483	0.013	0.081	0.691
trt6_cts~2	T06*After treatment*night	0.111	0.158	0.701	0.483	-0.199	0.420
trt18_ct~2	T18*After treatment*night	-0.306	0.185	-1.656	0.098	-0.668	0.056
trt19_ct~2	T19*After treatment*night	0.044	0.117	0.374	0.708	-0.186	0.273
trt20_ct~2	T20*After treatment*night	-0.071	0.230	-0.307	0.759	-0.522	0.381

APPENDIX F MODEL OUTPUT – CASUALTY CRASHES

Term	Meaning	Coef.	Std. Err.	z value	p-value	ll95%CI	ul95%CI
sel_bias_1	Pre-Application Bias	0.065	0.026	2.499	0.006	0.014	0.116
trt_cts1_2	T01*After treatment	-0.949	0.096	-9.874	0.000	-1.138	-0.761
trt_cts2_2	T02*After treatment	-0.143	0.093	-1.531	0.126	-0.326	0.040
trt_cts3_2	T03*After treatment	-0.638	0.097	-6.605	0.000	-0.827	-0.448
trt_cts4_2	T04*After treatment	-0.219	0.061	-3.607	0.000	-0.338	-0.100
trt_cts5_2	T05*After treatment	-0.476	0.326	-1.460	0.144	-1.114	0.163
trt_cts6_2	T06*After treatment	0.195	0.089	2.188	0.029	0.020	0.370
trt_cts7_2	T07*After treatment	-0.114	0.073	-1.562	0.118	-0.258	0.029
trt_cts8_2	T08*After treatment	0.004	0.089	0.050	0.960	-0.169	0.178
trt_cts9_2	T10*After treatment	0.209	0.080	2.616	0.009	0.052	0.365
trt_c~10_2	T11*After treatment	-0.059	0.080	-0.746	0.456	-0.215	0.097
trt_c~11_2	T12*After treatment	-0.182	0.137	-1.330	0.183	-0.451	0.086
trt_c~12_2	T14*After treatment	-0.025	0.110	-0.229	0.819	-0.240	0.190
trt_c~13_2	T15*After treatment	-0.597	0.348	-1.716	0.086	-1.279	0.085
trt_c~14_2	T16*After treatment	-0.117	0.101	-1.163	0.245	-0.315	0.080
trt_c~15_2	T17*After treatment	-0.294	0.153	-1.923	0.055	-0.593	0.006
trt_c~16_2	T18*After treatment	-0.147	0.174	-0.843	0.399	-0.488	0.195
trt_c~17_2	T19*After treatment	0.117	0.086	1.357	0.175	-0.052	0.285
trt_c~18_2	T20*After treatment	0.107	0.214	0.500	0.617	-0.313	0.527
trt_c~19_2	T22*After treatment	-1.002	0.256	-3.915	0.000	-1.503	-0.500
trt_c~20_2	Unsp*After Treatment	0.004	0.098	0.037	0.970	-0.188	0.196
trt_c~21_2	T10*T19*After Treatment	-0.462	0.142	-3.245	0.001	-0.742	-0.183
trt_c~22_2	T04*T07*After Treatment	0.060	0.116	0.513	0.608	-0.168	0.287
trt_c~23_2	T18*T19*After Treatment	0.082	0.192	0.427	0.669	-0.294	0.458
trt_c~24_2	T12*T19*After Treatment	-0.309	0.236	-1.309	0.191	-0.772	0.154
trt_c~25_2	T02*T07*After Treatment	0.300	0.154	1.956	0.050	-0.001	0.601
trt_c~26_2	T10*T14*After Treatment	-0.139	0.188	-0.739	0.460	-0.508	0.230
trt_c~27_2	T12*T15*After Treatment	-0.644	0.316	-2.039	0.041	-1.264	-0.025
trt_c~28_2	T10*T12*After Treatment	0.319	0.235	1.358	0.174	-0.141	0.780
trt_c~29_2	T10*T15*After Treatment	-0.576	0.299	-1.927	0.054	-1.162	0.010
trt_c~30_2	T14*T19*After Treatment	-0.068	0.225	-0.304	0.761	-0.509	0.372
trt_c~31_2	T04*T04*After Treatment	0.015	0.125	0.119	0.905	-0.230	0.260
trt_c~32_2	T02*T20*After Treatment	-0.624	0.340	-1.833	0.067	-1.291	0.043
trt_c~33_2	T02*T19*After Treatment	0.155	0.182	0.852	0.394	-0.202	0.513
trt_c~34_2	T19*T19*After Treatment	0.180	0.124	1.451	0.147	-0.063	0.423
trt_c~35_2	T07*T07*After Treatment	0.309	0.173	1.786	0.074	-0.030	0.649
trt_c~36_2	T14*T18*After Treatment	0.071	0.232	0.308	0.758	-0.383	0.525

Term	Meaning	Coef.	Std. Err.	z value	p-value	ll95%CI	ul95%CI
trt_c~37_2	T10*T17*After Treatment	0.045	0.279	0.160	0.873	-0.502	0.591
trt_c~38_2	T15*T19*After Treatment	-0.030	0.318	-0.096	0.924	-0.653	0.592
trt_c~39_2	T07*T08*After Treatment	-0.370	0.218	-1.701	0.089	-0.796	0.056
trt_c~40_2	T19*T20*After Treatment	-0.045	0.253	-0.176	0.860	-0.541	0.452
trt_c~41_2	T17*T19*After Treatment	-0.409	0.305	-1.340	0.180	-1.007	0.189
trt_ct~u_2	T01*After treatment*Rural	0.243	0.158	1.533	0.125	-0.068	0.554
trt_cts~a2	T02*After treatment*Rural	-0.031	0.148	-0.210	0.834	-0.321	0.259
trt_cts~b2	T03*After treatment*Rural	0.625	0.171	3.656	0.000	0.290	0.960
trt_cts~c2	T04*After treatment*Rural	0.356	0.160	2.222	0.026	0.042	0.670
trt_cts~d2	T05*After treatment*Rural	0.931	0.375	2.485	0.013	0.197	1.665
trt_cts~e2	T06*After treatment*Rural	-0.075	0.163	-0.458	0.647	-0.394	0.245
trt_cts~f2	T07*After treatment*Rural	0.440	0.131	3.355	0.001	0.183	0.698
trt_cts~g2	T08*After treatment*Rural	0.208	0.180	1.157	0.247	-0.144	0.560
trt_cts~h2	T10*After treatment*Rural	0.008	0.126	0.063	0.950	-0.239	0.255
trt_cts~i2	T11*After treatment*Rural	0.399	0.166	2.408	0.016	0.074	0.724
trt_cts~j2	T12*After treatment*Rural	0.131	0.216	0.607	0.544	-0.292	0.555
trt_cts~k2	T14*After treatment*Rural	0.203	0.167	1.212	0.225	-0.125	0.530
trt_cts~l2	T15*After treatment*Rural	0.948	0.340	2.786	0.005	0.281	1.616
trt_cts~m2	T16*After treatment*Rural	0.024	0.235	0.102	0.919	-0.437	0.485
trt_cts~n2	T17*After treatment*Rural	0.311	0.223	1.398	0.162	-0.125	0.748
trt_cts~o2	T18*After treatment*Rural	0.112	0.200	0.559	0.576	-0.280	0.503
trt_cts~p2	T19*After treatment*Rural	0.087	0.112	0.778	0.437	-0.133	0.308
trt_cts~q2	T20*After treatment*Rural	-0.138	0.241	-0.571	0.568	-0.610	0.335
trt_cts~r2	T22*After treatment*Rural	1.058	0.373	2.834	0.005	0.326	1.790
trt_cts~s2	Unsp*After treatment*Rural	0.372	0.168	2.223	0.026	0.044	0.701
craXtrea~2	ImpYear*After Treatment	-0.038	0.009	-3.960	0.000	-0.056	-0.019
urorrur_~2	Rural*After Treatment	-0.473	0.098	-4.806	0.000	-0.665	-0.280
jur_cts_1	ACT*After Treatment	-0.896	0.321	-2.786	0.005	-1.526	-0.265
jur_cts_3	NT*After Treatment	0.215	0.151	1.418	0.156	-0.082	0.512
jur_cts_4	QLD*After Treatment	-0.076	0.067	-1.140	0.254	-0.206	0.055
jur_cts_5	SA*After Treatment	-0.087	0.076	-1.143	0.253	-0.235	0.062
jur_cts_6	Tas*After Treatment	-0.131	0.159	-0.826	0.409	-0.442	0.180
jur_cts_7	VIC*After Treatment	-0.110	0.048	-2.275	0.023	-0.205	-0.015
jur_cts_8	WA*After Treatment	0.074	0.057	1.306	0.191	-0.037	0.185
storloc_~2	State*After Treatment	0.136	0.037	3.685	0.000	0.064	0.208
trt3_cts~2	T03*After treatment*night	0.315	0.151	2.085	0.037	0.019	0.611
trt6_cts~2	T06*After treatment*night	-0.077	0.132	-0.584	0.559	-0.336	0.182
trt18_ct~2	T18*After treatment*night	0.191	0.168	1.134	0.257	-0.139	0.521
trt19_ct~2	T19*After treatment*night	-0.064	0.090	-0.716	0.474	-0.240	0.112
trt20_ct~2	T20*After treatment*night	0.256	0.241	1.060	0.289	-0.217	0.729

Contract Report

Investigation of Black Spot Treatments

by *Blair Turner, Tanya Styles and Chris Jurewicz*

for BITRE

VC72298- October 2008

Investigation of Black Spot Treatments

for BITRE

	Reviewed
Project Leader	
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VC72298- October 2008

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Summary

The Bureau of Infrastructure Transport and Regional Economics (BITRE) is conducting an evaluation of the National Black Spot Program, covering the period from 1996/97 to 2002/03. To coincide with this evaluation, the BITRE commissioned work on three separate topics:

- a review of how road safety treatments reduce crashes, and the relative merits of using different treatments
- a data analysis to determine crash reduction estimates for black spot treatments by vehicle movement type
- a data analysis to determine crash reductions for multiple engineering countermeasures used at the same location.

The key results from each of these studies are summarised below.

How road safety treatments reduce crashes, and the relative merits of using different treatments

In this section of the report, the causes of road crashes are assessed, making reference to the chain of events that lead to a crash, and the involvement of vehicle, road and human related causation.

The influence of the road environment is explored in further detail, and it is identified that although the greatest contributor to crashes is human error, it is expected that the greatest gains in terms of casualty reduction will come from changes to the road environment. This issue is discussed in the framework of a safe system approach. The ways in which road engineering features can improve safety are also identified, and these include:

- regulating/controlling movements and turns, especially at intersections and access points
- reducing speeds
- reducing conflict points
- warning road users of unusual or risky features (e.g. advanced warning)
- providing adequate information to enable road users to negotiate the roadway safely
- removing hazards (e.g. utility poles and trees from the roadside)
- protecting road users from hazards that cannot be removed (e.g. providing guardrailing and median barriers)
- separation of vehicles of different mass (e.g. specific facilities for pedestrians and cyclists)
- improvements in surface friction.

Considerations that need to be made when selecting road engineering based safety treatments are discussed, and it was identified that although the expected crash reduction and the cost of the treatment were key considerations, there is also need to consider issues such as the effect on traffic, health, the environment, accessibility, public acceptance, available staff resources and skills, and legal issues.

The final section provides details on different types of road safety treatments, each of which has been included in the BITRE evaluation. Each treatment is discussed in terms of how it can improve safety, the expected casualty reduction, and when the treatment should be used.

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Data analysis to determine crash reduction estimates for black spot treatments by vehicle movement type

This section of the report describes the method and outcomes of an analysis of crash data collected at treated black spot locations throughout Australia. The analysis was aimed at estimating the reduction in various types of crashes that can be expected following the installation of a select category of treatment types.

The report provides detailed information on the effect of different road safety treatments on individual crash types. Overall, most treatments resulted in crash reductions that were statistically significant. Crash rate reductions for different crash types were also calculated, and revealed a mix of changes in the expected direction (e.g. adding traffic signals increases 'rear-end' crashes and decreases 'from adjacent' crashes) as well as some that are more difficult to understand (e.g. anti-skid treatments were followed by an increase in 'opposing vehicle turning' crashes).

Comparison of the results obtained by ARRB, and crash reduction estimates published by Austroads and used in Victoria, New South Wales and Western Australia, revealed that the more robust (statistically significant) findings were generally concordant with the comparison figures.

More in-depth analyses, where detailed site characteristics are known and can be linked to the impact of various treatments would likely serve to explain many of the counter-intuitive findings. For example, the analysis suggested that the installation of barriers and guardrails was associated with an increase in some crash types.

Data analysis to determine crash reductions for multiple engineering countermeasures used at the same location.

This task was undertaken in light of previous research which has identified that many blackspot locations are treated by a combination of countermeasures rather than a single treatment. This means that information on the best way to combine the expected crash reductions from individual treatments to generate an expected crash reduction from a combination of these treatments would be valuable.

In this report, the crash reductions achieved with 18 black spot treatment combinations (15 treatment pairs and 3 treatment triples) were compared with the reductions predicted using a frequently applied formula designed to predict crash reductions associated with multiple countermeasures based on crash reduction factors for each countermeasure.

The results indicate that different treatment combinations act in different ways, and that some treatments will provide diminishing returns in their effect on safety, while others will work in combination to provide a benefit greater than the sum of the individual treatments. The application of a set formula is likely to produce errors when conducting economic evaluations, and careful thought is required when trying to determine the likely safety benefit from combinations of road safety treatments.

A more useful approach would be to determine the safety benefits from combinations of treatments, starting with those that are most commonly applied. Provision of such information would help improve the accuracy of economic evaluation associated with the treatment of crash locations.

Contents

1 Introduction

In its commitment to the National Road Safety Strategy 2001-2010, and its objective of achieving a 40% reduction in the number of road fatalities to no more than 5.6 per 100,000 population, the Federal Government has implemented the National Black Spot Program. This program has the objectives of reducing the social and economic costs of road trauma by:

- the identification and cost effective treatment of locations with a record of casualty crashes
- placing significant focus on the need to reduce rural road trauma, in accordance with national road safety policy objectives
- using a proportion of funds to treat sites, lengths of roads and areas which have been identified as potential crash locations through official road safety audits, and to implement other road safety measures (DOTARS, 2006).

There is a particular focus on the cost effective treatment of hazardous locations, requiring knowledge both of the costs of treatments, and also their potential for crash reduction in different situations.

The Bureau of Infrastructure, Transport and Regional Economics (BITRE) is currently conducting an evaluation of the National Black Spot Program, covering the period from 1996/97 to 2002/03. Over this seven year period, over 2,500 treatments were approved. Two previous evaluations have been conducted for earlier years of the program. The first report estimated that the economic benefit–cost ratio of the program was 4:1 (BTE, 1995), while the more recent evaluation indicated a benefit of 14:1 (BTE, 2001). A key objective of the black spot program is to achieve optimal safety benefits for the available budget. The current evaluation will provide an assessment of the overall effectiveness of the program, and will allow analysis on the effectiveness of individual treatments. This is important, as appropriate selection of treatments will provide greater overall effectiveness for the future delivery of the program.

There is an extensive literature available on the effect of various engineering-based safety treatments in different environments. However, much of the available research on this topic is from overseas (and sometimes not applicable in Australia), is dated, and/or is of poor methodological quality. Common methodological problems in treatment evaluation include the lack of adequate control groups to account for extraneous variables, regression to the mean, and small sample sizes.

Given the proposed methodology and sample size, the current BITRE evaluation provides a unique opportunity for a robust evaluation on the effectiveness and cost-effectiveness of a variety of safety treatments.

There are a large variety of engineering-based road safety treatments available to practitioners. However, information is required on when best to apply these. Without a firm understanding of the mechanisms that cause treatments to reduce crashes, inappropriate decisions may be made regarding treatment selection. For example, traffic signals are a very effective tool in addressing crash risk at some urban locations. However, application of traffic signals to high speed environments (i.e. greater than 80 km/h) is generally not appropriate, and alternative treatments should be selected. Published road safety guides often provide information on the expected reduction from the use of a treatment, but seldom give information on how and when treatments should be applied.

It is often the case that more than one treatment may be appropriate to address crash risk at a location. A number of practical issues (e.g. treatment cost, expected benefit) as well as wider issues (e.g. traffic delay impacts) need to be considered when selecting treatments.

To coincide with the evaluation of the black spot program, the BITRE commissioned ARRB to provide information on the following three topics:

- a review of how road safety treatments reduce crashes, and the relative merits of using different treatments
- a data analysis to determine crash reduction estimates for black spot treatments by vehicle movement type
- a data analysis to determine crash reductions for multiple engineering countermeasures used at the same location.

This current report provides details for each of these three projects, and is submitted as the final output for this project.

2 Review of how road safety treatments reduce crashes, and the relative merits of using different treatments

2.1 Method

The literature on the topic of crash treatments and crash risk is extensive. Along with general research covering the topic, there are literally thousands of studies covering a range of possible treatment types. A keyword search on ‘signs’ using ARRB’s library database (see below for details) produced over 1400 records. It was beyond the scope of this study to assess all of the literature, so instead selected relevant research has been identified on each of the topics of interest.

In order to identify relevant research, the resources of the MG Lay Library (located at ARRB Group’s head office) were utilised. This library contains the most comprehensive and up-to-date collection of international literature on land transport issues (particularly roads) in Australia, and is one of the leading technical libraries in its field in the world. The ARRB Group library has close contact with major libraries in Australia and overseas, for example the library at the UK Transport Research Laboratory.

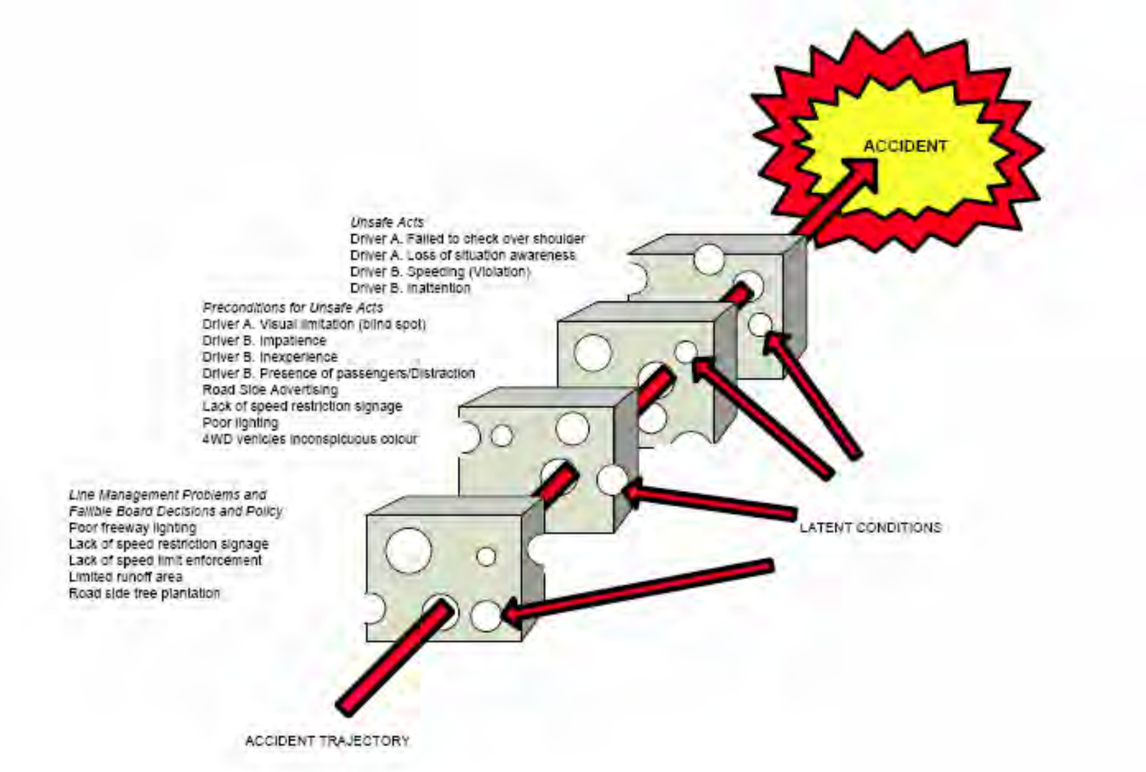
As well as searches through ARRB’s MG Lay Library, searches were undertaken using the Google search engine.

2.2 The causes of road crashes

The causes of crashes are many and varied, and often involve a chain of events. Take for example the hypothetical situation where a driver misjudges the appropriate speed at which to drive through a rural bend. The vehicle’s left wheel leaves the road, and in an attempt to return to the road, the driver over-corrects, spinning out of control. Having lost control, the vehicle leaves the roadway and collides with a tree that was close to the roadside. The impact with the tree is at high speed, and results in a serious injury.

The causes in this situation might include that the driver had been behind the wheel for a very long period, and so suffering from some degree of fatigue. They may have had little sleep the previous night, compounding this problem. However, the layout of the road may not have been clear to the driver, poor delineation leading to a misjudgement of the appropriate speed at which to take the bend. In addition, the road surface may have been in poor condition, with a lack of adequate surface friction. The tyres of the car may also have been worn, again compounding the problem. The road shoulder may have been too narrow, a wider shoulder allowing the driver to continue through the bend without losing control. And finally, the tree was too close to the side of the road for such a high speed environment. If it had been further away, the vehicle may have come to a rest without resulting in any serious injury to the driver.

The chain of events described in this example illustrates that a large number of factors can lead to a crash and its severity. If some of these events had been different, then the crash may not have occurred. Reason (1990) proposed the ‘Swiss cheese’ model of accident causation to illustrate the systems based approach to error. Taking a systems approach ensures that not just the individual errors made by drivers are considered in determining the cause of crashes, but also the latent system errors. Figure 2.1 (from Salmon et al, 2006) provides an illustrative example of this approach.



Source: Salmon et al, 2006

Figure 2.1: The Swiss cheese model of crash causation

In the example above, the driver certainly played a key role in the occurrence of the crash, but road environment and vehicle factors also had a significant effect. The road user, road environment, and vehicle are usually identified as the three main contributory elements in any crash. Much research has been conducted on the relative influence of each. The two most significant studies on this issue were undertaken independently, but at similar times in the US (Treat, 1980) and UK (Sabey, 1980), and produced similar results. Ogden (1996) summarised the findings from these studies, providing the comparison presented in Table 2.2.

Table 2.2: Factors contributing to road crashes, as a percentage

Contribution	UK study	US study
Road environment only	2	3
Road user only	65	57
Vehicle only	2	2
Road and road user	24	27
Road user and vehicle	4	6
Road and vehicle	1	1
Road, road user and vehicle	1	3

When adding the total contribution, between 28-34% of crash involvement was related to the road environment, 8-12% to the vehicle, and 93-94% to the road user. Although the road user has overwhelmingly been identified as the main contributory element in crashes, this is the most difficult factor to change, and so it does not necessarily follow that changing the road user is the easiest way to reduce the amount of road death and trauma. However, it does point strongly to the need to include the human factor in design of the road system to cater for limitations in driver abilities. In addition, when looking at such studies it must also be remembered that the road environment has a strong effect on the incidence of excessive and inappropriate speed, a very important human factor.

William Haddon, the first head of the US Federal National Highway Traffic Safety Administration, developed a useful conceptual framework for considering the factors which contributed to road crashes and their outcomes. Taking an epidemiological approach that focused on the prevention of crashes, Haddon developed a matrix of potential risks involving human, vehicle and road elements, and how each of these can influence safety before, during and after a crash (see Table 2.3 for an example Haddon Matrix).

Table 2.3: Haddon Matrix showing possible crash countermeasures

Element	Before a crash	During a crash	After a crash
Human	Training, education, behaviour (e.g. not drinking), attitudes, conspicuous clothing on pedestrians and cyclists	Wearing in-vehicle restraints	Prompt emergency medical service response
Vehicle	Primary safety (e.g. good brakes, roadworthiness, visibility)	Secondary safety (e.g. occupant protection)	Devices to attract attention (e.g. mobile phone, horn)
Road	Delineation, good road geometry, good surface condition, visibility	Roadside safety (e.g. frangible poles), adequate crash barriers	Emergency median breaks and shoulders provided on freeways

Source: Austroads, 2004

Each cell within this matrix provides a point at which to identify the causes of crashes and the severity of their outcomes, as well as offering instances at which these can be addressed.

Information on individual crashes are aggregated in crash databases, and can be used to identify sites, routes or areas for further assessment, as well as providing information on the likely causes and potential treatments at these locations. Crash causation is typically identified by analysing trends in crashes, and particularly trends in the crashes by movement types (termed Road User Movements, or Definitions for Classifying Accidents). Once a site has been identified as being of high risk (e.g. through prioritisation of sites based on crash numbers or costs from across the network), a factor matrix and / or collision diagram is typically produced to help identify trends in the cause of crashes (see Figure 2.4 for an example factor matrix and Figure 2.5 for an example collision diagram). Once such trends are identified, it is possible to select appropriate treatments.

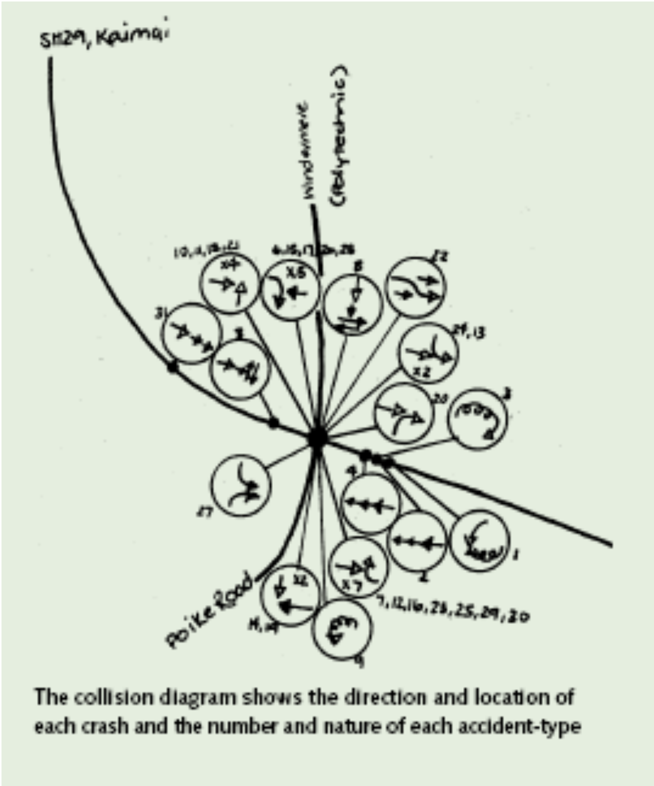
Crash ID	2205301	2605700	2505265	2402367	2503472	2602032	2505600	2505899	2506131	2200074
Severity	M	M	M	M	M	M	M	M	M	F
Year	2002	2006	2005	2004	2005	2006	2005	2005	2005	2002
Month	12	12	11	4	6	1	9	12	9	5
Day	22	12	26	07	23	04	23	06	07	16
Day of Week	1 Sunday	3 Tuesday	7 Saturday	4 Wednesday	5 Thursday	4 Wednesday	6 Friday	3 Tuesday	4 Wednesday	5 Thursday
Hour	05	16	23	07	20	15	23	22	06	15
Minute	30	10	30	56	30	43	00	03	34	35
Direction	S	N								
Street 1 or 2	1	1	1	1	1	1	1	1	1	1
Road Wetness	Dry	Dry	Wet	Wet	Dry	Dry	Wet	Dry	Dry	Dry
Natural Light	Twilight	Bright Sun	Dark	Overcast	Dark	Bright Sun	Dark	Dark	Overcast	Overcast
Movement Code										

Source: Land Transport NZ Crash Analysis System

Figure 2.4: Example factor matrix

Further details on the selection and analysis of crash locations can be found in Austroads (2004).

A variety of approaches can be used in treating crash locations, including behavioural measures (e.g. education, enforcement and training), and road environment improvements. The following section examines how changes to the road environment can influence both the incidence of crashes, and the severity of crashes when they do occur.



Source: Austroads, 2004

Figure 2.5: Example collision diagram

2.3 How altering the road environment can reduce crashes

Although ‘human factors’ have been highlighted in numerous studies as the prime cause of crashes, road engineering is currently recognised as providing the greatest potential in terms of crash and trauma reduction. Ogden (1996) suggests that the most cost effective remedies are not necessarily directly related to the main cause of the crash. He cites the UK Accident Investigation Manual (1986) which states that:

“In many accidents the primary cause may be said to be the driver’s lack of skill, but engineering remedies to improve the road are cheaper and easier to effect than training the driver to the necessary degree of skill.”

Although written over 20 years ago, this statement is still relevant today with the current Australian National Road Safety Strategy (Australian Transport Council, 2001) suggesting that:

“*Improving the safety of roads is the single most significant achievable factor in reducing road trauma*.”

One example of how an engineering based treatment can address a driver issue is the use of audio-tactile edgelines to reduce the incidence of run-off-road crashes resulting from fatigue. This treatment typically works by providing a raised ‘ribbing’ along the edge of the roadway. If drivers stray onto this edgeline, there is an auditory warning accompanied by a less distinct vibration that alerts the driver that they are leaving their lane. An example of this treatment is shown in Figure 2.6 .

Figure 2.6: Audio-tactile edgelines

It is expected that upon driving on these edgelines the attention of the motorist will be increased, allowing them to safety return to their lane.

2.3.1 The safe system approach

The previous section highlighted the systems based 'Swiss cheese model', and the conceptual matrix developed by Haddon that provided a framework for the prevention of crashes. These approaches have been extended in recent years with the move to a new basis for road safety in Australia. The 'safe system' approach has been formally adopted by Austroads, and forms a key component of the Australian National Road Safety Strategy (Australian Transport Council, 2001).

The approach accepts that humans will make errors and so crashes are likely to occur. What is required is a road infrastructure that takes account of these errors and of the physical tolerances of humans in such circumstances, allowing road users to survive and avoid serious injury in the event of a crash. The safe system is an attempt to manage vehicles, road and roadside infrastructure, and speeds to minimise death and serious injury as a consequence of a road crash.

Figure 2.7 shows the safe system framework as presented in the National Road Safety Action Plan for 2007/08 (Australian Transport Council, 2007).

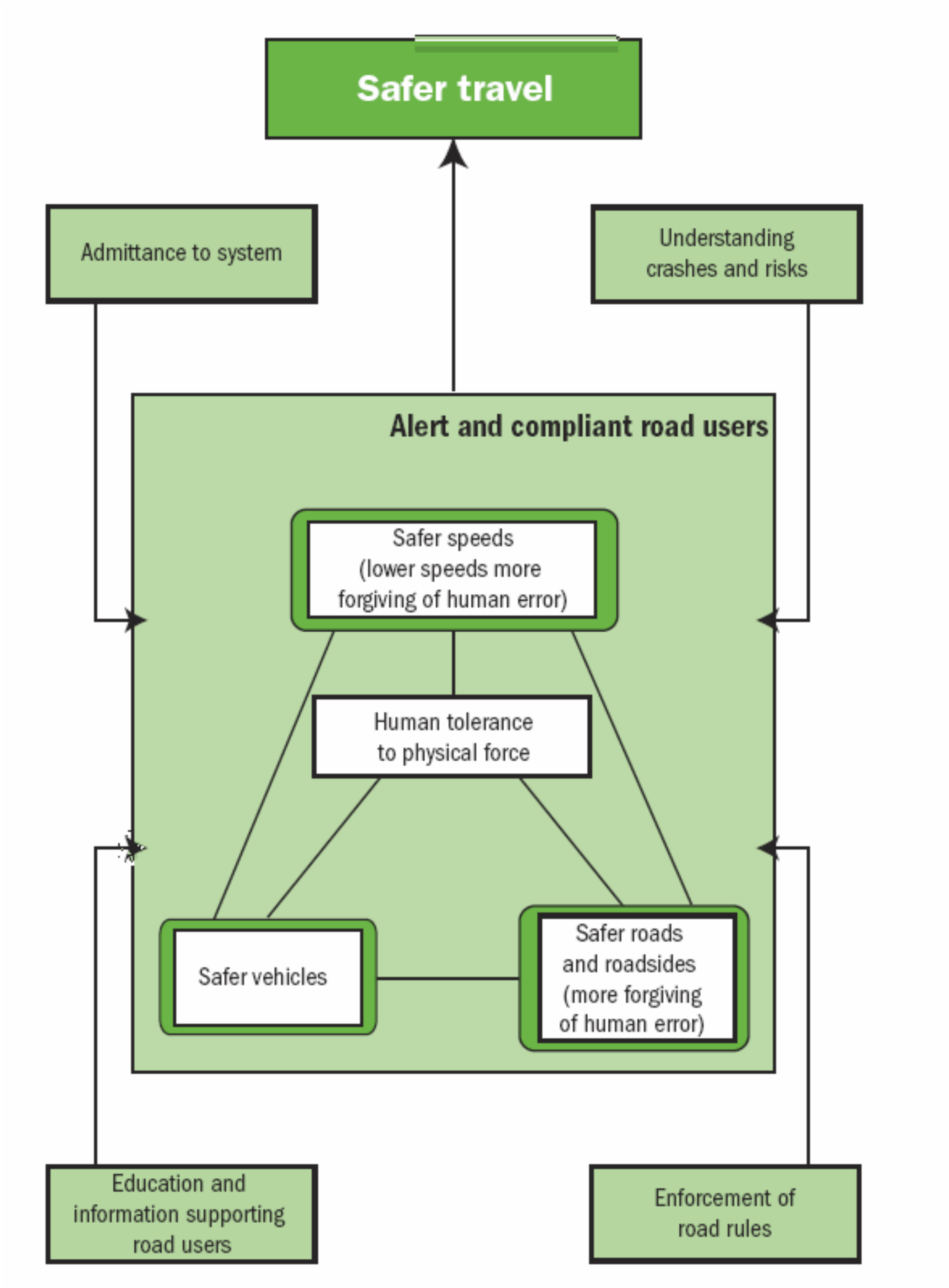
Of particular relevance from a road engineering perspective, the Action Plan suggests that a safe system requires:

- designing, constructing and maintaining a road system (roads, vehicles and operating requirements) so that forces on the human body generated in crashes are generally less than those resulting in fatal or debilitating injury

- improving roads and roadsides to reduce the risk of crashes and minimise harm: measures for higher speed roads include dividing traffic, designing ‘forgiving’ roadsides, and providing clear driver guidance. In areas with large numbers of vulnerable road users or substantial collision risk, speed management supplemented by road and roadside treatments is a key strategy for limiting crash forces
- managing speeds, taking into account the risks on different parts of the road system.

The Australian safe system approach is based primarily on the Swedish ‘Vision Zero’, and the Dutch ‘Sustainable Safety’ approaches. Vision Zero suggests that it is not acceptable for fatal or serious injuries to occur on the road system, and that account must be made of human tolerances when designing road infrastructure (see e.g. Tingvall, 1998).The Sustainable Safety approach (recently revised by Wegman and Aarts, 2006) is based on the following concepts, the first four of which relate most directly to road infrastructure improvements:

- Functionality: roads should be differentiated by their function, with through roads which are designed for travel over long distances (typically at high speed, ideally on a motorway); distributor roads which serve districts, regions and suburbs; and local roads, which allow access to properties.
- Homogeneity: differences in vehicle speeds, direction of travel and mass on specific roads should be minimised.
- Predictability: the function and rules of a road should be clear to all road users. This approach has led to the development of the ‘self explaining road’ (e.g. Theeuwes & Godthelp, 1992; Schermers, 1999; SWOV, 2006)
- Forgivingness: roads and roadsides should be forgiving to road users in the event of an error.
- State awareness: road users should be able to assess their capability of handling the driving task.



Source: Australian Transport Council, 2007

Figure 2.7: The Safe System Framework

Predictability and forgivingness are the two risk factors most easily influenced by road safety engineers when making changes to the road environment. Many treatments work to reduce risk by improving these aspects of the road environment, although there are other ways that changes to the road environment can influence safety. Turner et al. (2006) suggest that risk can be decreased by reducing the:

- exposure to the risk (an example may be to divert traffic from low quality roads to higher quality ones)
- likelihood of the crash (this includes the provision of a predictable road environment)
- severity of the crash (for example by providing a forgiving roadside to reduce harm if a vehicle does leave the road).

Based on these factors, crashes can be influenced in a number of ways through changes in the road environment. Specifically, improvement in safety can be gained from the following:

- regulating/controlling movements and turns, especially at intersections and access points
- reducing speeds
- reducing conflict points
- separation of vehicles of different mass (e.g. specific facilities for pedestrians and cyclists) and travelling in different directions (e.g. median barriers)
- warning road users of unusual or risky features (e.g. providing advanced warning)
- providing adequate information to enable road users to negotiate the roadway safely
- removing hazards (e.g. utility poles and trees from the roadside)
- protecting road users from hazards that cannot be removed (e.g. providing guardrailing and median barriers)
- improvements in surface friction

Engineering based treatments generally work by influencing one or more of these factors.

2.3.2 Crash history versus road risk

The traditional approach to road safety has been to treat high risk locations (e.g. black spots, routes or areas) based on crash history. Treatments that have been shown to be effective in reducing specific crash types are used at locations where there is a high incidence of crashes. Evaluations have shown this approach to be highly cost beneficial. As highlighted earlier, evaluations of the federally funded black spot program have shown benefit-cost ratios (BCRs) of 4:1 (BTE, 1995) and 14:1 (BTE, 2001), while those for state based programs have produced similar results.

With a movement to the safe system approach in Australia as well as a realisation that the majority of severe crashes do not occur in black spots[1], there appears to be a growing emphasis on preventative road safety treatments. This includes mass action programs to improve roadside protection, and the identification of high risk locations based on the risk associated with road and roadside features. As an example, for a rural route with a high incidence of run-off-road crashes, it is likely that locations with a crash history will be treated (for instance, improvements in delineation at bends), but also other high risk locations on this same route will be assessed for treatment (for instance other bends where crashes are likely to occur). This risk based approach has been extended to a variety of road environments, and is currently used to identify potential sites for treatment throughout Queensland (e.g. McInerney & Doyle, 2006).

[1] Based on an examination of New Zealand and Victorian crash data, only a third of fatal crashes occur in 'black spots', while the rest are scattered around the road network. Additionally, when fatal crash locations are assessed for previous crash history, more than half of the sites had no other crashes over a 5 year period (based on New Zealand data).

Once locations have been identified as high risk an appropriate treatment needs to be selected. Typically this selection will be made based on the expected reduction in crashes from a treatment (or combination of treatments) and the cost of that treatment. However, there are other issues that should be considered before selecting a treatment to address crashes. The following section provides examples of some of these.

2.4 The relative merits of different treatments where a choice exists

The selection of appropriate treatments is primarily based on the expected crash reduction of that treatment in any given situation, but also on issues such as the cost of the treatment and the effect on traffic. Other issues may also be considered, and these relate to broader transport or other policy at Commonwealth, State and local government level. These include issues such as health implications, environmental issues, and accessibility. The issue of public acceptance is also an important consideration in the selection of some treatments.

Economic assessments for road safety treatments normally only include crash reduction benefits, maintenance and operating costs of treatments, and construction costs. Costs and benefits of other impacts (especially environment and accessibility) are more difficult to value in monetary terms and so often the choice of treatment involves subjective weighing up of the monetised and non-monetised impacts.

This section examines the different issues that should be considered when selecting road safety treatments.

2.4.1 Expected crash reduction

With any new treatment, there is a desire to maximise the reduction in casualties. Information exists on the expected overall crash reduction for most treatment types (see Section 2.5 for some key examples). Information also exists on the change in specific crashes by movement type from the use of various treatments (see e.g. Austroads, 2004). Information on crash reduction by movement type allows calculation of the expected crash reduction of ‘target’ crashes, or those crashes for which a treatment is expected to address. Calculating the expected crash benefit based on an overall reduction (i.e. one not broken down by movement type) means that ‘non-target’ crashes (or crash types for which the treatment would not normally be expected to have any material benefit) may also be inadvertently included.

Information on reduction in crashes based on vehicle movement type is also useful because it takes the change in severity into account. This is important as with some treatments the crash types actually change (or are ‘substituted’), sometimes replacing high severity crashes with lower severity ones. A good example of this is the introduction of roundabouts, where there is likely to be a large decrease in high severity adjacent approach crashes, but there may be increases in a variety of low severity crashes, such as rear end crashes.

Information on expected crash reduction is often assumed to be more reliable than it actually is, and in reality there are large gaps in our knowledge in this area. These gaps in knowledge occur both for overall reduction and reductions by movement type (more so for the latter group). In addition, the effectiveness of specific treatments is often overstated, and this is because in many instances evaluations do not include consideration of relevant issues, such as changes in traffic volumes, regression to the mean, maturation and the effect of other changes at the site (see Text Box 1). Care needs to be taken when interpreting the results of such studies for these reasons.

A further complication is that typically more than one treatment type is selected to treat any site (also see Section **Error! Reference source not found.**). Based on a review of New Zealand data (the results of which could be assumed to be similar to Australia), it appears that approximately 80% of treated sites use more than one treatment, with many using more than three or four treatments (there are examples where up to 15 treatments were used). Guidance exists on how to calculate the cumulative benefit of various treatments, and this is not normally done in an additive way, but rather benefits reduce as new treatments are added. For example, for three treatments where the expected benefits are 40%, 25% and 20%, an overall reduction of 85% would not be expected. Rather, a figure of 64% is typically used[2]. However, recent research shows that this is not likely to be an accurate reflection of the actual effectiveness (see Turner and Roberts, in press, for a discussion of this issue. Also see Section **Error! Reference source not found.**).

Text Box 1: Confounding factors in evaluating treatment effectiveness

Crash reduction figures often do not consider the impact of changes in traffic volumes. In some situations, traffic volumes may change substantially as a result of the installation of a treatment (e.g. traffic calming may divert traffic elsewhere, or cycle lanes may encourage more cyclists). Many studies do not take account of this change in volume when calculating the change in crashes. In some situations it could be assumed that traffic volumes will remain the same, but this will not always be the case (also see the discussion on crash risk migration in Section 2.4.3).

Regression to the mean refers to a situation that commonly arises during evaluation of road safety treatments. Sites to be treated are selected on the basis of a high number of crashes. However, given the often random nature of crashes, sites may have been selected because of abnormally high crash numbers in one or more years. Crashes may return to normal levels (or regress to the mean) in subsequent years, and if this is included as part of the 'after' evaluation, the treatment will appear to be more effective than it really is. The result is an over-estimate of the benefit of a safety treatment.

Maturation refers to the general change in crashes over time (typically a decrease across a state or nationally).

For a fuller discussion of these and other related issues, see Austroads, 2004.

2.4.2 Cost and cost effectiveness of treatments

Cost is obviously an important consideration when selecting appropriate treatments. There is a limited budget available with which to address crashes, and so a trade-off needs to be made between potential sites for treatment. Those that provide the maximum reduction in crashes (particularly those of high severity) for the amount spent are typically selected. The benefit to cost ratio (BCR) is often used as a measure of cost effectiveness of schemes. Despite its usefulness, advice on the BCR of specific safety treatments is relatively scarce. Some evaluations do include information on the BCR for treatments (see e.g. Scully et al., 2006), and a concerted effort is currently being made in Europe to fill gaps in knowledge in this area. The RoseBud project (**Ro**ad **S**afety and **E**nvironmental **B**enefit-Cost and Cost-Effectiveness Analysis for **U**se in **D**ecision-Making project) aims to provide information on treatments to allow the most efficient use of available resources (further details are available on the project website,

[2] The structure of the formula is $CRF_t = 1-(1-CRF_1)(1-CRF_2)(1-CRF_3)\ldots$, where CRF_t is the total crash reduction, and CRF_x is the individual crash reduction. For the above example, this equates to 1-(1-0.4)(1-0.25)(1-0.2), which equals 1 – 0.6 x 0.75 x 0.80, or 0.64.

http://partnet.vtt.fi/rosebud). Although care needs to be taken when examining BCRs from overseas research (as an example, the cost of crashes varies greatly between countries), this information will be of some interest to Australian based practitioners.

There is often a degree of uncertainty in the likely costs for a safety treatment. Utilities under the road surface can dramatically increase the cost of projects if they need to be moved. Error in the cost estimates for safety treatments is common. Although information is not currently available from Australia on this issue, research based on New Zealand data shows that there is a great deal of variation between the predicted cost of a project at the planning stage, and the actual cost upon completion. Costs for common treatment types tend to be over-estimated, while those for less frequently used treatments tend to be under-estimated (Turner et al. in press).

2.4.3 Effect on traffic

The likely effect of a safety treatment on traffic in terms of delay and redistribution is an important consideration in treatment selection. What may be beneficial in terms of safety may have negative consequences in terms of delay, and there is a cost associated with this. Although under a safe system approach, safety is the prime consideration, in reality, a compromise must often be made between safety and mobility. However, installation of specific safety measures may also have a beneficial effect on delay, and the combined benefits with safety may provide a stronger case for the installation of a treatment.

In addition, the effect of safety treatments needs to be considered in light of changes in traffic volumes. If the treatment causes displacement of traffic onto alternative routes, it is possible that the risk on these routes may change. If the alternative route is of a higher standard than the treated location, it is likely there will be an overall reduction in casualties. However, if traffic moves to low standard routes, it is possible that overall casualties may actually increase. A recent study (Styles et al, in press) identified a number of treatment types where this phenomenon (termed crash risk migration) needs to be considered. These treatments include (but are not limited to):

- Turn controls or bans
- Major changes to a route such as parking changes
- Bridge/route closure
- Localised speed limit changes
- Intersection changes e.g. signalisation, turn phase timing change, turning lanes
- Traffic calming
- Lane additions
- Addition of overtaking lanes
- Pedestrian treatments at intersections and at mid-block locations
- Railway crossing control
- Mid block turning provision.

The traffic impacts of road safety treatments can be costed through modelling, and the costs (or benefits) included in the BCR calculation. However, in practice this is rarely done for projects aimed primarily at improving safety.

2.4.4 Health implications

A reduction in trauma is the most obvious health implication relating to the installation of safety treatments. However, there are other health issues that can be considered, particularly the benefits associated with a switch from motor vehicles to walking and cycling. Although there is relatively limited information available on the issue of safety improvements and an increase in walking or cycling, there is some evidence that a perceived lack of safety will reduce walking or cycling. As an example, the UK DETR (2000) report that fear of speeding traffic, accidents and injury is one of the main reasons people give for not walking or letting their children walk more. In some cases, lower speeds outside schools have been introduced to improve the perception of safety in order to encourage a modal shift from trips by car to walking and cycling (e.g. Osmers, 2001). Further research is required on this link between road safety and broader health implications.

2.4.5 Environmental issues

A variety of road safety treatments have the potential to impact on the environment, including through increased air and noise pollution, and detriment to the visual environment. As an example, Haworth and Symmons (2001) reviewed some of the evidence relating to traffic calming and emissions. They identified several studies that indicated an increase in fuel consumption and emissions with the use of physical traffic calming measures, although there is conflicting information on this issue from other sources, with indications of either a positive or neutral effect (e.g. DfT, 1999; Webster et al., 2006). In contrast, the replacement of traffic signals with roundabouts resulted in a decrease in emissions, while they also identified a number of studies where a lowering of speed limits led to a lower level of emissions.

Aesthetics may need to be taken into consideration in some circumstances. As an example, an over-abundance of warning and other signs in areas of scenic or cultural significance may be seen as undesirable.

Another environmental issue is the removal of roadside vegetation. The provision of clear zones (an area free of hazards adjacent to the roadway which offers protection if vehicles do leave the roadway) can lead to environmental damage and a reduction in the environmental value of the roadside. This is particularly true on some rural roads where the roadside often contains most, if not all, of the remaining indigenous vegetation in the area. Jurisdictions often have environmental policies that recognise the value of the vegetation on roadsides. A trade-off may need to be made in some circumstances between provision of an adequate clear zone, and maintenance of significant vegetation. Alternatively, valuable vegetation can instead be shielded with appropriate safety barriers.

2.4.6 Accessibility

In recent years the issue of accessibility to services, social exclusion and community cohesion has seen increased interest within transport policy, research and urban planning. As an example, a report released by the UK's Social Exclusion Unit (2003) identified that deprived communities suffer disproportionately from pedestrian deaths and pollution as a result of living near busy roads, and that poor transport restricts access to work, learning, health care and other key activities.

Within Australia the issue is being addressed indirectly through an increased emphasis about the quality of urban design and designing quality public spaces. For example, the Roads and Traffic Authority (NSW) has a comprehensive set of urban design practice notes which combine traffic engineering, landscape and urban design features to enhance public space (see http://www.rta.nsw.gov.au/constructionmaintenance/downloads/urbandesign/urban_design_dl1.html, viewed 16 April 2007).

Individual projects, on their own, may not in most cases change a road environment for non-motorised users, but the cumulative impact of a series of small changes over time may contribute to the road becoming a greater barrier to movement for some people. For example, the RTA (2000) identify that for roads that have a through traffic and local access function, progressive traffic management measures over time can make roads harder for pedestrians to cross safely and promptly, create a more hazardous environment for cyclists, and increase traffic noise and reduce air quality.

When selecting engineering treatments to address road safety issues, the broader and cumulative impact of the treatment on vehicle and local pedestrian and cyclist movements must be considered. Conscious effort is required to ensure that new projects have a minimal impact on accessibility for vulnerable groups, and when possible, the opportunity is used to improve safety and accessibility, particularly for more than just motorised road users. As examples, the 'excessive' installation of pedestrian fencing, median barriers in urban areas, and use of pedestrian and cyclist under- or over-passes often create a barrier to accessibility, particularly for disabled or elderly road users. In some instances it may be advantageous to conduct road safety audits involving specific groups of road users to ensure that designs consider the needs of these groups, and that these road users are not penalised by the installation of new treatments.

However, accessibility can also be directly improved through the installation of road safety treatments. In particular, pedestrian and cyclist treatments (such as pedestrian crossing points and cycle lanes) can improve accessibility for these road user groups.

2.4.7 Public acceptance

The installation of many new safety treatments has a direct impact on the behaviour of road users. Although traffic engineers typically have the best interests of road users in mind when installing treatments (i.e. their safety), some treatments may be seen as an imposition upon the freedom of some road users. Ward et al (2003) consider that the following are likely to have an influence on the acceptability of treatments:

- perception of the risk against which the measure is directed
- social acceptance of the behaviour being regulated
- inconvenience caused by the measure
- intrusiveness of the measure into personal lifestyles.

In addition, the perceived effectiveness of the measure is likely to have an influence on the level of acceptance of a treatment (note that the perceived effectiveness may differ from the actual effectiveness, and education may be required to inform the public of the true level of benefit).

Ward et al. (2003) suggest that decisions about the implementation of some treatments is often complicated by the role of the media in influencing and interpreting public opinion. The same may also be true of other interest groups. Ward et al suggest that to counter sometimes false impressions regarding the public response to treatments, public opinion surveys are required.

2.4.8 Available staff resources

The capacity to deliver a road safety treatment is important not only from the financial point of view (see Section 2.4.2), but also from a human resource perspective. There may be a lack of staff available to deliver treatments, or a lack of skilled staff available to deliver particular measures, for instance due to the complexity or relatively infrequency of their use.

2.4.9 Feasibility

In some instances it is not physically possible or safe to install specific treatments at a location. For instance, traffic calming that uses horizontal deflection to slow vehicles should not be installed on roads with a steep grade (Damen et al, 2004 recommend a maximum longitudinal grade of 3%, or an absolute maximum of 10% where there is no reasonable alternative). This is because vehicles are likely to become grounded on the treatment. Similarly, in some situations it is not possible to safely install pedestrian crossings due to sight distance restrictions. In these instances alternative treatment types will need to be considered.

2.4.10 Legal issues

It is obviously important to consider the current legal framework before selecting an appropriate treatment. Some treatment types might not be acceptable in some jurisdictions, even though they may be the most beneficial from a safety perspective. As an example, hidden speed cameras have been shown to be highly effective, providing a benefit over and above ordinary speed cameras (Keall et al, 2001; 2002). However, it is not possible to install these in most Australian jurisdictions under current legislation.

2.5 Specific treatments and crash reduction

This section of the report provides information on how specific treatments have an influence on crash reduction. The treatments discussed are based on those adopted by the BITRE in their evaluation of the Federal Black spot Program. Information is provided on the types of crashes or deficiencies that are addressed by each specific measure, and on the expected crash reduction based on previously available literature (i.e. no reference is made to the reductions identified by the BITRE evaluation). Where possible, reference is also made to the non-safety impacts of each treatment based on the issues discussed in Section 2.4. A summary is provided at the end of this section highlighting how the various treatment types influence major groupings of crash types and deficiencies.

Given the limited scope of this document, only a cursory discussion is provided on each treatment type. The information in this section is directly based on new Austroads Road Safety Engineering Toolkit (www.engtoolkit.com.au). Some of the text from this toolkit has been reproduced here with Austroads permission. This toolkit, developed by ARRB Group for Austroads, is an online source of information regarding the use of various road safety treatments. It provides detailed information on 'best-practice', low cost and high return engineering treatments to address road safety problems. Further information on specific treatment types and how they impact on safety can be found on this website. Additional information includes the benefits for each treatment type, implementation issues, costs, treatment life, and relevant standards and guidelines.

Other key references on how treatments impact on crash reduction include the Austroads' G*uide to the treatment of crash locations* (Austroads, 2004), Ogden's *Safer roads: A guide to road safety engineering* (1996), and Elvik and Vaa's (2004) *Handbook of road safety measures* (note that this reference is primarily based on overseas experience, and interpretation may be required to translate this to the Australian context).

Crash reduction figures in this section are generally based on those used in the Austroads Road Safety Engineering Toolkit. These are generally derived from the Austroads-funded Road Safety Engineering Risk Assessment project (Turner, 2007), or where information is not available from that project, supplemented by Ogden (1996) and Elvik and Vaa (2004). It is important to note that these figures are only a guide, and that the actual crash reduction will vary from site to site. In addition, the expected reduction only applies where the treatment is justified (e.g. where specific, relevant crash types exist). All figures indicate reductions in casualty crashes unless otherwise indicated.

2.5.1 Roundabouts

Roundabouts are controlled intersections which involve one way circulation of traffic around a central island. They are used primarily in urban areas, although increasingly in rural (extra care needs to be taken in such environments that speed is reduced to an appropriate level). Roundabouts potentially have a better crash record than other intersection types with similar volumes as the number of vehicle conflict points is reduced, and when conflicts do occur, the angle of collision is typically changed, producing lower severity outcomes. With appropriate design, motorists are forced to slow through the intersection, again reducing the severity if crashes occur.

Roundabouts provide an important alternative to signalised intersections. Roundabouts can serve moderate traffic volumes with less delay than signalised or other intersections of similar size because traffic can often traverse the roundabout without stopping. Guidance (Austroads, 2005) suggests that the intersection capacity of roundabouts is greater than that for signals with the same number of lanes (2600 vehicles per hour for a single lane roundabout compared with 1500 for signals; 4560 vehicles per hour for a two lane roundabout compared with 3000 for two lane signals; 6000 vehicles per hour for three lane roundabouts compared with 4500 for three lane signals).

Roundabouts can involve land acquisition making this a high cost treatment type in some situations, while in others, provision of a roundabout may not be physically possible. Roundabouts have greater capacity than other Give Way or signal controlled intersections, and so are of benefit in terms of mobility. However, cyclists tend to experience conflicts at roundabouts, possibly because they are not easily seen in this busy environment type.

Crash reduction of between 55% and 70% can be expected with the installation of roundabouts, depending on the number of legs and the previous type of traffic control. There is a greater reduction for conversion of a Give Way controlled intersection than for a signalised intersection, and a greater reduction for four leg intersections than for three legs. High severity and fatal crashes could be expected to reduce by a greater amount than lower severity crashes.

2.5.2 Medians

Physical separation between opposing traffic streams increases the distance, and therefore the recovery area in case of a driver error. This treatment type can dramatically reduce the incidence of head-on crashes, one of the highest severity crash types. In addition, medians prevent turning and property access options along a road section and provide opportunities to redirect these movements to safer locations. These treatments are valuable where frequent property access results in an increased crash frequency.

Painted medians (also called flush medians) provide increased separation between opposing vehicles on undivided roads, thereby reducing the probability of crashes involving vehicles crossing the centreline. In addition, provision of painted medians may result in narrower lanes, encouraging slower speeds. Painted medians may be used both in rural and urban areas.

In urban areas, painted medians provide some protection to pedestrians crossing the road, and may be coupled with pedestrian treatments such as pedestrian refuge islands to provide added security. Depending on width available, right turn lanes are often accommodated in these medians. In some jurisdictions where road rules permit driving on hatched pavement areas, narrow painted medians are used as informal turning lanes.

Benefits of around 40% could be expected from the use of median islands. There is less information available on the use of painted medians, but evidence from New Zealand shows a reduction of around 20% in overall crashes, while pedestrian-related crashes have reduced by 30%.

Adequate road width is required to install median islands, so their use may be limited in some circumstances. There is little information to suggest that there are any negative impacts from the use of median islands in terms of non-safety issues.

Median islands of various types can also be used as spot treatments, typically at intersections. Types of treatments include splitter islands and median islands on the major through road. These are designed to separate the opposing traffic movements, channelise traffic to a defined travel path, limit vehicles' turning speed by restricting the turning radius, and sometimes to provide a staging point for crossing vehicles and pedestrians.

At roundabouts, traffic islands are used to reduce the approach speeds by forcing vehicles to deflect from the straight path. Traffic islands are widely used in intersection design and traffic calming.

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%.

2.5.3 New Signals

The crossing and turning manoeuvres that occur at intersections create opportunities for vehicle conflicts which may result in traffic crashes. The installation of traffic signals can have a positive effect on intersection safety. The intent of traffic signals is to control and separate conflicts between vehicles, pedestrians, and cyclists to enable safe and efficient operations.

Traffic signals may also be used in mid-block locations to improve safety for pedestrians and cyclists at high demand locations.

In addition to the installation of new traffic signals, improvements in the method of assigning right-of-way at signalised intersections can reduce the potential for conflicts. This can be accomplished by modifying signal phasing, providing additional traffic control devices (e.g. mast arms, additional lanterns) and pavement markings, and restricting turn movements. As an example, fully controlled right turn phases are provided at signalised intersections to eliminate right turn filtering (where vehicles are allowed to select their own gaps in oncoming traffic). This treatment substantially reduces the occurrence of through-right crashes at signalised intersections. It can also be considered where there is a history of right turners conflicting with the pedestrians crossing the road being entered by the right turners.

Warrants exist for the installation of traffic signals (see Austroads, 2003), and these are based on traffic demand volumes, continuous traffic, pedestrian safety and crashes (or a combination of these factors).

The operating and maintenance costs for traffic signals are quite high when compared to other types of treatments, and this needs to be considered when assessing the appropriateness of signal installation.

Reductions of between 35 - 50% in all crashes can be expected from the introduction of new traffic signals. Reductions are likely to be greater for 4-arm intersections than for 3-arm.

2.5.4 Modify Existing Signals/Change Phase

Operation of traffic signals should be reviewed every 2–3 years to ensure the phasing and coordination settings match the current traffic demands.

Traffic signals operations specialists review the following traffic signals characteristics:

- signal cycle times
- phase lengths, types and sequences
- phasing plan selection triggers (by time of day or traffic flow characteristics)
- vehicle movement allocations to different phases (e.g. diamond right turns, leading/lagging turns, left turn overlap)
- pedestrian walk and clearance times
- green and inter-green times (amber and red) for each phase
- all-red times
- phase extension or start-up delay settings
- special use commands
- assignment of traffic loops
- existing signal coordination offsets
- and a host of other signal control data.

An upgrade of the controller software and the chip (prom) can also be incorporated into the review. Changes should normally be related to changes in vehicle or pedestrian demands and the mix of traffic in the traffic stream (e.g. proportion of heavy vehicles). Reductions in crashes of up to 10% could be expected from these types of improvements to signals. Re-modelling of existing signals (including controlling right turns with the use of arrows) can also provide large safety benefits of around 30 – 45%.

2.5.5 Traffic Calming Measures

The main aims of traffic calming are to lower the traffic speeds, reduce the number and severity of crashes, and in many cases, to lower the volume and restrict some types of through traffic. These aims can best be achieved through applying a comprehensive area-wide traffic calming scheme, leading to a permanent change in the traffic character of the local streets.

Traffic calming works by segmenting the road into shorter sections of between 60 m and 120 m long, which causes drivers to change their driving patterns. Most frequently, drivers have to reduce their speeds to negotiate the traffic calming devices. In other instances, drivers are exposed to an undesirable experience, e.g. rumbling, vertical displacement, or undue delay, which may encourage them to choose another route. The main point of the traffic calming device selection is that they are self-evident and self-enforcing.

There is a wide range of traffic calming devices available to achieve the desired road segmentation, and hence, the lower speeds and safer streets. These devices include: roundabouts, slow points, kerb build-outs, speed humps, raised tables, entry statements, speed cushions, driveway links, modified intersections and many others.

In many cases traffic calming has the effect of redirecting traffic to alternative routes (indeed this is often its intention). Care should be taken when considering traffic calming that safe alternative routes exist. Movement of traffic from one route to another that is less safe may actually increase overall risk (see discussion in Section 2.4.3 on crash risk migration). Also, traffic calming measures are not suited to routes that have buses, high numbers of heavy vehicles, or that are used as emergency vehicle routes. Also, unless carefully designed, traffic calmed routes can act as a barrier to cyclists.

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). Estimates of expected crash reduction can be obtained by estimating drops in mean speeds, and deriving equivalent crash reduction figures from this change in speed (see e.g. Elvik et al, 2004).

2.5.6 Lighting Treatments

Visibility of the roadway decreases as light diminishes thereby making it more difficult for a driver to manoeuvre safely or to detect road hazards. Street lighting provides visibility, helping drivers obtain enough visual information to complete the driving task.

In addition to the increased benefit in terms of road safety, the public also see lighting as a positive safety and security measure. Good placement of lighting and adequate lighting levels can enhance an environment for walking at night, as well as increase pedestrian and vehicular safety and security.

There are cost and practical implications associated with the introduction of street lighting, especially in rural and remote locations with low traffic volumes. Although of higher cost, they can be used effectively both for intersections and for lengths.

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).

2.5.7 Turning Lanes

Reducing the risk of rear end conflicts at intersections or significant driveways can be achieved by providing a dedicated turn lane. Turning vehicles can safely decelerate or stop without impacting on the flow of the through vehicles behind them. In addition, at unsignalised intersections, turn lanes provide sheltered locations for turning drivers to wait for a gap in the opposing traffic. Thus, the turn lanes encourage drivers to be more selective in choosing a gap to complete the turning manoeuvre safely. This reduces the potential for collisions between the turners and the opposing through vehicles.

Turning lanes are often ‘indented’ and kerbed on divided rural and urban roads. Right turn lanes sheltered by a median are more desirable as they provide better separation from the opposing traffic stream. However, on many existing rural and urban undivided roads, turning lanes may be created with linemarking utilising the existing pavement width, e.g. by sealing the shoulder or expanding into the parking lane. This has an advantage of lower costs than building turning lanes indented into the road verge or median. Sometimes however, road carriageway widening cannot be avoided in order to provide adequate space for turning lanes.

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.

2.5.8 Pedestrian Treatments

Pedestrians are amongst the most vulnerable of all road users. There are a number of different treatments that can be used to improve the safety of pedestrians, including those designed to separate pedestrians and other road users, and those designed to slow motorist speed. Specific measures that have been found to be effective include provision of pedestrian crossing points (including signals and raised crossing points), pedestrian refuge islands, kerb buildouts, and a variety of traffic calming techniques.

In recent years, there has been a move towards installing signalised pedestrian crossings at all signalised intersections at locations where pedestrians are likely to be present. There are a number of signal phasing techniques which minimise the impact on the overall intersection capacity. Similarly, on busy roads with significant traffic volumes, mid-block pedestrian signals may be necessary to create a safe crossing opportunity. The level of pedestrian demand should be substantial to warrant the delay of the main road traffic. The proposed signals may be included in a co-ordinated signal system to reduce traffic delays.

Pedestrian refuges are raised median islands in the middle of the road that provide an area for pedestrians to safely wait until an appropriate gap allows them to cross. This simplifies the crossing manoeuvre for pedestrians by creating the equivalent of two narrower one-way streets instead of one wide two-way street. Refuges are most commonly used on wide, multi-lane roads and are often provided where pedestrian crossings (including pedestrian signals) cannot be provided without adversely affecting the traffic flow. Refuges are particularly useful for those who are wheelchair-bound, elderly, or otherwise unable to completely cross the road in one movement.

Islands can also have additional benefits including acting to separate traffic moving in opposite directions, controlling vehicle speeds by narrowing the roadway, and providing motorists with an indication of where pedestrians might cross a roadway.

A raised pedestrian crossing is an elevated flat-topped section of the road extending the full width of the road. They act as a form of traffic calming, forcing motorists to slow in locations where pedestrians cross. Raised pedestrian crossings elevate pedestrians above the surface of the roadway and can make them more visible to motorists. Raised crossings may be used at intersections or mid-block locations, and can be implemented in association with medians or refuge islands in some circumstances.

There are also a variety of traffic calming techniques that can be applied to slow motorists, thereby making it easier for pedestrians to cross the road, and for motorists to stop if required. Further details on some of these techniques can be found in Section 2.5.5.

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.

2.5.9 Bicycle Treatments

Cyclists are also highly vulnerable as a road user group. Treatments to improve cyclist safety generally involve the separation of cyclists from other types of traffic, typically through the use of on-road or off-road cycle lanes.

On-road cycle lanes are the preferred type of on-road bicycle facility because they designate different parts of the road for cyclists and other road users, and raise the awareness of motorists to the presence of cyclists. They are usually delineated by a single unbroken line on the right side of the bicycle lane and large painted bicycle symbols and bicycle lane signs installed periodically along the length of the route. They may have green surfacing to increase the visibility of cycle lanes, particularly in complex situations at major intersections. They may also have advanced stop lines at signalised intersections to make cyclists more visible to motorists waiting at the stop line so they can proceed more safely through the intersection.

The width of the lane is often dictated by the amount of space available, but where possible, the speed of the surrounding traffic should determine minimum lane width, in accordance with guidelines. Bicycle lanes can be created by redistributing existing sealed carriageway space, or sealing the shoulder of a road with an unsealed shoulder.

Sometimes the amount of cycle traffic does not justify the installation of a designated cycle lane. In such cases, advisory treatments could be adopted indicating to road users the potential presence of cyclists. This may take the form of pavement markings with no regulatory signage.

Off-road cycle paths are provided to meet the transport and/or recreational needs of communities, and may provide an alternative for commuter cyclists adjacent to arterial roads that are severely restricted in width to reduce the risk of serious injury. They may be for the exclusive use of cyclists but are usually shared with pedestrians. The widths of cycle paths vary depending on function and demand.

There is little information on the effect of cycle lanes on crash reduction in Australia, but crash reductions for cyclists of up to 30% could be expected from the introduction of on-road cycle lanes.

2.5.10 Sealing & Resealing

The sealing of a road surface has an obvious benefit for surface friction (see Section 2.5.11 for discussion and possible crash reduction) while benefits can also be gained by widening and sealing the road shoulder.

Sealed shoulders provide drivers with a smooth, sound surface that improves their ability to regain control of an errant vehicle if their vehicle leaves the roadway. In addition, widened or sealed shoulders allow vehicles to pull over with adequate clearance from the high speed traffic. They also provide opportunities for informal driver rest stops which may reduce fatigue related crashes. Further, sealed shoulders provide cyclists with a safe cycling space, and may be at times, marked as rural cycle lanes.

If a vehicle has entered the shoulder area either intentionally or unintentionally, it should be able to either stop or safely recover back into the traffic lane. The chances of stopping or recovery will increase if the shoulder is sufficiently wide and can provide adequate wheel traction. Shoulder treatments that promote safe recovery include shoulder widening and shoulder sealing. These treatments enable the vehicle's recovery to be made in a more controlled fashion and at a less sharp angle, thereby reducing the chances that the recovering vehicle will over-correct into the opposing lane or into the roadside.

Crash reduction of around 10% could be expected from shoulder widening, while a reduction of 30% could be expected from shoulder sealing.

2.5.11 Non-Skid Treatment

Poor skid resistance is likely to result in longer stopping distances, and may cause longitudinal or sideways skidding and the loss of vehicle control. A driver who loses control of the vehicle is more likely to crash into the roadside (run-off road crashes) or into other vehicles (head on, adjacent directions and rear end crashes). Additionally, vehicles which lose ability to brake due to skidding are more likely to crash at higher impact speeds adding to the severity of crashes.

Resurfacing is the most obvious countermeasure in situations where skid resistance is poor. Pavement resurfacing may be undertaken as part of a crash-related treatment or mass action programme, or as part of periodic pavement maintenance. Specific sites for treatment are often identified as those involving high proportions of skidding or crashes in wet conditions.

Crash reductions of around 35% can be expected from the improvement of skid resistance.

2.5.12 Alter Road Width (Including Addition of Lanes)

Narrow lanes can result in a range of different crash types, including head-on, run-off-road and side swipe crashes. Widening of traffic lanes is occasionally carried out on safety grounds to reduce these crash types, allowing a greater margin of error. Rural roads with through traffic lanes below 3.0 m attract significantly higher crash rates. Literature and various design guidelines generally recommend that straight through traffic lanes should be 3.5 m wide, except where presence of cyclists or other special uses dictate wider lane width. The desirable lane widths on curves are dependent on the curve radius, width of the lanes on the straight section, and the operating speeds. Increasing lane widths above 3.6 m has little benefit in reducing crash frequency. In fact, when lane widths become too wide, drivers can become confused as to the total number of lanes on a roadway. This can lead to an increase in some types of crashes, especially same-direction sideswipes.

In addition to road widening, lanes can be added in response to various safety issues, including the provision of turning lanes to address rear-end crashes and various intersection related crashes (see Section 2.5.7) and overtaking lanes (see Section 2.5.13).

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. Crash reductions of between 5 and 10% could be expected, depending on width added.

2.5.13 Overtaking Lanes

Overtaking lanes may be introduced to reduce head-on and loss of control type crashes. The presence of slow vehicles on a two-lane two-way road, together with limited opportunities for overtaking may increase crashes occurring due to overtaking manoeuvres. Installation of an additional lane provides a much safer overtaking opportunity as well as improving the general flow of traffic along the roadway by breaking up the vehicle platoons.

Crash reduction of around 20% could be expected from the installation of overtaking lanes.

2.5.14 Barriers/Guardrails

Barriers and guardrails refer to a range of devices designed to restrict the movement of errant vehicles, with the intention of either guiding them back onto the roadway or bringing them to a stop safely. Subsets of the safety barriers category include end treatments and crash cushions, which reduce the severity of head-on crashes into barriers and hazards. Safety barriers fall into three broad categories according to their stiffness: flexible barriers (or wire rope barriers), semi-rigid barriers (e.g. W-beam or box-beam) and rigid barriers (e.g. concrete barriers).

Flexible barriers require more deflection space than semi-rigid barriers, however the difference in deflection between wire rope and W-beam guardrail is very small. Flexible barriers are often preferred as they minimise the risk of injury to vehicle occupants in a collision, although there are concerns among motorcycling groups over their use. Rigid barriers should be used where there is no room for deflection of a semi-rigid or flexible barrier, such as on top of a bridge or in the centre of a narrow carriageway.

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.

2.5.15 Realign Road Length

Removing substandard horizontal or vertical road alignments can directly reduce the crash risk by making the driving task easier. In particular, the consequences of failing to reduce speeds at curves are reduced thereby lessening the risk of head-on and run-off-road crashes.

This treatment is usually a long term, high cost alternative considered for improving the safety of a road section because it usually involves total reconstruction of that section.

There are several ways in which the horizontal alignment of a roadway may be modified to improve safety. These include increasing the radius, providing transition curves between the straight and the bend, eliminating compound curves and improving superelevation. Vertical realignments include reduction of the grade, increasing the radius of the crest for adequate sight distance and minimising the vertical acceleration changes.

A combination of other safety strategies with carriageway realignment, including lane and shoulder widening, can provide additional safety benefits.

Crash reduction of around 50% could be expected for a horizontal realignment.

Superelevation is one of the key geometric elements of curve design. Superelevation is defined as the amount of rotation (of a carriageway cross section) provided on a horizontal curve to counterbalance part of the centrifugal force that acts on a vehicle traversing the curve. Improving the superelevation of a curve can reduce curve crashes where there is a superelevation deficiency. Improved superelevation can partially compensate for drivers making errors in safe speed selection at curves, as this reduces the surface friction required when safely negotiating horizontal curves.

2.5.16 Realign Intersection

A staggered intersection is a cross intersection where two opposing minor road approaches to the intersection are offset with respect to each other. This creates two closely spaced T intersections in lieu of one cross intersection. A staggered intersection is a very effective treatment for crashes from adjacent directions at low volume unsignalised intersections. This solution is commonly applied both in rural and residential areas.

In the case of rural cross roads, vehicles on the staggered approaches are forced to stop or slow down by traffic islands and geometric deflection before turning or crossing the major road.

Staggered intersections reduce the speed of traffic approaching on the side roads, the number of conflict points and conflict streams, and the relative speeds of the vehicles.

There are two types of staggered intersections. The right-left (R-L) stagger is where traffic arriving at the intersection undertakes a right turn followed by a left turn in order to cross the major road. The second type, the left-right (L-R) stagger, is where traffic arriving at the intersection undertakes a left turn followed by a right turn. The right-left stagger is most common in Australia.

Staggered intersections are not a good choice for signalisation as they cause inefficient signal phasing and are confusing to negotiate by pedestrians. This must be considered when planning future road networks.

Crash reduction of around 30% can be expected from converting a X intersection into a staggered intersection.

Safety improvements can also be made by modifying an existing Y intersection into a T. Y intersections typically have inadequate deflection, meaning that motorist can continue at high speeds through such intersections. The priority control is also unclear in some circumstances at

Y intersections. By re-orientating the Y configuration to a T, motorists are forced to slow at the intersection, and the priority control is made clearer.

2.5.17 Clear Obstacles or Hazards

Collisions between vehicles leaving the road and unforgiving roadside objects such as trees, poles, road signs and other street furniture are a major road safety problem. This is particularly true on high speed roads, especially those in rural areas.

The intent of a clear zone is to provide a driveable space for the driver of a vehicle that runs off the road to regain control or come to a stop while sustaining minimum damage to the vehicle and its occupants. A clear zone is defined as the roadside area, starting at the outer edge of the trafficable lane, available for safe use by errant vehicles. This area may consist of a shoulder, a side slope (embankment) and/or a clear run-out area.

Widening a clear zone involves removal or relocation of unforgiving hazards located close to the roadside. Widening of clear zones is particularly important near intersections or bends, where the complexity of the driving task and interaction with other vehicles add to the likelihood of run-off-road crashes.

In some situations it may be difficult or undesirable to remove roadside hazards (particularly trees) for environmental reasons (see Section 2.4.5). In these cases, the hazard can be shielded with appropriate safety barriers. However, it should be recognised that barriers are a hazard in their own right and should only be considered if it is not possible to remove the roadside object.

Crash reductions are mainly dependant on the width of clear zone before and after the change and the speed environment, and are based on research which indicates that in a high speed environment (e.g. 100 km/h or higher), 85% of vehicles will move less than 9m laterally after leaving the roadway. Crash reductions of up to 45% could be expected from increasing the clear zone by 6m on straight roads, while a 30% reduction from the same increase in clear zone could be expected on curves.

2.5.18 Warning Signs

Where visibility is obscured due to reduced sight distance (for example by adverse horizontal alignment), or there is a higher chance of encountering an unexpected hazard (such as children on the road) advanced warning signs may be used to alert motorists to the presence of hazards. This has the effect of raising driver awareness of a potential conflict, as well as providing some advanced warning to motorists in certain situations (for instance prior to intersections).

Advanced warning signs can be used in a variety of situations including providing warnings for hazardous curves (sometimes used in association with a speed advisory sign), intersections or railway crossings, traffic control (e.g. signals or ‘Stop’ sign), vulnerable road user warning (for instance children or elderly road users), lane narrowing or merges, road works or warning of adverse road surface conditions, and animals on the roadway.

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.

2.5.19 Line Marking (Painted & Audible)

A variety of line markings are available to improve safety, with centre and edgelines the most commonly used. Centrelines separate vehicles travelling in opposing directions into clearly marked lanes, thereby reducing conflicts between vehicles. They also provide delineation which is particularly important at night. Edge lines provide a continuous guide for drivers by delineating the edges of sealed roads making driving safer and more comfortable particularly at night and under adverse weather conditions. They have an effect on the position of the vehicle within a lane, and so are useful in preventing vehicles from leaving the road, particularly at curves.

Recently, the use of audible centre and edgelines have become more widespread. The main function of audible markings is to alert drowsy or otherwise inattentive drivers that their vehicles are drifting from the road. When a tyre runs along the profile edge line, the effect is to produce a distinct ‘hum’. These markings also have the benefit of remaining visible long after surface water would render standard painted edge lines invisible.

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.

2.5.20 Priority Sign Treatments

Give Way and Stop signs are regulatory signs used to control traffic at unsignalised intersections. They allocate priority to traffic on one of the intersecting roads. Give Way or Stop signs are provided at T intersections on minor roads where the layout is such that it is not clear how or whether the ‘T-junction’ rule would operate, for example at a Y-junction. Unsignalised approaches entering arterial roads are also controlled by Stop or Give Way signs. Details about where to use Stop rather than Give Way signs are contained in the Australian Standard on traffic control devices.

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.

2.5.21 Ban Turns

Banning vehicle turns is a traffic management practice used to remove the possibility of conflict between through and turning vehicles. The bans can be applied at an individual intersection or along a chosen route. The bans are best accepted by motorists when they affect a small number of drivers and when alternative turning opportunities exist nearby.

Turn bans are considered to be a very restrictive practice, used only when other less intrusive measures have been exhausted or found to be inappropriate. Consideration must be made of upstream and downstream intersections, as the diverted drivers will attempt to turn at other convenient locations. If these locations are less safe for turns than the existing location, it is possible that overall risk will be increased.

Crash reductions of around 30% could be expected from the banning of turns in situations where this is warranted.

2.5.22 Alterations to Direction of Traffic Flow

Alterations to the direction of traffic flow can take a number of forms, including conversion of a trafficked street to a pedestrianised street (particularly in commercial areas), closure of one or more approaches at an intersection, or closure of a road to through traffic (particularly in residential areas).

Converting a shopping street to a pedestrian mall (pedestrianisation) dramatically reduces the interaction between pedestrians and motorised vehicles (although there will still need to be provision of access to delivery and other vehicles). In some cases it is likely that safety will decrease on surrounding streets (as traffic will be diverted), but typically there is a net safety benefit.

T intersections are generally safer than X intersections, as there are fewer conflict points. Closing one arm of a X intersection can have a beneficial impact on safety for this reason. Street closures can be partial, for example, a four way cross intersection may be modified into a T intersection with a left turn only permitted into the fourth leg. Some street closures may apply only in certain times of the day.

Street closures are normally performed as part of local area traffic management (traffic claming) initiatives to restrict and channel the traffic movements to chosen traffic carrying roads, away from local access streets. For this reason, some street closures are carried out in the middle of the block. This severs the connectivity through an area and forces the traffic to use other more appropriate routes. The closures can be achieved by erecting a barrier, construction of kerb and channel, or in some cases by turning part of the road into a landscaped nature reserve.

Conversion of two-way traffic to one-way flow is usually undertaken as part of an area wide strategy. The benefits include the reduction in the number of conflict points, particularly at intersections (conflict points are halved). It is also easier for pedestrians to cross the road, with more orderly gaps in traffic. Care needs to be taken that speeds do not increase with conversion to one-way flow, or that any increase in speed that does occur has no adverse effect on safety.

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.

It is difficult to estimate the safety benefits of one-way streets, particularly as traffic flow on surrounding streets is also likely to be affected. In general, conversion to one-way flow could be expected to reduce crashes, particularly in central business districts.

2.5.23 Cameras

Red light and speed cameras can be effective tools in reducing casualties. Red light cameras can be used to detect vehicles entering an intersection after the signals have changed to red. This may be due to motorists not complying with the red signal, but also motorist inattention, poor vision or poor signal visibility. Red light running crashes tend to be more severe than other type of crashes in an intersection and have a high cost to the community. The use of red light cameras produces a significant decrease in violations, not only at intersections where cameras are installed, but also at other intersections in the area. However, cameras should not be used as an easy remedy for poorly designed intersections, and improvements should be made to the intersection layout and signal timing where possible before considering the installation of red light cameras.

Crash reductions of between 5 and 10% can be expected from the installation of red light cameras, with around a 30% reduction in right-angle crashes.

Speed cameras are used to reduce speeds, particularly at locations with a high incidence of speed related crashes. Excessive speed is associated with higher rates of crashes and increased injury severity. At higher speeds vehicle stability is compromised, the driver has less time to react to hazards, other road-users have less time to react to the driver's behaviour, and the severity of impact increases exponentially as the vehicle's speed increases.

Speed cameras automatically detect vehicles travelling at excessive speed and photograph the vehicle for identification. The owner of the offending vehicle is then sent an infringement notice. Cameras can either be mobile (i.e. vehicle based, and moved between sites) or fixed (i.e. located in fixed camera housings). 'Point to point' camera systems have recently introduced to Australia that calculate the mean vehicle speed based on the time to travel between two points. This is an effective way to manage speed over a wider area. In some jurisdictions speed cameras can be hidden, although generally in Australia, speed cameras are visible.

Typical crash reductions at speed camera sites are between 5% and 30% on urban roads, and between 5% and 10% on rural roads. There is a greater reduction in higher severity crashes (property damage crashes could be expected to reduce by around 20% and fatal and serious injury crashes by 20% to 40%). Hidden cameras have been shown to be more effective than visible cameras.

2.5.24 Speed Limits

There is a strong link between reduction in speed limits, reduction in median traffic speeds and reduction in the number of all crashes. In situations where there is a high crash risk, it may be appropriate to review the current speed limit with consideration of a more appropriate lower limit. It must be noted, however, that if speed limit changes are to be used for safety reasons they should be part of a combined strategy such as traffic calming or driver perception changes designed to reduce the speeds of vehicles. It should also be noted that unrealistic speed limits (for instance, those perceived as too low) may result in an increase in crash risks unless supported by physical means (e.g. traffic calming) or intensive traffic enforcement.

Typical reductions in crashes resulting from changes in speed limits are as follows:

15% may be used as a general figure for any reduction in the speed limit

15% by reducing the speed limit from 100 km/h to 80 km/h

20% by reducing the speed limit from 80 km/h to 60 km/h

20% by reducing the speed limit from 60 km/h to 50 km/h

2.5.25 Parking

In some circumstances, the provision of on-street parking can increase risk, as parked vehicles may reduce sight distance (e.g. at intersections or visibility of pedestrians), or the act of parking may introduce conflict with other vehicles. Occasionally on-road parking needs to be removed or relocated for safety reasons.

Removal of parking creates less traffic friction, and thus, lessens the potential for side swipe or rear end crashes. Removing a short section of parking near a pedestrian crossing point means that pedestrians are less likely to be obscured by stationary vehicles when crossing the road, reducing the likelihood of pedestrian related crashes. Similarly, removal of parking near intersections provides an improvement in sight distance, reducing intersection related crashes.

In addition, the type of parking has an impact on the level of risk, with parallel parking generally considered safer than angle parking. This is because sight distance to conflicting traffic is impeded by adjacent parked vehicles where drivers are required to back out of angle parking spaces on roads.

Reductions in crashes of around 10 to 20% are typically experienced with the banning of parking.

2.5.26 Railway Crossing Improvement

Collisions between vehicles (or pedestrians and cyclists) and trains are an infrequent but usually high severity event, often involving a fatality. There are a number of measures that may be taken to improve the safety at such locations. These include removing the crossing point, introducing grade separation (e.g. an over-bridge), use of active controls (e.g. flashing lights, audio devices, pedestrian gates, vehicle boom barriers and traffic signals which are triggered by the passing train), and the use of passive controls (e.g. static signs and markings). In some cases the road may be realigned to improve the sight distance at uncontrolled rail crossings.

Upgrading level crossings from passive to active control or introduction of physical separation can dramatically reduce the incidence of crashes. Reduction in total crashes are typically 50% for upgrade of warning signs to flashing lights, 70% for upgrade of warning signs to boom barriers, and 45% for upgrade of flashing lights to boom barriers. The installation of signs where there were previously no facilities would result in an estimated 25% reduction.

2.5.27 Grade Separation

Most conflicts involving motorised vehicles, bicycles and pedestrians occur at intersections. While traffic signals can separate the conflicting movements in time, they cannot separate them physically as they still occur within the same plane. Should drivers fail to follow traffic signal messages or other applicable road rules, the conflict potential remains.

The most effective road safety outcome in separating the conflicting intersection movements is achieved by placing them at different levels, or at separated grades. This is achieved by various forms of overpasses and interchanges. These forms of intersection control also provide the greatest capacity benefits.

Grade separation is very expensive in terms of construction costs and land resumption needs, however, there are typically considerable traffic flow benefits and therefore a high traffic level is needed before they can be justified.

While grade separation can have clear safety benefits, they are considered by some sections of the community to adversely affect the appearance of an area and may act as a barrier to walking and cycling and create community separators due to their size and impacts on the local amenity.

Crash reductions of up to 60% are typically experienced when converting signalised intersections to grade separated intersections.

2.5.28 Channelisation

Channelisation is defined as “a system controlling traffic by the introduction of a traffic island or median, or markings on a carriageway to direct traffic into predetermined paths, usually at an intersection or junction” (Austroads, 2005). It is applied at intersections to provide a clear indication to motorists about the path they are required to take, and the priority on each approach. Physical measures (e.g. raised kerbs, traffic islands, painted road markings and bollards) are often used, and this also acts to segregate different traffic flows, reducing the potential area of conflict. Physical islands provide a point at which traffic devices such as signs and traffic signals can be located, and may also be used to provide a refuge point for pedestrians.

On minor approaches to intersections, splitter islands (see Section 2.5.2) may be used to help define the intersection, and increase its visibility. They may also be used to safely pull vehicles into a better position within which to see approaching vehicles, thereby improving sight distance.

On major approaches, channelisation may be used for a variety of purposes, including to protect turning vehicles, control speeds (e.g. through narrowed road width), prohibit certain movements, provide refuge to pedestrians or cyclists, and to provide clear delineation through the intersection.

Provision of splitter islands can reduce casualties by around 40%. Reductions are greatest at urban intersections. Providing median islands on the through-road typically results in reductions of 25% for kerbed islands, and 15% for painted islands.

2.5.29 Summary of crash types addressed by treatments

Table 2.8 provides a summary of the types of crashes addressed by each of the treatment identified above, as well as the estimated casualty crash reduction.

Table 2.8: Summary of crash types addressed by treatments

	Adjacent approaches	Head-on	Opposing turns	Rear end	Lane change	Parallel lanes turning	Loss of control	Pedestrian	Cyclist	Delineation	Speed	Hit Train	Estimated % reduction
Roundabouts	✓		✓								✓		55-70%
Medians	✓	✓	✓							✓			20-40%
New Signals	✓		✓					✓			✓		35-50%
Modify Signals/Change Phase	✓		✓					✓			✓		10-45%
Traffic Calming Measures							✓	✓	✓		✓		up to 60%
Lighting Treatments	✓		✓							✓			30-50%*
Turning Lane			✓	✓									30-35%
Pedestrian Treatments								✓					35%**
Bicycle Treatments									✓				30%***
Sealing & Resealing				✓			✓						10-30%
Non-Skid Treatment				✓			✓						35%
Alter Road Width		✓			✓	✓			✓				5-10%
Overtaking Lanes		✓					✓						20%

	Adjacent approaches	Head-on	Opposing turns	Rear end	Lane change	Parallel lanes turning	Loss of control	Pedestrian	Cyclist	Delineation	Speed	Hit Train	Estimated % reduction
Barriers/Guardrails		✓					✓	✓	✓				40%
Realign Road Length		✓					✓						50%
Realign Intersection	✓	✓	✓	✓			✓	✓	✓	✓	✓		30%
Clear Obstacles or Hazards							✓						up to 45%
Warning Signs	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	5-30%
Line Marking (Painted & Audible)		✓			✓		✓			✓			5-30%
Priority Sign Treatments	✓												20-35%
Ban Turns	✓		✓	✓		✓	✓						30%
Alterations to Direction of Traffic Flow	✓	✓	✓			✓		✓	✓		✓		30-65%
Cameras	✓		✓				✓				✓		5-30%
Speed Limits											✓		15-20%
Parking	✓			✓	✓			✓	✓				10-20%
Railway Crossing Improvements												✓	25-70%
Grade Separation	✓		✓									✓	60%
Channelisation	✓	✓	✓				✓			✓	✓		15-40%

*night crashes only

**pedestrian crashes only

***cyclist crashes only

3 Data analysis to determine crash reduction estimates for black spot treatments by vehicle movement type

3.1 Method

The method employed in this study was based on that employed by Andreassen (2003), whose report provided the basis for the crash reduction matrix published by Austroads (2004).

The crash reduction estimates associated with various types of black spot treatment that are presented in this section were based on data collected at 1497 federally-funded projects installed throughout Australia between 1996 and 2004 and a sample of 57,086 crashes.

The BITRE provided ARRB with both site details (including treatment type and installation commencement and completion dates) and crash data for each site (including date and crash type). The treatment type at each site was assigned according to the categories presented in Table 3.1. These are based on a categorisation system developed by BITRE. This categorisation system was designed to distil road safety engineering treatments to their most basic and irreducible form.

Appendix A presents the number of each type of site included in this study by State. Some treatment types (cameras, speed limits and grade separation) were not represented in the data available. Cameras are not an approved treatment under the National Black Spot Program. Speed limit changes and grade separation are approved treatments, but were not part of the data that was analysed.

There was only one railway crossing site, represented by only eight crashes, and so this treatment was not included in the analysis. The category ‘other’ treatments was also not included. The treatment types not included are marked with an asterisk in Table 3.1.

Table 3.1: Treatment categories

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 (including addition of lane/s)
T13	Overtaking lane/s
T14	Barriers/guardrails
T15	Realign road length - horizontal & vertical (mid-block treatments)
T16	Realign intersection
T17	Clear obstacles or hazards
T18	Warning signs
T19	Line marking (painted & audible)
T20	Priority sign treatments
T21	Ban turns
T22	Alterations to direction of traffic flow (including road closure or re-opening)
T23	Cameras*
T24	Speed limits*
T25	Parking
T26	Railway crossing*
T27	Grade separation*
T28	Channelisation
T29	Other*

* These treatments were not included in the analysis.

The 'before' period was taken to include any crashes that occurred before the date on which the treatment was recorded to have commenced. The 'after' period was taken to include any crashes that occurred after the date on which the treatment was said to have been completed (i.e., no 'settling-in' period was allowed for). This means that the long term crash reduction impact of some of the treatments may be underestimated due to crashes in the after period that occur because road users are unfamiliar with the treated site. Alternatively, drivers may have been more cautious at recently altered sites, resulting in a temporarily reduced crash rate. It is anticipated that these impacts would be negligible in most cases however.

Sites for which less than two years of before data or less than two years of after crash data were available were excluded from the analysis. Based on work conducted for DoTARS by Andreassen (2003), which indicated that 'there was no great difference observed in the effects' when results based on an equal amount of before/after time for each site were compared with those obtained when all the available crash data was used, all crash data was used in this analysis. Before periods and after periods ranged from 24 months to 84 months.

Sites where more than one treatment type had been employed were included in the analyses, categorised according to the 'primary' treatment type. Approximately 40% of sites included in the analyses had multiple treatment types.

The final numbers of projects/sites assessed whose results were used for reviewing the matrix were as presented in Table 3.2.

Table 3.2: Sites available for analysis in each state/territory

State/territory	Number of sites	Years of data used
New South Wales	301	Jan 1992 to Jun 2005
Victoria	497	Feb 1990 to Jun 2005
Queensland	206	Jul 1991 to Jun 2005
Western Australia	315	Jan 1991 to Nov 2005
South Australia	108	Feb 1990 to Mar 2007
Tasmania	41	May 1990 to Jun 2005
Australian Capital Territory	8	Aug 1992 to Dec 2004
Northern Territory	25	May 1990 to Jun 2005

Crashes of all severity levels were included in the analysis without distinguishing between them. This included property damage only crashes for all states except Victoria, where property damage only crashes are not routinely recorded. Thus some differences were expected between the states in the apparent effects of specific treatments. Excluding property damage only crashes from the analysis would have reduced the sample of crashes by 60% and meant a loss of up to 95% (for the ACT) for each state individually. By retaining crashes of all severity levels in the analysis, ARRB's analysis is also kept consistent with that undertaken by Andreassen.

Each crash that occurred at a treatment site was assigned to a crash type category based upon its DCA or RUM code. The conversion matrix developed by Thoresen (2006) and presented in Table 3.3 outlines what crash type categories were assigned to various DCA or RUM codes. This reclassification resulted in the loss of approximately 5% of crashes from the sample due to their not falling within one of the specified categories. These were mainly crashes coded as 'other' within the respective state road authority crash database.

The observation start and end dates for each site were assigned based on instructions provided by the BITRE. The earliest start date and latest end date for sites located in each state are presented in Table 3.2.

As per BITRE instruction, no observation start or end date was more than seven years remote from the treatment start or end date, respectively. Truncating the data in this way was designed to reduce the impact of extraneous variables on crash rates. For example, comparisons between crash rates seven years prior to site treatment and those which occur seven years after site treatment probably highlight factors like changes in enforcement practices and vehicle safety as well as changes in site characteristics, such as traffic volumes. Further, the broader the observation period, the more likely it is that a site will have undergone treatments other than that undertaken as part of the Black Spot Program being assessed in this project.

Table 3.3: Crash code conversion matrix

ARRB category	NSW/ Qld/Tas /ACT	Vic	WA	SA	NT
Pedestrian, crossing carriageway 001-003	001-003	100-102	01-03	6	0-2
Hit permanent obstruction 605	605	164	65	2	64
Off carriageway, on straight 701, 702	701,702	170,172	71,73	12	70,72
Off carriageway, on straight, hit object 703, 704	703,704	171,173	72,74		71,73
Out of control on straight 705	705	174	75	7	74
Off carriageway, on curve 801, 802	801,802	180,182	81,83		80,82,84,86
Off carriageway, on curve, hit object 803, 804	803,804	181,183	82,84		81,83,85,87
Out of control, on curve 805	805,	184	85		88
Intersection, from adjacent approaches 101-109	101-109	110-118	11-19	4	10-18
Head-on 201	201	120	21	5	20
Opposing vehicles, turning 202-206	202-205	121-124	22-26	8	21-25
Rear-end 301-303	301-303	130-132	31-33	1	30-32
Lane change 305-307	305-307	133-135	35-37	3	33,34
Parallel lanes, turning 308, 309	308,309	136,137	38,39		36,37
U- turn 207 & 304	207,304,	140,141	27,34		40,41
Vehicle leaving driveway 406	406	147	47		47
Overtaking, same direction 503, 506	503,506	152,	53,56		52,53
Hit parked vehicle 601	601	160	61	9	60

Results for a site for any particular crash type were included in the analysis only if there had been at least three crashes of that type during the 'before' observation period. Presenting results based on one or two crashes per site was deemed to be potentially misleading. Although the statistically significant changes remained fairly consistent when this filtering was made more inclusive (i.e. the minimum number of crashes could be achieved across all sites within the treatment category combined), several counterintuitive (but non-significant) changes became apparent. For example, audible edgelining was shown to be associated with a 34% increase in 'hit parked vehicle' crashes. This finding turned into a more credible non-significant decrease in 'hit parked vehicle' crashes after the more stringent filtering process.

For each treatment type/crash type combination, the annual crash rate during the before period (number of crashes for all relevant sites combined divided by the number of years of observation data for all sites combined) was compared with the annual crash rate for the after period, see Equation 1. This method of devising crash rates was chosen over calculating the mean of the annual crash rates for each individual site because it does not give equal weight to rates based on small samples of crashes and those based on a large sample. Crash rates were calculated to provide an indication of effect size.

$$R_b = \frac{\sum_{i=1}^{n} C_{b_i}}{\sum_{i=1}^{n} Y_{b_i}} \qquad R_a = \frac{\sum_{i=1}^{n} C_{a_i}}{\sum_{i=1}^{n} Y_{ai}}$$

R_b = before crash rate

R_a = after crash rate

C_b = number of crashes at site *i* in the before period

C_a = number of crashes at a site *i* in the after period

Y_b = years of before observation at site *i*

Y_a = years of after observation at site *i*

n = number of sites

Equation 1: Calculation of crash rates

To determine whether observed changes in 'before' and 'after' crash rate were statistically significant when either or both the before and/or after rates were based on less than 100 events (crashes), 95% confidence intervals were computed for both rates using the relationship between the Chi-square and Poisson distributions (see Equation 2, Johnson & Kotz, 1969; Stuart & Ord, 1994).

$$LL = \frac{\chi^2_{2n,\alpha/2}}{2}$$

$$UL = \frac{\chi^2_{2n+2,1-\alpha/2}}{2}$$

LL and *UL* are lower and upper confidence limits for *n* respectively

n is the observed number of crashes

χ^2,v and α is the chi-square quantile for upper tail probability α on v degrees of freedom.

Equation 2: Poisson confidence intervals

If the confidence intervals did not overlap, the difference was considered statistically significant (at the 95% level). If they did overlap, the difference was not considered statistically significant.

If rates to be compared are based on 100 or more events, a better and less complicated alternative for testing the difference between these two types of rates is to construct a 95% confidence interval for the ratio (instead of the difference) between the two rates (Pennsylvania Department of Health, 2001). So, when both the before and after rates were based on more than 100 events, confidence limits for the relative crash risk (‘after period’ crash rate divided by ‘before period’ crash rate), based on Poisson distribution were calculated (see Equation 3, Sahai & Kurshid 1996).

$$I\hat{R}R = \frac{a}{PT_1} \bigg/ \frac{b}{PT_2}$$

$$I\hat{R}R_L = \left(\frac{PT_2}{PT_1}\right)\left(\frac{a}{b+1}\right)\frac{1}{F_{\alpha/2,2(b+1),2a}}$$

$$I\hat{R}R_U = \left(\frac{PT_2}{PT_1}\right)\left(\frac{a+1}{b}\right)F_{\alpha/2,2(a+1),2b}$$

$I\hat{R}R$ is the incidence rate ratio

a is the number of after crashes, *b* is the number of before crashes

PT is the total time (years) observed

F is a quantile of the F distribution (denominator degrees of freedom are quoted last).

Equation 3: Confidence intervals for relative risk, based on Poisson distribution

If the confidence interval calculated using the above method included 1, then the relative risk was not statistically different from 1.

In 26 cases there were crashes in the ‘before period’ and no crashes in the ‘after period’. In ten instances (of these 26), the lower 95% confidence interval for the before period crash rate was greater than 0.20. This indicates a less than 2.5% chance that the actual crash rate was less than one crash every five years. The reduction in crashes in these ten instances was considered to be statistically significant.

For these 26 cases a 100% decrease in crashes is reported. It should be noted that even one crash in the after period may have had a substantial impact on this figure of 100%. As such, a reported 100% decrease, even if statistically significant, should not be interpreted to mean that the treatment will eliminate all such crashes, and simply that it may have at that specific site, or group of sites, for the duration of the ‘after period’.

3.1.1 Some limitations

Ideally, these analyses would have better taken account of exposure. However, traffic volume data was not available for the vast majority of sites, and so could not be used in the calculation of crash rates. It is likely that most black spot sites saw an increase in traffic volumes between the before and after periods. This means that the effects highlighted in the matrix presented below may be magnified over what could be expected if traffic volumes are assumed to remain the same.

Further, no data was provided for control sites. Crash reductions from factors such as improved vehicle safety are included amongst the reductions arrived at in this study. Therefore, they are likely to be an over-estimate of the effect.

In a related vein, regression to mean has not been addressed. Nonetheless, some amelioration of regression to the mean effects will have occurred at sites for which data for several years was available.

There was evidence of some errors in the data. For example it appeared that there was some miscoding of accident types, with crash codes for use on curves being applied to roundabouts. In addition, it appears that overtaking lanes were installed at a Queensland site and a Victorian site where no head-on or overtaking crashes had been recorded during the 'before' period (the Queensland site was excluded from the final analysis due to insufficient data).

As noted, it is also the case that approximately 40% of sites included in the analyses had multiple treatment types, although they were analysed according to the 'primary treatment type' category only.

Statistical significance is important because it provides an indication of the reliability of a finding. Findings that are statistically significant are unlikely to be due to chance. However, statistical significance is partly a function of sample size. While the statistical significance of the difference between before and after crash rates was determined in this project, for several treatment type/crash type combinations the limited amount of data available has meant that only very large differences in crash rate would be statistically significant. Non-significant results, although they must be interpreted with caution, should not be dismissed.

Similarly, statistical significance should not be considered to indicate a meaningful result in the absence of consideration of the effect size, indicated in this report by the 'change in crash rate'. With a large enough sample, very small effects (or, in this case, very small changes in crash rate) can be statistically significant.

It should also be noted that with small sample sizes, outlying data points can have an undue impact on results. In this study, counter-intuitive findings were followed up with investigation of raw site and crash data, in order to identify the contribution of sites with unusual characteristics. The results of these investigations are presented in SectionTable 3.4.

3.2 Results

The results of the analyses are presented below in Table 3.4 and Table 3.5. For each treatment/crash type combination for which results were calculated, the change observed in annual crash rates after the treatments were installed is presented. The percentage change (change in rate divided by the 'before' crash rate) is also presented. Only figures presented in bold type were statistically significant at an alpha level of 0.05. Findings that are not statistically significant should be seen as a guide only.

Confidence intervals for the risk ratio associated with each crash rate change are presented in Appendix B and Appendix C to assist in the determination of the likely accuracy of the results presented in Table 3.4 and Table 3.5.

Changes of less than 0.2 crashes per year (one crash per five years) are omitted from the table to preserve clarity. None of these changes were statistically significant.

3.2.1 Some unexpected findings

Many changes in the expected direction occurred. Other changes were unexpected. Those presented in red text were subject to closer scrutiny, based on revisitation of the raw data and site descriptions.

The apparent 200% increase in head-on crashes associated with lighting schemes was a non-statistically significant finding based largely on crash data from one site in Victoria, where there were four head-on crashes in the 'before' period and 12 in the 'after' period. This site was an intersection where lights were 'upgraded to code standard'. It is not possible to determine why this apparent increase may have occurred or whether it was related to the treatment.

The statistically significant 21% increase in 'opposing vehicle turning crashes' following non-skid treatments was based on crash data from 25 different sites. Eleven of these sites saw increases in 'opposing vehicles turning' crashes after the installation of these treatments. This indicates that a peculiarity associated with one particular site is not responsible for this finding. One site, in Western Australia, saw a particularly large increase of 3.67 'opposing vehicle turning' crashes per year. This site involved the use of skid resistant surfacing to reduce 'right turn/right through crashes', which in terms of the crash categories employed in this study, are 'opposing vehicles turning' crashes.

According to the results presented in Table 3.4 there were statistically significant increases in 'off carriageway on curve' crashes following the alteration of road width. These findings are based largely on one New South Wales site which saw 39 such crashes during the before period and 114 during the after period. Seven other sites all saw either decreases or no change in 'off carriageway on curve' crashes following the alteration of road width, but these results are based on much smaller crash samples. The New South Wales site which saw the dramatic increase in 'off carriageway on curve' crashes involved the construction and sealing of road shoulders to allow more room for vehicles, especially heavy vehicles. It is possible that this is due to drivers perceiving that they can travel faster on the wider lane.

The installation of barriers and guardrails was associated with an increase in a few of the crash categories. The increase in 'off carriageway on curve, hit object' crashes is not unexpected because given that a run-off road crash has occurred, the likelihood that an object will be hit increases, conceivably to 100%, if a guardrail is present. Similarly, the 'off-carriageway on straight crashes' may have 'increased' (inspection of site level data indicates that it did at two sites) because a crash where something is struck is more likely to be reported to police.

The increase in 'head on' crashes following the installation of barriers or guardrails is more unexpected and due largely to a New South Wales site which saw 15 such crashes in the before period and 45 in the after period. At this site guardrails were installed to protect steep batter slopes. Overall, six of the nine sites where barriers or guardrails were installed saw at least small reductions in head-on crash rate. It is possible that in an effort to keep a comfortable distance from the guardrails, drivers are choosing to travel closer to the centreline.

A 242% (but not statistically significant) increase in the rate of lane change crashes was shown to be associated with priority sign treatments. However, this was based on one site in Western Australia which saw three lane change crashes in the before period and five during the after period. The treatment at this site was described as 'relocate power pole and sign'. This does not appear to fit well within the 'priority sign treatments' category and so this finding should be disregarded and is not presented in Table 3.4.

In relation to the impact of each treatment type on 'all crashes', three statistically significant increases were noted. The installation of overtaking lanes and barriers and guardrails and intersection realignment all appear to be associated with increased crashes overall.

A potential mechanism for guardrails to increase head-on and off carriageway crashes has already been mentioned. It also appears that overtaking lanes may increase crashes overall. The potential for overtaking lanes to result in crash risk migration should be considered. Although crashes at the site of the overtaking lane may be increased (due to required merge manoeuvres and potentially higher speeds travelled by drivers during the overtaking) crashes at other points on the network may be decreased due to a reduction in attempts to overtake in unsafe locations.

Intersection realignment appeared to be associated with a small increase in crashes, according to Table 3.5. Table 3.4 indicates that part of this increase may be lane change crashes. It is possible that some of the increase may be due to driver confusion arising from the changed conditions. It is not clear what else may have contributed to this apparent increase.

Table 3.4: Crash rate reduction matrix

TREATMENT/ CRASH TYPE	Pedestrian Change %	Pedestrian Change Rate	Hit permanent obstruction Change %	Hit permanent obstruction Change Rate	Off cway on straight Change %	Off cway on straight Change Rate	Off cway on straight hit object Change %	Off cway on straight hit object Change Rate	Out of control on straight Change %	Out of control on straight Change Rate	Off cway on curve Change %	Off cway on curve Change Rate	Off cway on curve hit object Change %	Off cway on curve hit object Change Rate	Out of control on curve Change %	Out of control on curve Change Rate	Intersection; from adjacent Change %	Intersection; from adjacent Change Rate	Head on Change %	Head on Change Rate	Opposing vehicle, turning Change %	Opposing vehicle, turning Change Rate	Rear end Change %	Rear end Change Rate	Lane change Change %	Lane change Change Rate	Parallel lanes, turning Change %	Parallel lanes, turning Change Rate	U turn Change %	U turn Change Rate	Vehicle leaving driveway Change %	Vehicle leaving driveway Change Rate	Overtaking, same direction Change %	Overtaking, same direction Change Rate	Hit parked vehicle Change %	Hit parked vehicle Change Rate
Roundabout	-41	-0.24	-36	-0.27			-77	-0.99			-76	-0.59	-42	-0.26	-67	-0.76	-57	-1.05			-67	-1.02					-100	-0.57	-100	-0.43	45	1.56			-66	-0.56
Medians							-34	-0.44									-34	-0.55	-35	-0.23			-7	-0.25	-23	-0.42	-37	-0.27			249	1.07			-35	-1.00
New signals (incl. those with turning arrows)	-47	-0.31	-73	-0.42			-39	-0.20									-78	-2.08	-100	-0.50	-14	-0.20	29	0.57					-100	-0.60	-76	-0.76				
Modify signals/change phase			54	0.58			-55	-0.32	-76	-0.46			-100	-0.46			-31	-0.41			-42	-1.03	13	0.41					-100	-0.44						
Traffic calming																	-29	-0.33			-45	-0.87	69	0.91	-68	-0.58	-62	-0.44	-77	-1.10						
Lighting							33	0.38									-37	-0.84	200	1.14	30	0.29	9	0.33	46	0.56	-30	-0.18			-32	-0.35	-100	-0.52	-66	-0.41
Turning lanes	-41	-0.24							-55	-0.27			-70	-0.40			-11	-0.20					6	0.25			75	0.57							-71	-0.78
Pedestrian treatments	-37	-0.46					-42	-0.21									-51	-0.87			-27	-0.57	-16	-0.39	-43	-1.05					50	0.43			-38	-0.74
Bicycle treatments							-29	-0.29													54	0.95	89	1.37							-71	-0.71				
Sealing & resealing (incl. sealing of unpaved roads)					-60	-0.44			-40	-0.28					-100	-1.29			-45	-0.39	23	0.25					-100	-0.43	-60	-0.30					-53	-0.38
Non-skid treatment	43	0.21	-100	2.14	-100	-0.57					27	0.21	-28	-0.33							21	0.36	-6	-0.28			118	0.84								
Alter road width (incl. adding lane/s)	-100	-0.43					-36	-0.40	-100	-0.43	216	1.83	94	1.22	-46	-0.74	39	0.46			-37	-0.57	-30	-0.59	-55	-0.44										
Overtaking lane/s																	86	0.86																		
Barriers/guardrails	-70	-1.32	-22	-0.21	36	0.57			-64	-0.60			20	0.65	19	0.25	-16	-0.35	58	1.03	-19	-0.20			-15	-0.23	-45	-0.29	-36	-0.33					-100	-0.71
Realign road - horizontal & vertical (mid-block)					-100	-0.43	-57	-0.42	-48	-0.37							-65	-0.59																		
Realign intersection	-62	-0.26					-40	-0.26	-100	-0.43											-10	-0.20	-5	-0.43	78	0.72										
Clear obstacles or hazards	-80	-0.80									-100	-0.43	-60	-0.68	-78	-0.56	-34	-0.40	-100	-0.86	-42	-0.56	-11	-0.20							-100	-0.57	-100	-0.52		
Warning signs	-100	-0.57							-87	-1.87							-20	-0.27	22	0.22	-58	-1.70														
Line marking (painted & audible)	-51	-0.51			-27	-0.45			-49	-0.67					-67	-0.29					20	0.21					-42	-1.92			-43	-0.21				
Priority sign treatments																	-23	-0.35			-15	-0.20														
Ban turns																	-100	-0.86			-100	-0.86	-100	-0.43												
Alterations to direction of traffic flow (incl. road closure or re-opening)	45	0.28					-32	-0.27									-43	-0.89			152	0.86	-21	-0.37	-73	-0.52										
Parking	-37	-0.74					-26	-0.11									40	0.29			-65	-0.42	-65	-0.84					-63	-0.27					-76	-1.35
Channelisation							33	0.20									-29	-0.53			-100	-0.55	-87	-1.38												

Table 3.5: Crash rate reduction matrix (all crash types combined)

Treatment	Treatment code	Change	
		%	Rate
Roundabout	T01	**-50.84**	**-1.26**
Medians	T02	**-15.85**	**-0.61**
New signals (incl. those with turning arrows)	T03	**-42.11**	**-1.67**
Modify signals/change phase	T04	**-19.89**	**-1.09**
Traffic calming	T05	-17.82	-0.50
Lighting	T06	**-15.25**	**-1.28**
Turning lanes	T07	-2.86	-0.17
Pedestrian treatments	T08	**-19.31**	**-1.00**
Bicycle treatments	T09	+7.28	+0.44
Sealing & resealing (incl. sealing of unpaved roads)	T10	**-14.39**	**-0.32**
Non-skid treatment	T11	+0.83	+0.06
Alter road width (incl. adding lane/s)	T12	+10.19	+0.32
Overtaking lane/s	T13	**+161.54**	**+1.50**
Barriers/guardrails	T14	**+20.37**	**+1.18**
Realign road - horizontal & vertical (mid-block)	T15	**-29.23**	**-0.61**
Realign intersection	T16	**+8.60**	**+0.63**
Clear obstacles or hazards	T17	**-37.10**	**-0.86**
Warning signs	T18	-14.51	-0.44
Line marking (painted & audible)	T19	-3.63	-0.34
Priority sign treatments	T20	**-21.19**	**-0.62**
Ban turns	T21	**-100**	**-1.18.**
Alterations to direction of traffic flow (incl. road closure or re-opening)	T22	**-32.19**	**-0.94**
Parking	T25	**-44.88**	**-1.60**
Channelisation	T28	**-37.22**	**-0.84**

3.3 Comparison of findings with previous work

Where overlaps on treatment type and crash type categories allowed, comparisons between the crash reduction matrix developed during this project and other matrices were made. As well as the crash reduction matrix published by Austroads (2004) Victorian, New South Wales and Western Australian crash reduction matrices have also been produced.

Comparisons between the matrices are presented in Table 3.6. A '+' sign indicates there was an increase in crashes, while those figures with no sign represent a decrease. Rail related treatments and crashes and 'grade separation' were excluded from these tables as they were also excluded from the analyses conducted by ARRB (due to lack of adequate samples). Blank cells are those where no data was available and all ARRB figures have been rounded to the nearest multiple of five.

By and large the matrices are fairly concordant, although there is rarely no difference between the ARRB results and those presented in the other matrices. This is to be expected due to the varying means by which the statistics were arrived at and the large number of intervening factors which will determine the magnitude and direction of the change in crash rate at any one treatment site.

The statistics in red font are those that suggest a change in the opposite direction to that predicted by the Victorian, New South Wales or Western Australian matrices.

Only two of these were statistically significant. The 20% increase in ‘off road on curve, hit object’ crashes was mentioned previously and may be an artefact not of more crashes, but of the fact that should a vehicle leave the road, it is more likely to hit an object if barriers are in place.

The other was the apparent reduction in ‘parallel lanes turning’ crashes after roundabout installation. It is not clear why this disparity has occurred.

Table 3.6: Comparison of matrices*

Treatment		Change in all crashes		Adjacent approach				Head on			
		Estimated Crash Reduction – Percent Change									
2001 BTRE Type	2007 BTRE Type	ARRB	VicRoads	ARRB	Astrds	WA	NSW	ARRB	Astrds	WA	NSW
Roundabout	Roundabout	50	85	55	70	50	75	10		100	70
New traffic signal [no turn arrow]	New signals (incl. those with turning arrows)	40	45	80	70	70	80				
New signal with turn arrows			45		70	70	80				
Remodel signal	Modify signals/change phase	20		30	50	50					
Protected L turn lane in crossing street			15			30	10				
Improve sight lines	Clear obstacles or hazards	35		35	30	30					
Frangible posts, poles			20								
Roadside hazards – remove			20								
Street closure [one leg of cross]	Alterations to direction of traffic flow (incl. road closure or re-opening)			45	50	50	70			50	50
Street closure [close stem of Tee]					100	100	100				50
Non-skid treatment	Non-skid treatment	0	20	17			10	15			15
Non-skid surface			20								15
Stagger cross intersection [right-left]	Realign intersection	+10	50	15	50	50	50			50	50
Reduce radius on left turn sliplane						30					
Improve/reinforce priority signs [eg Stop]	Priority sign treatments			25	30	30					
Ban right turns	Ban turns			100			70				
Ban left or U turns							70				
Improve lighting	Lighting treatments	20	25	35		10	20	+200		10	20
Improve route lighting			25							30	20
Ped crossing lighting											
Traffic islands on approaches	Medians	20	45	35				35	20	20	
Extend median through intersection					100	100	90		100	100	20
Median (midblock)			40						**90**	90	20
Indented right island	Turning lanes	0	30	10			15	10		20	
Painted turn lane							15				
Ban parking adjacent to intersection	Parking	40		+40	10	10					
Clearway parking bans											
Pedestrian refuge	Pedestrian treatments	20	30								
Pedestrian crossing											
Pedestrian signals			25								
Seal shoulder	Sealing and resealing	15	40					45	**40**	40	5
Climbing lane [overtaking lane]	Overtaking lanes	160	20						**30**	30	25
Roadside hazards - guardrail	Barriers/guardrails	+20	25								
Reconstruct superelevation on curve	Realign road	30	15					+10	**50**	50	50
Advisory speed sign on curve	Warning signs	15	20					+22	**30**	30	
Delineation	Line marking	5	25								
Edgelines											

* a '+' value represents an increase in crashes

Table 3.6: Comparison of matrices (continued)

Treatment		Opposing turns				Rear end				Lane change			
		Estimated Crash Reduction – Percent Change											
2001 BTRE Type	2007 BTRE Type	ARRB	Astrds	WA	NSW	ARRB	Astrds	WA	NSW	ARRB	Astrds	WA	NSW
Roundabout	Roundabout	70		60	60	11	*+20*	+25	0	16			+20
New traffic signal [no turn arrow]	New signals (incl. those with turning arrows)	15	*+90*	+90	+30	+30			+40				
New signal with turn arrows			5	5	90				+40				
Remodel signal	Modify signals/change phase	40	60	60		+15				+5			
Protected L turn lane in crossing street					15		10	20	60				40
Improve sight lines	Clear obstacles or hazards	40	30	30		10		20	25				
Frangible posts, poles													
Roadside hazards – remove													
Street closure [one leg of cross]	Alterations to direction of traffic flow (incl. road closure or re-opening)	+152	50	50	70	20		50	50	75		50	
Street closure [close stem of Tee]			100	100	100			50	50			50	
Non-skid treatment	Non-skid treatment	+21			10	5	40	20	50				
Non-skid surface					10		**40**	40	50				
Stagger cross intersection [right-left]	Realign intersection	10	50	50	50	5	*+30*	+30	0	80	*+10*	+10	
Reduce radius on left turn slipline							50	50					
Improve/reinforce priority signs [eg Stop]	Priority sign treatments												
Ban right turns	Ban turns	100	50	50	70	100		50	70				
Ban left or U turns				50	70		50	50	70				
Improve lighting	Lighting treatments	+30		10	20	+10		10	25	+45		10	20
Improve route lighting				30	20			30	25			30	20
Ped crossing lighting													
Traffic islands on approaches	Medians	10	20	20		10	20	20					
Extend median through intersection			100	100	100			50	60				
Median (midblock)				100	100				60				
Indented right island	Turning lanes	10	30	30	40	+10	40	40	60	+17			40
Painted turn lane			20	20	40		20	20	60				40
Ban parking adjacent to intersection	Parking					65	20	20	20		20	20	
Clearway parking bans							**20**	20	20				
Pedestrian refuge	Pedestrian treatments					15							
Pedestrian crossing									+50				
Pedestrian signals									+10				
Seal shoulder	Sealing and resealing					+8		15	15				
Climbing lane [overtaking lane]	Overtaking lanes										***+10***	+10	
Roadside hazards - guardrail	Barriers/guardrails												
Reconstruct superelevation on curve	Realign road												
Advisory speed sign on curve	Warning signs					10			15				
Delineation	Line marking												
Edgelines													

Table 3.6: Comparison of matrices (continued)

Treatment		Parallel lanes, turning				Vehicle hits pedestrian				Hit parked, parking vehicle			
		Estimated Crash Reduction – Percent Change											
2001 BTRE Type	2007 BTRE Type	ARRB	Astrds	WA	NSW	ARRB	Astrds	WA	NSW	ARRB	Astrds	WA	NSW
Roundabout	Roundabout	100	+20	+20	+20	40	+30	+10	10				
New traffic signal [no turn arrow]	New signals (incl. those with turning arrows)					45	30	30	0				
New signal with turn arrows							30	30	10				
Remodel signal	Modify signals/change phase	35				20	30	30					
Protected L turn lane in crossing street					40								
Improve sight lines	Clear obstacles or hazards					80	30	30	25				
Frangible posts, poles													
Roadside hazards – remove													
Street closure [one leg of cross]	Alterations to direction of traffic flow (incl. road closure or re-opening)			50		+45	50	50	30				
Street closure [close stem of Tee]				50			50	50	40				
Non-skid treatment	Non-skid treatment												
Non-skid surface													
Stagger cross intersection [right-left]	Realign intersection					60			50				
Reduce radius on left turn sliplane													
Improve/reinforce priority signs [eg Stop]	Priority sign treatments												
Ban right turns	Ban turns		50	50	70								
Ban left or U turns			50	50	70								
Improve lighting	Lighting treatments	30		10	20	10	30	30	20	65		10	
Improve route lighting							**30**	30	20			30	
Ped crossing lighting							**60**	60					
Traffic islands on approaches	Medians	35				20				35	10	10	
Extend median through intersection				100			50	50	25				
Median (midblock)							**50**	50	25				
Indented right island	Turning lanes	+75			40					65	20	20	
Painted turn lane					40						20	20	
Ban parking adjacent to intersection	Parking					35	30	30	30	75	50	50	40
Clearway parking bans							**30**	30	30		**50**	50	50
Pedestrian refuge	Pedestrian treatments					35	**50**	50	30				
Pedestrian crossing							**40**	40	+30				
Pedestrian signals							**70**	70	50				
Seal shoulder	Sealing and resealing					+16		30	3				
Climbing lane [overtaking lane]	Overtaking lanes												
Roadside hazards - guardrail	Barriers/guardrails												
Reconstruct superelevation on curve	Realign road												
Advisory speed sign on curve	Warning signs												
Delineation	Line marking												
Edgelines													

Table 3.6: Comparison of matrices (continued)

Treatment		Off road - straight				Off road straight, hit object				Loss of control, on straight road			
		Estimated Crash Reduction - Percent Change											
2001 BTRE Type	2007 BTRE Type	ARRB	Astrds	WA	NSW	ARRB	Astrds	WA	NSW	ARRB	Astrds	WA	NSW
Roundabout	Roundabout												
New traffic signal [no turn arrow]	New signals (incl. those with turning arrows)												
New signal with turn arrows													
Remodel signal	Modify signals/change phase												
Protected L turn lane in crossing street													
Improve sight lines	Clear obstacles or hazards												
Frangible posts, poles						20			40				
Roadside hazards – remove			***+80***				**80**	80	70				
Street closure [one leg of cross]	Alterations to direction of traffic flow (incl. road closure or re-opening)												
Street closure [close stem of Tee]													
Non-skid treatment	Non-skid treatment	100				0							
Non-skid surface			**10**	10	5		**10**	10	5		**10**	10	10
Stagger cross intersection [right-left]	Realign intersection												
Reduce radius on left turn sliplane													
Improve/reinforce priority signs [eg Stop]	Priority sign treatments												
Ban right turns	Ban turns												
Ban left or U turns													
Improve lighting	Lighting treatments												
Improve route lighting		10		30	25	+33		30	25	+25		30	
Ped crossing lighting													
Traffic islands on approaches	Medians												
Extend median through													
Median (midblock)													
Indented right island	Turning lanes												
Painted turn lane													
Ban parking adjacent to	Parking												
Clearway parking bans													
Pedestrian refuge	Pedestrian treatments												
Pedestrian crossing													
Pedestrian signals													
Seal shoulder	Sealing and resealing	60	**40**	20	20	15	**40**	20	20	40	**40**	20	20
Climbing lane [overtaking lane]	Overtaking lanes				30				30				30
Roadside hazards - guardrail	Barriers/guardrails	65	**30**	30		5	**30**	30	40	65	***+30***	0	
Reconstruct superelevation on curve	Realign road												
Advisory speed sign on curve	Warning signs												
Delineation	Line marking	25	**15**	15		+6	**15**	15		45	**15**	15	
Edgelines			**30**	30	15		**30**	30	15				15

Table 3.6: Comparison of matrices (continued)

Treatment		Off road - curve				Off road on curve, hit object				Loss of control on curve			
		Estimated Crash Reduction - Percent Change											
2001 BTRE Type	2007 BTRE Type	ARRB	Astrds	WA	NSW	ARRB	Astrds	WA	NSW	ARRB	Astrds	WA	NSW
Roundabout	Roundabout												
New traffic signal [no turn arrow]	New signals (incl. those with turning arrows)												
New signal with turn arrows													
Remodel signal	Modify signals/change phase												
Protected L turn lane in crossing street													
Improve sight lines	Clear obstacles or hazards												
Frangible posts, poles		100				60			40				
Roadside hazards – remove			+80				80	80	70				
Street closure [one leg of cross]	Alterations to direction of traffic flow (incl. road closure or re-opening)												
Street closure [close stem of Tee]													
Non-skid treatment	Non-skid treatment	+27				25							
Non-skid surface			10	10	30		10	10	30		10	10	30
Stagger cross intersection [right-left]	Realign intersection												
Reduce radius on left turn sliplane													
Improve/reinforce priority signs [eg Stop]	Priority sign treatments												
Ban right turns	Ban turns												
Ban left or U turns													
Improve lighting	Lighting treatments												
Improve route lighting				30	25	+20		30	25			30	25
Ped crossing lighting													
Traffic islands on approaches	Medians												
Extend median through													
Median (midblock)													
Indented right island	Turning lanes												
Painted turn lane													
Ban parking adjacent to	Parking												
Clearway parking bans													
Pedestrian refuge	Pedestrian treatments												
Pedestrian crossing													
Pedestrian signals													
Seal shoulder	Sealing and resealing	20	40	60	10	20	40	60	10	100	40	60	10
Climbing lane [overtaking	Overtaking lanes				20				20				20
Roadside hazards - guardrail	Barriers/guardrails	+7	30	30		+20	30	30	40	+20	+30	0	
Reconstruct superelevation on curve	Realign road	10	50	50	50	10	50	50	50	30	50	50	50
Advisory speed sign on	Warning signs		30	30	20	20	30	30	20		30	30	30
Delineation	Line marking	10	15	15		+18	15	15		65	15	15	
Edgelines			30	30	15		30	30	15				15

3.4 Summary and conclusion

This section of the report has outlined the method and outcomes of an analysis of crash data collected at black spot treatment locations throughout Australia. As a result of the analysis, it was possible to provide estimates of the reductions in various types of crash that can be expected following the installation of a range of treatments.

Overall, it appears that black spot treatments reduce crashes. When different crash types are considered separately however, some increases are apparent. Some of these were expected, for example adding or changing traffic signals appears to increase rear-end crashes. Others are more difficult to understand; for example, the apparent increase in opposing vehicle turning crashes following anti-skid treatments.

It is also the case that the more robust (statistically significant) findings generally corresponded with those that have been published and/or adopted in Victoria, New South Wales and Western Australia.

More in-depth analyses, where detailed site characteristics are known and can be linked to the impact of various treatments would likely serve to explain many of the counter-intuitive findings. For example, in this study the installation of barriers and guardrails was associated with an increase in a few of the crash categories. The increase in ‘off carriageway on curve, hit object’ crashes is not unexpected because given that a run-off road crash has occurred, the likelihood that an object will be hit increases, conceivably to 100%, if a guardrail is present.

4 Data analysis to determine crash reductions for multiple engineering countermeasures used at the same location

4.1 Method

Crash rate changes associated with each treatment were calculated based on a comparison of 'before' and 'after' crash rates at each site. No control site data was available. This section of the report describes the data that was used and how it was analysed.

4.1.1 Data and data preparation

The crash reduction estimates associated with various black spot treatments and treatment combinations that are presented in this report were based on data collected at projects installed throughout Australia between 1996 and 2004.

The BITRE provided ARRB with both site details (including treatment type and installation commencement and completion dates) and crash data for each site (including crash date and crash type). The treatment type at each site was assigned according to the categories presented in Table 3.1. The treatments that were included in combined treatments at a sufficient number of sites for inclusion in the analyses presented in this report are shaded in grey.

The 'before' period was taken to include any crashes that occurred before the date on which the treatment was recorded to have commenced. The 'after' period was taken to include any crashes that occurred after the date on which the treatment was said to have been completed (i.e., no 'settling-in' period was allowed for). This means that the long term crash reduction impact of some of the treatments may be underestimated due to crashes in the after period that occur because road users are unfamiliar with the treated site. Alternatively, drivers may have been more cautious at recently altered sites, resulting in a temporarily reduced crash rate. It is anticipated that these impacts would be negligible in most cases however.

Sites for which less than two years of before data or less than two years of after crash data were available were excluded from the analysis. Work conducted for DoTARS by Data Capture and Analysis (2003) had indicated that 'there was no great difference observed in the effects' when results based on an equal amount of before/after time for each site were compared with those obtained when all the available crash data was used. Based on this conclusion, all crash data was used in this analysis. Before periods and after periods ranged from 24 months (2 years) to 84 months (7 years).

The observation start and end dates for each site were assigned based on instructions provided by the BITRE. As per BITRE instruction, no observation start or end date was more than seven years remote from the treatment start or end date, respectively. Truncating the data in this way was designed to reduce the impact of extraneous variables on crash rates. For example, comparisons between crash rates seven years prior to site treatment and those which occur seven years after site treatment probably highlight factors like changes in enforcement practices and vehicle safety as well as changes in site characteristics, such as traffic volumes. Further, the broader the observation period, the more likely it is that a site will have undergone treatments other than that undertaken as part of the Black Spot Program being assessed in this project.

Crashes of all severity levels were included in the analysis. This included property damage only crashes for all states except Victoria, where property damage only crashes are not routinely recorded. Thus some differences were expected between the states in the apparent effects of specific treatments.

Results for a site were included in the analysis only if there had been at least three crashes at the site during the 'before' observation period. Presenting results based on one or two crashes per site was deemed to be potentially misleading.

Table 4.1: Treatment categories

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 (including addition of lane/s)
T13	Overtaking lane/s
T14	Barriers/guardrails
T15	Realign road length - horizontal & vertical (mid-block treatments)
T16	Realign intersection
T17	Clear obstacles or hazards
T18	Warning signs
T19	Line marking (painted & audible)
T20	Priority sign treatments
T21	Ban turns
T22	Alterations to direction of traffic flow (including road closure or re-opening)
T23	Cameras
T24	Speed limits
T25	Parking
T26	Railway crossing
T27	Grade separation
T28	Channelisation
T29	Other

4.1.2 Treatments and treatment combination

In previous phases of this work (i.e. the development of the crash reduction factor matrix), sites with more than one treatment type were simply categorised according to the 'primary' treatment type. This is reflective of the fact that engineering treatments are rarely implemented in isolation (possibly even when they are reported as such).

For the purposes of this study, however, where comparisons between single treatments and multiple treatments were important, sites with only a single treatment recorded were compared with the various treatment combinations of interest. As just noted, it is possible that many of the 'single' treatment sites reported were actually treated with more than one countermeasure that was not reported, but there was no way to identify these sites from among those sites where only one treatment really was implemented[3].

4.1.3 Calculating crash rates and crash reduction factors

For each treatment type or treatment combination, the annual crash rate during the before period (number of crashes for all sites with the treatment, or treatment combination, combined divided by the number of years of observation data for all sites with the treatment, or treatment combination, combined) was compared with the annual crash rate for the after period.

This method of devising crash rates was chosen over calculating the mean of the annual crash rates for each site because this latter approach gives equal weighting to rates based on small samples of crashes and those based on a large sample.

To determine whether observed changes between the before and after crash rates were statistically significant when either or both the before and/or after rates were based on less than 100 crashes, 95% confidence intervals were computed for both rates based on a Poisson distribution. If the confidence intervals overlapped, the difference was not considered statistically significant (at the 95% level). If they did not overlap, the difference was considered statistically significant.

If rates to be compared are based on 100 or more events, a better and less complicated alternative for testing the difference between these two rates is to construct a 95% confidence interval for the ratio (instead of the difference) between the two rates (Pennsylvania Department of Health, 2001). So, when both the before and after rates were based on more than 100 events, 95% confidence limits for the relative crash risk (based on the 'after period' crash rate relative to the 'before period' crash rate), based on the Poisson distribution were calculated. If the confidence interval included 1, then the relative risk was not statistically different from 1.

For the purposes of this study, crash rate changes were calculated for:

- any treatment pair represented by at least five sites with before AND after data
- any treatment triple represented by at least three sites with before AND after data

[3] Comparison of the reductions in 'all crashes' revealed that all but two of the statistically significant changes identified in the matrix revision project (where sites with multiple treatments were included under the category associated with the primary treatment) were within 10 percentage points of those obtained during this study when only single treatment sites were included. The exceptions were associated with sealing and resealing and priority sign treatments. Excluding multiple treatment sites for sealing and resealing resulted in a 13 percentage point reduction in the estimated benefit and excluding multiple treatment sites for Priority Sign Treatments resulted in an 11 percentage point improvement in the estimated benefit.

- any single treatment type included in the treatment pairs or treatment triples that met the above criteria (all of these were represented by at least 5 sites with before AND after data).

Table 4.2: Treatment pairs represented by sufficient sites for inclusion in analyses

Treatment code	Treatment combination	Number of sites
1st T10 2nd T19	Seal/reseal Linemarking	45
1st T10 2nd T14	Seal/reseal Barriers/guardrails	16
1st T04 2nd T07	Modify signals Turning lanes	24
1st T02 2nd T07	Median Turning lanes	12
1st T02 2nd T20	Median Priority signage	11
1st T18 2nd T19	Warning signs Linemarking	9
1st T12 2nd T10	Alter road width Seal/reseal	9
1st T02 2nd T05	Median Traffic calming	10
1st T17 2nd T10	Clear hazards Seal/reseal	8
1st T19 2nd T20	Linemarking Priority signage	6
1st T15 2nd T10	Realign road Seal/reseal	6
1st T07 2nd T08	Turning lane Ped. treatments	6
1st T02 2nd T19	Median Linemarking	6
1st T15 2nd T12	Realign road Alter road width	5
1st T07 2nd T12	Turning lane Alter road width	5

Table 4.3: Treatment triples represented by sufficient sites for inclusion in analyses

Treatment code	Treatment combination	Number of sites
1st T02 2nd T07 3rd T08	Medians Turning lanes Ped. treatment	4
1st T10 2nd T11 3rd T19	Seal/reseal Non-skid treatment Line marking	5
1st T10 2nd T17 3rd T19	Seal/reseal Clear hazards Line marking	5

Sites considered to represent treatment pairs had exactly two treatments reported (and therefore were mutually exclusive from single treatment sites and sites with three or more treatments). Similarly, sites comprising triples always had exactly three treatments reported. This means that sites were not 'double counted' and that crash reductions (or increases) that were actually the result of the third treatment in a triple were not attributed to a treatment pair (comprised of the first two treatments of the triple).

4.1.4 The crash reduction equation

There is general consensus that CRFs cannot be simply added together to arrive at a CRF for a combined treatment, but rather that some multiplicative method is required.

Roberts and Turner (2007) report that:

> Much of the available literature on the issue appears to come from the United States. The Federal Highways Administration (FHWA) has provided advice to practitioners (e.g. FHWA 1991, cited in Iowa Office of Traffic and Safety 2005) on an appropriate formula and Shen et al. (2004) report that this formula is the most widely used in the US, and this assertion appears to be supported in the literature. However, despite there being common usage of this formula, Bonneson and Lord (2005) report that there has been no research conducted to verify its appropriateness.

The general structure of the formula referred to by Roberts and Turner is as follows:

$$CRF\mathit{t} = CRF_1+(1-CRF_1)CRF_2+(1-CRF_1)(1-CRF_2)CRF_3+\ldots..$$

where

CRF_t = total crash reduction

CRF_x = individual crash reductions

As an example, if three countermeasures are being considered in one location, with respective reductions of 40%, 25% and 20%, the results would be as follows:

CRF_t = 0.4 + (1-0.4) x 0.25 + (1-0.4) x (1-0.25) x 0.2

=0.4 + 0.6 x 0.25 + 0.6 x 0.75 x 0.2

=0.4 + 0.15 + 0.09

=0.64, or a 64% reduction.

A 64% reduction in casualties is obviously less than the 85% reduction that would be calculated if each reduction was added together.

The crash reductions that can be calculated for the various treatment combinations presented in Section 4.1.3 using this formula were compared with the crash reductions that actually occurred at sites where these treatment combinations were installed. The inputs for the formula were the crash reductions known to have occurred at single treatment sites.

4.1.5 Statistical significance

As noted, the statistical significance of crash rate changes was calculated. Statistical significance is important because it provides an indication of the reliability of a finding. Findings that are statistically significant are unlikely due to chance. However, statistical significance is partly a function of sample size. While the statistical significance of the difference between before and after crash rates was determined in this project, for several treatment type/crash type combinations the limited amount of data available has meant that only very large differences in crash rate would be statistically significant. Non-significant results, although they must be interpreted with caution, should not be dismissed.

Similarly, statistical significance should not be considered to indicate a meaningful result in the absence of consideration of the effect size, indicated in this report by the ‘change in crash rate’. With a large enough sample, very small effects (or, in this case, very small changes in crash rate) can be statistically significant.

It should also be noted that with small sample sizes, outlying data points can have an undue impact on results. In this study, counter-intuitive findings were followed up with investigation of raw site and crash data, in order to identify the contribution of sites with unusual characteristics.

4.1.6 Some limitations

Ideally, the calculation of crash rates would have better taken account of exposure. However, traffic volume data was not available for the vast majority of sites, and so time was the only available measure of exposure.

No data was provided for control sites. Crash reductions from factors such as improved vehicle safety are included amongst the reductions arrived at in this study. Therefore, these reductions may be an over-estimate of the true effect. However, the main focus of this study is to assess the methodology used to combine the effectiveness of different countermeasures, and not the effectiveness of individual or groups of countermeasures per se. Although the latter issue is of concern, it is likely that the bias will be in the same direction (i.e. an over-estimate of effectiveness) in each case. Therefore, it was assumed that this lack of control group would not greatly influence the results relating to a process for combining individual benefits.

In a related vein, regression to mean has not been addressed. Nonetheless, some amelioration of regression to the mean effects will have occurred at sites for which data for several years was available.

Lastly, as already noted, it is likely that many treatments that occurred at blackspot sites were not captured in the crash data provided to the BITRE. It is unusual for a treatment to be implemented in isolation, with data from New Zealand indicating that around 80% of treated sites used multiple treatments (Turner & Roberts, in press). Yet, according to the black spot data, most sites were single treatment sites. As already highlighted, previous research has indicated an under-recording of the number of treatments used at specific sites (Hanley et al. 2000), and it is likely that this has been the case with the sample data in this current study.

4.2 Results and discussion

Table 4.4 and Table 4.5 show CRFs for the selected treatment combinations and the constituent single treatment types. CRFs as calculated using the equation presented in Section 4.1.4 are also presented. Statistically significant CRFs are presented in bold. Treatment combinations for which all the input CRFs were statistically significant are highlighted in grey. A more detailed account of the results presented below (which includes relative risk for the before/after conditions) is reported in Appendix D.

Table 4.4: Observed and calculated crash reduction factors for treatment pairs

Treatment code	Treatment combination	Change in crashes for first treatment	Change in crashes for second treatment	Change in crashes for combination treatment	Combined change predicted by equation
1st T10 2nd T19	Seal/reseal Linemarking	-1%	-3%	**- 47%**	-4%
1st T10 2nd T14	Seal/reseal Barriers/guardrails	-1%	+14%	**-1%**	+13%
1st T04 2nd T07	Modify signals Turning lanes	**-24%**	**-14%**	**-17%**	-35%
1st T02 2nd T07	Median Turning lanes	**-18%**	**-24%**	**-24%**	-38%
1st T02 2nd T20	Median Priority signage	**-18%**	-32%	**-49%**	-44%
1st T18 2nd T19	Warning signs Linemarking	+12%	-3%	-22%	+9%
1st T12 2nd T10	Alter road width Seal/reseal	**-21%**	-1%	+65%	-22%
1st T02 2nd T05	Median Traffic calming	**-18%**	**-38%**	-18%	-49%
1st T17 2nd T10	Clear hazards Seal/reseal	**-39%**	-1%	-27%	-40%
1st T19 2nd T20	Linemarking Priority signage	-3%	-32%	+8%	-34%
1st T15 2nd T10	Realign road Seal/reseal	**-35%**	-1%	-44%	-36%
1st T07 2nd T08	Turning lane Ped. treatments	**-24%**	**-23%**	**-34%**	-42%
1st T02 2nd T19	Median Linemarking	**-18%**	-3%	**-36%**	-21%
1st T15 2nd T12	Realign Road Alter road width	**-35%**	**-21%**	**-52%**	-49%
1st T07 2nd T12	Turning lane Alter road width	**-24%**	**-21%**	**-59%**	-40%

Table 4.5: Observed and calculated crash reduction factors for treatment triples

Treatment code	Treatment combination	Change in crashes for first treatment	Change in crashes for second treatment	Change in crashes for third treatment	Change in crashes for combination treatment	Combined change predicted by equation
1st T02 2nd T07 3rd T08	Medians Turning lanes Ped. treatment	**-18%**	**-24%**	**-35%**	-26%[4]	-60%
1st T10 2nd T11 3rd T19	Seal/reseal Non-skid treatment Line marking	-1%	-3%	-3%	21%	-7%
1st T10 2nd T17 3rd T19	Seal/reseal Clear hazards Line marking	-1%	**-21%**	-3%	-27%	-24%

The analyses conducted suggest, firstly, that there are site specific factors not captured in this study that impact changes in crash rate between the before and after phases of a treatment. For example, the sample of sites where a combination of sealing and resealing and linemarking were carried out experienced a statistically significant 47% reduction in crashes. The sites where sealing and resealing and linemarking were carried out individually (at 54 and 28 sites respectively) as a group, saw only very small crash reductions.

Inconsistencies such as these made it difficult to draw firm conclusions in relation to the key objectives of this project; to compare CRFs for combined treatments arrived at via a commonly applied equation to those actually realised. When considering only the examples where statistically significant 'inputs' were available to insert into the formula (six treatment pairs and one treatment triple), the mean difference between the results obtained using the formula and those realised was 13 percentage points, suggesting that, for this sample, on average, the formula tended to overestimate the magnitude of the reductions realised.

However, in two cases where all the input CRFs were statistically significant, the equation actually produced an estimated CRF less than that realised (realign road and alter road width, and turning lane and alter road width). For the sample overall, the variation in the difference between the estimated and actual CRF was large, ranging from 3 to 34 percentage points.

[4] The initial sample for this treatment combination indicated that it produced a 55% increase in crashes. Inspection of the raw data indicated that this was due to one site, where the crash rate had increased 74%. The apparent increase was due solely to property damage only crashes however, as the rate of serious injury and minor injury crashes had actually decreased at the site (and there were no fatal crashes reported at this site). The data from this site was not included in the results presented in the table.

4.3 Summary and recommendations

In this section of the report, the crash reductions achieved with 18 black spot treatment combinations (15 treatment pairs and 3 treatment triples) were compared with the reductions predicted by a widely used formula designed to predict crash reductions associated with multiple countermeasures based on the CRF for each countermeasure.

Overall, it is likely that limited sample sizes combined with the fact that site characteristics only account for a component of crash risk resulted in some unexpected findings which emerged from this study. It is also possible that recording inconsistencies, primarily the under-reporting of 'non-primary treatments' resulted in some irregular findings. For example, where a treatment pair has a CRF several times the sum of the individual CRFs for each treatment, and a CRF much greater than that predicted by the formula applied.

Although there is some evidence that the multiple countermeasure crash reduction formula is more likely to 'overestimate' actual CRFs than it is to result in an 'underestimation', further work is required in order to draw any definitive conclusions. It is likely that different combinations of treatments may act in different ways. Some may have an additive effect, or provide a greater benefit overall than the sum of each treatment. Others may produce a diminishing return, as they each act in a similar way to improve safety (for example, different delineation devices). Still other treatments may reduce the overall effectiveness when added. Therefore, it is recommended that careful thought be given to calculating the combined benefit of different treatments on a case-by-case basis. When applying two or more treatments that act in similar ways to reduce risk, some generic formula involving a decreasing benefit may provide guidance on the expected degree of crash reduction. However, other treatment combinations will not adhere to the principles of such a formula.

It is apparent that the quality of treatment data recorded in Australia is less than adequate. Based on information from overseas (including New Zealand, where detailed monitoring information is routinely collected) it appears that many sites recorded here as having single treatments are more likely to have been treated with combinations of treatments. Improvements are required in record keeping to ensure that accurate evaluations of road safety treatments are possible. Further to this, it may be appropriate for jurisdictions to instigate monitoring databases to help improve the ease and accuracy of conducting future evaluations of road safety treatments.

As concluded in Turner and Roberts (in press), it appears that there are errors in treatment evaluation at two key stages. In order to determine the effectiveness of individual treatments at a site (or across a network), combinations of treatments are often disaggregated via statistical techniques to estimate the relative effect of individual treatments. There are likely to be errors in this process (especially because as has been seen, often treatments remain unrecorded). It is likely that the effectiveness of treatments is over-estimated due to this error. In addition, when aggregating the effectiveness of two or more treatments, inaccuracies are likely to occur due to errors in the process typically applied (specifically, the formula tested in this report). A more useful approach would be to collect information on the most commonly used 'groups' of treatments, and determine the overall effectiveness based on these groups. It is recommended that such information be collected and assessed in future.

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Appendix A – Treatment type by State

Treatment category/State	NSW	Vic	Qld	WA	SA	Tas	ACT	NT	Total
Roundabout (T01)	92	67	38	58	15	10	1	2	283
Medians (T02)	17	30	4	28	5	6	2	7	99
New signals (incl. those with turning arrows) (T03)	30	32	26	16	4	4	1	2	115
Modify existing signals/change phase (T04)	26	83	52	35	11	2	0	0	209
Traffic calming (T05)	13	3	1	2	0	0	0	0	19
Lighting (T06)	1	9	3	10	0	0	0	3	26
Turning lanes (T07)	25	31	14	50	14	6	2	2	144
Pedestrian treatments (T08)	13	20	2	4	2	3	0	4	48
Bicycle treatments (T09)	0	1	2	1	0	0	0	0	4
Sealing & resealing (incl. previously unpaved roads) (T10)	5	99	17	15	17	2	0	2	157
Non-skid treatment (T11)	3	18	3	21	1	1	0	0	47
Alter road width (incl. adding lane/s) (T12)	6	12	9	6	7	0	0	1	41
Overtaking lane/s (T13)	0	1	1	0	0	0	0	1	3
Barriers/guardrails (T14)	24	11	2	1	20	2	0	0	60
Realign road - horizontal & vertical (mid-block) (T15)	17	7	2	2	2	0	0	0	30
Realign intersection (T16)	6	18	6	19	1	0	0	0	50
Clear obstacles or hazards (T17)	2	6	4	5	2	0	0	0	19
Warning signs (T18)	4	6	0	4	1	4	0	1	20
Line marking (painted & audible) (T19)	3	27	1	19	2	1	1	0	54
Priority sign treatments (T20)	7	4	7	7	0	0	0	0	25
Ban turns (T21)	1	3	0	0	0	0	0	0	4
Alter direction of traffic flow (incl. road closure or re-opening) (T22)	4	3	7	7	2	0	0	0	23
Parking (T25)	1	2	0	0	0	0	0	0	3
Channelisation (T28)	1	4	4	1	0	0	0	0	10
Total	301	497	205	311	106	41	7	25	1493

There were no data for ‘camera’, ‘speed limit’ or ‘grade separation’ sites.

Appendix B – Confidence Intervals (results for specific crash types)

Treatment type	Crash type	Annual crash rate		Crash rate change	% change	Relative risk	95% confidence limits for relative risk		Total crashes
		Before	After				Lower limit	Upper limit	
Roundabout (T01)	Parallel lanes, turning	0.57	-	-0.57	-100	-	-	-	12
	U turn	0.43	-	-0.43	-100	-	-	-	3
	Off cway on straight hit object	1.28	0.29	-0.99	-77	0.23	0.1	0.7	37
	Off cway on curve	0.79	0.19	-0.59	-76	0.24	0.1	1.7	12
	Opposing vehicle, turning	1.53	0.51	-1.02	-67	0.33	0.3	0.4	550
	Out of control on curve	1.14	0.38	-0.76	-67	0.33	0.1	1.7	10
	Hit parked vehicle	0.86	0.29	-0.56	-66	0.34	0.1	2.8	7
	Intersection; from adjacent	1.83	0.79	-1.05	-57	0.4	0.39	0.47	3400
	Off cway on curve, hit object	0.62	0.36	-0.26	-42	0.58	0.3	1.3	34
	Pedestrian	0.59	0.35	-0.24	-41	0.59	0.2	2	16
	Hit permanent obstruction	0.77	0.49	-0.27	-36	0.64	0.2	1.9	25
	Lane change	0.75	0.63	-0.12	-16	0.84	0.4	1.7	43
	Head on	0.43	0.38	-0.05	-11	0.89	0.2	4.3	11
	Rear end	1.44	1.6	0.16	11	1.1	0.96	1.3	702
	Vehicle leaving driveway	3.43	4.98	1.56	45	1.45	0.8	2.8	41

Treatment type	Crash type	Annual crash rate		Crash rate change	% change	Relative risk	95% confidence limits for relative risk		Total crashes
		Before	After				Lower limit	Upper limit	
Medians (T02)	Parallel lanes, turning	0.72	0.45	-0.27	-37	0.63	0.3	1.5	41
	Head on	0.64	0.42	-0.23	-35	0.65	0.2	3.1	11
	Hit parked vehicle	2.86	1.86	-1	-35	0.65	0.3	1.4	33
	Off cway on straight hit object	1.26	0.83	-0.44	-34	0.66	0.4	1.1	63
	Intersection; from adjacent	1.6	1.05	-0.55	-35	0.7	0.58	0.74	1207
	Hit permanent obstruction	0.64	0.47	-0.17	-27	0.73	0.2	2.3	15
	Lane change	1.8	1.39	-0.42	-23	0.77	0.6	1.1	168
	Pedestrian	0.76	0.62	-0.14	-18	0.82	0.4	1.9	26
	Rear end	3.78	3.53	-0.25	-7	0.9	0.85	1.03	1626
	Opposing vehicle, turning	0.96	0.86	-0.09	-10	0.9	0.7	1.2	234
	Off cway on curve, hit object	0.79	0.78	-0.01	-1	0.99	0.5	2.3	30
	Overtaking, same direction	0.57	0.75	0.18	31	1.31	0.3	6.6	10
	Vehicle leaving driveway	0.43	1.5	1.07	249	3.5	0.9	14.7	10
New signals (incl. those with turning arrows) (T03)	Head on	0.5	-	-0.5	-100	-	-	-	7
	U turn	0.6	-	-0.6	-100	-	-	-	4
	Intersection; from adjacent	2.68	0.6	-2.08	-78	0.22	0.19	0.26	1750
	Vehicle leaving driveway	1	0.24	-0.76	-76	0.24	0	1.9	8
	Hit permanent obstruction	0.57	0.15	-0.42	-73	0.27	0	2.7	5
	Pedestrian	0.65	0.34	-0.31	-47	0.53	0.3	1.1	51
	Off cway on straight hit object	0.51	0.31	-0.2	-39	0.61	0.3	1.4	32
	Off cway on curve, hit object	0.43	0.33	-0.1	-22	0.78	0.1	9.7	4
	Opposing vehicle, turning	1.53	1.32	-0.2	-14	0.87	0.75	1.01	783
	Lane change	0.43	0.46	0.03	8	1.08	0.2	8	6
	Rear end	1.95	2.52	0.57	29	1.29	1.14	1.47	994

Treatment type	Crash type	Annual crash rate		Crash rate change	% change	Relative risk	95% confidence limits for relative risk		Total crashes
		Before	After				Lower limit	Upper limit	
Modify signals/change phase (T04)	Off cway on curve, hit object	0.46	-	-0.46	-100	-	-	-	3
	U turn	0.44	-	-0.44	-100	-	-	-	12
	Out of control on straight	0.6	0.14	-0.46	-76	0.24	0	2.4	5
	Off cway on straight hit object	0.58	0.26	-0.32	-55	0.44	0.26	0.78	83
	Opposing vehicle, turning	2.46	1.43	-1.03	-42	0.58	0.54	0.62	3743
	Parallel lanes, turning	0.54	0.35	-0.19	-35	0.65	0.3	1.3	39
	Intersection; from adjacent	1.33	0.92	-0.41	-31	0.69	0.63	0.77	1749
	Vehicle leaving driveway	0.55	0.42	-0.13	-24	0.77	0.2	3.3	16
	Pedestrian	0.76	0.60	-0.16	-21	0.8	0.6	1.1	238
	Lane change	0.86	0.91	0.04	5	1.05	0.8	1.4	240
	Rear end	3.19	3.60	0.41	13	1.13	1.07	1.19	4959
	Hit permanent obstruction	1.07	1.65	0.58	54	1.54	0.7	3.3	31
Traffic calming (T05)	U turn	1.43	0.33	-1.1	-77	0.23	0	1.6	11
	Lane change	0.86	0.27	-0.58	-68	0.32	0.1	2.6	7
	Parallel lanes, turning	0.71	0.27	-0.44	-62	0.38	0.1	3.4	6
	Opposing vehicle, turning	1.94	1.06	-0.87	-45	0.55	0.3	0.9	82
	Intersection; from adjacent	1.16	0.83	-0.33	-29	0.71	0.4	1.2	97
	Pedestrian	0.67	0.65	-0.02	-3	0.97	0.4	2.3	30
	Off cway on straight hit object	0.43	0.57	0.14	33	1.33	0.3	6.2	9
	Rear end	1.32	2.22	0.91	69	1.69	1.1	2.7	87

Treatment type	Crash type	Annual crash rate		Crash rate change	% change	Relative risk	95% confidence limits for relative risk		Total crashes
		Before	After				Lower limit	Upper limit	
Lighting (T06)	Overtaking, same direction	0.52	-	-0.52	-100	-	-	-	11
	Hit parked vehicle	0.63	0.21	-0.41	-66	0.34	0.1	2.1	23
	Intersection; from adjacent	2.28	1.44	-0.84	-37	0.6	0.52	0.78	448
	Vehicle leaving driveway	1.1	0.74	-0.35	-32	0.68	0.3	1.5	32
	Parallel lanes, turning	0.61	0.43	-0.18	-30	0.7	0.3	1.7	25
	U turn	0.64	0.51	-0.13	-20	0.8	0.3	2.1	24
	Pedestrian	1.09	0.99	-0.1	-9	0.91	0.6	1.3	140
	Off cway on straight	0.71	0.65	-0.06	-9	0.92	0.2	4.7	8
	Rear end	3.84	4.17	0.33	9	1.1	0.94	1.25	791
	Off cway on curve, hit object	0.95	1.12	0.17	18	1.18	0.6	2.5	33
	Out of control on straight	0.57	0.71	0.14	25	1.25	0.3	6.3	9
	Opposing vehicle, turning	0.96	1.25	0.29	30	1.3	0.99	1.72	211
	Off cway on straight hit object	1.18	1.56	0.38	33	1.33	0.9	1.9	120
	Lane change	1.22	1.79	0.56	46	1.46	1	2.2	104
	Head on	0.57	1.71	1.14	200	3	1.1	8.5	20

Treatment type	Crash type	Annual crash rate		Crash rate change	% change	Relative risk	95% confidence limits for relative risk		Total crashes
		Before	After				Lower limit	Upper limit	
Turning lanes (T07)	Hit parked vehicle	1.1	0.32	-0.78	-71	0.29	0.1	0.8	27
	Off cway on curve, hit object	0.57	0.17	-0.4	-70	0.3	0	3	5
	Out of control on straight	0.5	0.23	-0.27	-55	0.45	0.1	3.5	8
	Pedestrian	0.57	0.34	-0.24	-41	0.59	0.3	1.5	26
	Hit permanent obstruction	0.73	0.65	-0.09	-12	0.88	0.5	1.7	49
	Intersection; from adjacent	1.82	1.62	-0.2	-11	0.9	0.81	0.98	1998
	Opposing vehicle, turning	1.83	1.69	-0.14	-8	0.9	0.82	1.04	1149
	Off cway on straight hit object	0.52	0.47	-0.05	-10	0.9	0.4	2	31
	Head on	0.43	0.4	-0.03	-7	0.93	0.1	8.1	5
	U turn	0.43	0.43	0	0	1	0.2	7.5	6
	Rear end	4.16	4.41	0.25	6	1.06	1.0	1.12	4586
	Lane change	1.14	1.33	0.19	17	1.17	0.9	1.6	219
	Vehicle leaving driveway	0.62	0.74	0.12	19	1.19	0.5	3.1	21
	Parallel lanes, turning	0.76	1.33	0.57	75	1.75	0.7	4.7	22
Pedestrian treatments (T08)	Intersection; from adjacent	1.71	0.84	-0.87	-51	0.5	0.4	0.6	279
	Lane change	2.43	1.38	-1.05	-43	0.57	0.4	0.9	114
	Off cway on straight hit object	0.42	0.37	-0.05	-11	0.87	0.1	7.6	5
	Pedestrian	1.24	0.78	-0.46	-37	0.63	0.5	0.8	264
	Hit parked vehicle	1.96	1.22	-0.74	-38	0.62	0.4	1.1	75
	Opposing vehicle, turning	2.12	1.55	-0.57	-27	0.7	0.7	0.9	328
	Rear end	2.41	2.02	-0.39	-16	0.8	0.7	0.98	638
	U turn	0.68	0.73	0.05	7	1.07	0.5	2.6	27
	Vehicle leaving driveway	0.86	1.29	0.43	50	1.5	0.6	3.9	21

Treatment type	Crash type	Annual crash rate		Crash rate change	% change	Relative risk	95% confidence limits for relative risk		Total crashes
		Before	After				Lower limit	Upper limit	
Bicycle treatments (T09)	Vehicle leaving driveway	1	0.29	-0.71	-71	0.29	0.1	1.5	9
	Off cway on straight hit object	1	0.71	-0.29	-29	0.71	0.2	2.6	12
	Pedestrian	0.43	0.43	0	0	1	0.2	7.5	6
	Intersection; from adjacent	3.37	3.46	0.08	3	1.02	0.7	1.5	124
	Opposing vehicle, turning	1.76	2.71	0.95	54	1.54	0.8	3	42
	Rear end	1.54	2.91	1.37	89	1.89	1.2	3	77
Sealing & resealing (Incl. sealing unpaved roads) (T10)	Out of control on curve	1.29	-	-1.29	-100	-	-	-	9
	Parallel lanes, turning	0.43	-	-0.43	-100	-	-	-	6
	U turn	0.5	0.2	-0.3	-60	0.4	0.1	1.3	18
	Off cway on straight	0.74	0.3	-0.44	-60	0.4	0.2	0.7	68
	Hit parked vehicle	0.71	0.34	-0.38	-53	0.47	0.1	2.9	7
	Head on	0.86	0.47	-0.39	-45	0.55	0.4	0.8	165
	Out of control on straight	0.71	0.43	-0.28	-40	0.6	0.3	1.6	30
	Vehicle leaving driveway	0.5	0.39	-0.11	-21	0.79	0.2	4.1	9
	Off cway on straight hit object	0.77	0.61	-0.16	-21	0.79	0.6	1	288
	Off cway on curve	0.7	0.56	-0.14	-20	0.8	0.5	1.2	112
	Off cway on curve, hit object	0.86	0.71	-0.15	-17	0.8	0.66	1.04	349
	Lane change	0.73	0.61	-0.12	-16	0.84	0.5	1.5	61
	Intersection; from adjacent	0.94	0.86	-0.08	-9	0.9	0.71	1.17	269
	Rear end	1.53	1.66	0.13	8	1.1	0.93	1.26	693
	Pedestrian	0.57	0.66	0.09	16	1.16	0.5	2.9	23
	Opposing vehicle, turning	1.07	1.32	0.25	23	1.23	0.9	1.7	135
	Hit permanent obstruction	0.57	0.72	0.14	25	1.25	0.6	2.6	36

Treatment type	Crash type	Annual crash rate		Crash rate change	% change	Relative risk	95% confidence limits for relative risk		Total crashes
		Before	After				Lower limit	Upper limit	
Non-skid treatment (T11)	Hit permanent obstruction	2.14	-	-2.14	-100	-	-	-	15
	Off cway on straight	0.57	-	-0.57	-100	-	-	-	4
	Off cway on curve, hit object	1.2	0.87	-0.33	-28	0.72	0.5	1.2	86
	Head on	1.09	0.92	-0.17	-16	0.84	0.4	1.9	31
	Rear end	5.17	4.88	-0.28	-6	0.9	0.87	1.03	2275
	Off cway on straight hit object	0.57	0.57	0	-1	0.99	0.5	2	39
	Lane change	0.89	0.9	0.01	2	1.02	0.7	1.6	89
	Intersection; from adjacent	1.1	1.29	0.19	17	1.2	0.96	1.43	420
	Opposing vehicle, turning	1.69	2.05	0.36	21	1.2	1.02	1.44	536
	Off cway on curve	0.79	1	0.21	27	1.27	0.4	4.8	14
	Pedestrian	0.5	0.71	0.21	43	1.43	0.4	5.2	12
	Parallel lanes, turning	0.71	1.56	0.84	118	2.18	0.6	8.1	15
Alter road width (incl. adding lanes) (T12)	Pedestrian	0.43	-	-0.43	-100	-	-	-	3
	Out of control on straight	0.43	-	-0.43	-100	-	-	-	3
	Lane change	0.8	0.36	-0.44	-55	0.45	0.1	1.5	15
	Out of control on curve	1.6	0.86	-0.74	-46	0.54	0.2	1.8	14
	Opposing vehicle, turning	1.56	0.98	-0.57	-37	0.63	0.4	1	92
	Off cway on straight hit object	1.1	0.71	-0.4	-36	0.64	0.4	1.1	69
	Rear end	1.98	1.39	-0.59	-30	0.7	0.5	1	193
	Head on	1.21	1.02	-0.19	-16	0.84	0.5	1.5	55
	Off cway on straight	0.62	0.71	0.1	16	1.16	0.3	4.2	12
	Intersection; from adjacent	1.2	1.67	0.46	39	1.39	1	1.9	192
	Off cway on curve, hit object	1.3	2.53	1.22	94	1.94	1.4	2.7	174
	Off cway on curve	0.85	2.68	1.83	216	3.16	1.7	5.8	49

Treatment type	Crash type	Annual crash rate		Crash rate change	% change	Relative risk	95% confidence limits for relative risk		Total crashes
		Before	After				Lower limit	Upper limit	
O/taking lane (T13)	Rear end	0.43	0.57	0.14	33	1.33	0.2	9.1	7
	Intersection; from adjacent	1	1.86	0.86	86	1.86	0.6	5.5	20
Barriers/guardrails (T14)	Hit parked vehicle	0.71	-	-0.71	-100	-	-	-	10
	Pedestrian	1.9	0.57	-1.32	-70	0.3	0.1	0.7	27
	Out of control on straight	0.93	0.33	-0.6	-64	0.36	0.1	0.9	21
	Parallel lanes, turning	0.65	0.36	-0.29	-45	0.55	0.2	1.7	16
	U turn	0.9	0.57	-0.33	-36	0.64	0.2	1.9	17
	Hit permanent obstruction	0.95	0.74	-0.21	-22	0.78	0.5	1.3	82
	Intersection; from adjacent	2.23	1.88	-0.35	-16	0.8	0.67	1.06	326
	Opposing vehicle, turning	1.05	0.85	-0.2	-19	0.81	0.4	1.6	41
	Lane change	1.58	1.35	-0.23	-15	0.85	0.5	1.4	82
	Rear end	2.14	1.99	-0.15	-7	0.9	0.76	1.14	382
	Off cway on straight hit object	2.53	2.45	-0.09	-3	1	0.73	1.28	205
	Off cway on curve	2.55	2.74	0.19	7	1.07	0.8	1.5	175
	Out of control on curve	1.32	1.57	0.25	19	1.19	0.7	2	62
	Off cway on curve, hit object	3.2	3.85	0.65	20	1.2	1.02	1.42	583
	Off cway on straight	1.58	2.15	0.57	36	1.36	0.9	2.2	83
	Head on	1.76	2.79	1.03	58	1.58	1.2	2.2	174

Treatment type	Crash type	Annual crash rate		Crash rate change	% change	Relative risk	95% confidence limits for relative risk		Total crashes
		Before	After				Lower limit	Upper limit	
Realign road - horizontal & vertical (mid-block treatments) (T15)	Off cway on straight	0.43	-	-0.43	-100	-	-	-	3
	Intersection; from adjacent	0.9	0.32	-0.59	-65	0.35	0.1	1.2	22
	Off cway on straight hit object	0.73	0.31	-0.42	-57	0.43	0.2	1	33
	Out of control on straight	0.76	0.4	-0.37	-48	0.52	0.1	4.5	5
	Out of control on curve	0.57	0.4	-0.17	-30	0.7	0.1	4.9	6
	Off cway on curve	0.91	0.81	-0.1	-11	0.89	0.5	1.7	47
	Off cway on curve, hit object	1.45	1.29	-0.16	-11	0.89	0.6	1.2	171
	Rear end	0.57	0.58	0.01	2	1.02	0.2	7.1	6
	Head on	1.57	1.75	0.18	12	1.12	0.7	1.8	74
	Out of control on straight	0.57	-	-0.57	-100	-	-	-	4
	Pedestrian	0.43	0.16	-0.26	-62	0.38	0	4.8	4
	Off cway on straight hit object	0.64	0.38	-0.26	-41	0.59	0.3	1.4	27
	Intersection; from adjacent	1.3	1.12	-0.19	-14	0.9	0.71	1.03	492
	Opposing vehicle, turning	1.95	1.75	-0.2	-10	0.9	0.7	1.14	282
	Rear end	9.21	8.78	-0.43	-5	1	0.88	1.04	2154
	Parallel lanes, turning	0.5	0.54	0.04	8	1.08	0.3	3.7	13
	Lane change	0.91	1.63	0.72	78	1.78	1.1	2.9	73
Realign intersection (T16)	Out of control on straight	0.57	.	-0.57	-100	.	.	.	4
	Pedestrian	0.43	0.16	-0.26	-62	0.38	0	4.8	4
	Off cway on straight hit object	0.64	0.38	-0.26	-41	0.59	0.3	1.4	27
	Intersection; from adjacent	1.3	1.12	-0.19	-14	0.9	0.71	1.03	492
	Opposing vehicle, turning	1.95	1.75	-0.2	-10	0.9	0.7	1.14	282
	Rear end	9.21	8.78	-0.43	-5	1	0.88	1.04	2154
	Parallel lanes, turning	0.5	0.54	0.04	8	1.08	0.3	3.7	13
	Lane change	0.91	1.63	0.72	78	1.78	1.1	2.9	73

Treatment type	Crash type	Annual crash rate		Crash rate change	% change	Relative risk	95% confidence limits for relative risk		Total crashes
		Before	After				Lower limit	Upper limit	
Clear obstacles or hazards (T17)	Off cway on curve	0.43	-	-0.43	-100	-	-	-	3
	Head on	0.86	-	-0.86	-100	-	-	-	6
	Vehicle leaving driveway	0.57	-	-0.57	-100	-	-	-	4
	Overtaking, same direction	0.43	-	-0.43	-100	-	-	-	3
	Pedestrian	1	0.2	-0.8	-80	0.2	0	1.6	8
	Out of control on curve	0.71	0.15	-0.56	-78	0.22	0	1.9	6
	Off cway on curve, hit object	1.14	0.46	-0.68	-60	0.4	0.1	1.7	11
	Opposing vehicle, turning	1.33	0.77	-0.56	-42	0.58	0.2	1.5	23
	Intersection; from adjacent	1.17	0.77	-0.4	-34	0.66	0.5	1	127
	Off cway on straight hit object	0.74	0.59	-0.15	-21	0.79	0.4	1.6	43
	Rear end	1.8	1.6	-0.2	-11	0.89	0.6	1.3	111
	Lane change	0.71	0.8	0.08	12	1.12	0.3	5.2	9
Warning signs (T18)	Pedestrian	0.57	-	-0.57	-100	-	-	-	4
	Out of control on straight	2.16	0.29	-1.87	-87	0.13	0	0.8	7
	Opposing vehicle, turning	2.94	1.24	-1.7	-58	0.42	0.2	0.8	53
	Off cway on curve, hit object	0.92	0.73	-0.18	-20	0.8	0.2	3	14
	Intersection; from adjacent	1.36	1.09	-0.27	-20	0.8	0.5	1.2	104
	Rear end	1.77	1.64	-0.14	-8	0.92	0.6	1.3	137
	Off cway on straight hit object	1.3	1.43	0.13	10	1.1	0.2	6.2	13
	Head on	1	1.22	0.22	22	1.22	0.3	5.3	10

Treatment type	Crash type	Annual crash rate		Crash rate change	% change	Relative risk	95% confidence limits for relative risk		Total crashes
		Before	After				Lower limit	Upper limit	
Line marking (painted & audible) (T19)	Out of control on curve	0.43	0.14	-0.29	-67	0.33	0.1	2.4	10
	Pedestrian	1	0.49	-0.51	-51	0.49	0.3	0.9	52
	Out of control on straight	1.35	0.69	-0.67	-49	0.51	0.3	0.8	109
	Vehicle leaving driveway	0.5	0.29	-0.21	-43	0.57	0.1	3	9
	Parallel lanes, turning	4.52	2.6	-1.92	-42	0.58	0.4	0.8	221
	Hit parked vehicle	0.43	0.29	-0.14	-33	0.67	0.1	5.8	5
	Off cway on straight	1.66	1.21	-0.45	-27	0.73	0.5	1	180
	U turn	0.5	0.37	-0.13	-26	0.74	0.3	2.3	18
	Head on	0.84	0.71	-0.13	-15	0.85	0.5	1.4	86
	Lane change	2.42	2.23	-0.19	-8	0.9	0.74	1.15	328
	Off cway on curve	0.71	0.65	-0.05	-8	0.92	0.6	1.5	75
	Hit permanent obstruction	0.86	0.86	0	0	1	0.3	3.7	12
	Intersection; from adjacent	2.54	2.49	-0.06	-2	1	0.84	1.14	703
	Rear end	5.23	5.09	-0.14	-3	1	0.88	1.08	1477
	Off cway on straight hit object	2.51	2.65	0.14	6	1.1	0.91	1.23	707
	Overtaking, same direction	1.11	1.28	0.18	16	1.16	0.6	2.1	49
	Off cway on curve, hit object	1.08	1.27	0.19	18	1.2	0.92	1.5	275
	Opposing vehicle, turning	1.05	1.27	0.21	20	1.2	0.9	1.6	212
Priority sign treatments (T20)	Intersection; from adjacent	1.55	1.2	-0.35	-23	0.8	0.61	0.98	309
	Opposing vehicle, turning	1.31	1.12	-0.2	-15	0.85	0.5	1.4	74
	Rear end	3.5	3.62	0.12	3	1	0.8	1.33	254
	Off cway on straight hit object	0.57	0.59	0.01	3	1.03	0.2	7.2	6
	Lane change	0.43	1.47	1.04	242	3.42	0.6	22	8

Treatment type	Crash type	Annual crash rate		Crash rate change	% change	Relative risk	95% confidence limits for relative risk		Total crashes
		Before	After				Lower limit	Upper limit	
Ban turns (T21)	Intersection; from adjacent	0.86	-	-0.86	-100	-	-	-	24
	Opposing vehicle, turning	0.86	-	-0.86	-100	-	-	-	6
	Rear end	0.43	-	-0.43	-100	-	-	-	3
Alter direction of traffic flow (incl. road closure or re-opening) (T22)	Lane change	0.71	0.19	-0.52	-73	0.27	0	2.4	6
	Intersection; from adjacent	2.07	1.18	-0.89	-43	0.57	0.4	0.7	348
	Off cway on straight hit object	0.86	0.59	-0.27	-32	0.68	0.2	3.2	9
	Rear end	1.76	1.39	-0.37	-21	0.79	0.5	1.2	116
	Pedestrian	0.63	0.91	0.28	45	1.45	0.4	6	11
	Opposing vehicle, turning	0.57	1.43	0.86	152	2.52	1.2	5.5	31

Treatment type	Crash type	Annual crash rate		Crash rate change	% change	Relative risk	95% confidence limits for relative risk		Total crashes
		Before	After				Lower limit	Upper limit	
Parking (T25)	Hit parked vehicle	1.78	0.43	-1.35	-76	0.24	0.1	1	12
	Opposing vehicle, turning	0.64	0.22	-0.42	-65	0.35	0.1	1.4	12
	Rear end	1.29	0.45	-0.84	-65	0.35	0.1	0.9	24
	U turn	0.43	0.16	-0.27	-63	0.37	0	4.6	4
	Pedestrian	2	1.26	-0.74	-37	0.63	0.3	1.6	22
	Off cway on straight hit object	0.43	0.32	-0.11	-26	0.74	0.1	6.4	5
	Intersection; from adjacent	0.71	1	0.29	40	1.4	0.4	5.6	12
Channelisation (T28)	Opposing vehicle, turning	0.55	-	-0.55	-100	-	-	-	3
	Rear end	1.59	0.21	-1.38	-87	0.13	0	1	10
	Intersection; from adjacent	1.8	1.27	-0.53	-29	0.71	0.5	1.1	98
	Off cway on straight hit object	0.6	0.8	0.2	33	1.33	0.2	9.9	6

Appendix C – Confidence intervals (all crashes combined)

The figures presented below include statistics based on the crash types that could not be grouped into one of the categories used throughout the rest of this project.

Treatment type	Annual crash rate		Crash rate change	% change	Relative risk	95% confidence limits for relative risk		Total crashes
	Before	After				Lower limit	Upper limit	
Roundabout (T01)	2.48	1.22	-1.26	-50.84	.50	.46	.53	4998
Medians (T02)	3.85	3.24	-.61	-15.85	.80	.79	.90	3651
New signals (incl. those with turning arrows) (T03)	3.96	2.29	-1.67	-42.11	.60	.54	.62	3710
Modify existing signals/change phase (T04)	5.50	4.40	-1.09	-19.89	.80	.77	.83	11371
Traffic calming (T05)	2.81	2.31	-.50	-17.82	.80	.65	1.05	354
Lighting (T06)	8.39	7.11	-1.28	-15.25	.80	.78	.92	2191
Turning lanes (T07)	6.09	5.91	-.17	-2.86	1.00	.93	1.02	8307
Pedestrian treatments (T08)	5.17	4.17	-1.00	-19.31	.80	.73	.89	1926
Bicycle treatments (T09)	6.04	6.48	.44	7.28	1.10	.84	1.36	283
Sealing & resealing (Incl. previously unpaved roads) (T10)	2.21	1.89	-.32	-14.39	.90	.79	.93	2441
Non-skid treatment (T11)	6.87	6.93	.06	.83	1.00	.94	1.08	3683
Alter road width (incl. adding lane/s) (T12)	3.11	3.42	.32	10.19	1.10	.97	1.26	921
Overtaking lane/s (T13)	.93	2.43	1.50	161.54	2.60	1.17	5.86	30
Barriers/guardrails (T14)	5.80	6.98	1.18	20.37	1.20	1.11	1.30	2464
Realign road - horizontal & vertical (mid-block) (T15)	2.09	1.48	-.61	-29.23	.70	.57	.88	367
Realign intersection (T16)	7.35	7.99	.63	8.60	1.10	1.01	1.17	3173
Clear obstacles or hazards (T17)	2.33	1.47	-.86	-37.10	.60	.50	.79	361
Warning signs (T18)	3.02	2.58	-.44	-14.51	.90	.69	1.06	369
Line marking (painted & audible) (T19)	9.31	8.97	-.34	-3.63	1.00	.91	1.02	5023
Priority sign treatments (T20)	2.94	2.32	-.62	-21.19	.80	.67	.92	668
Ban turns (T21)	1.18	0	-1.18	-100	.	.	.	33
Alter direction of traffic flow (incl. road closure or re-opening) (T22)	2.93	1.99	-.94	-32.19	.70	.56	.82	537
Parking (T25)	3.57	1.97	-1.60	-44.88	.60	.37	.83	108
Channelisation (T28)	2.25	1.41	-.84	-37.22	.60	.43	.93	117

Appendix D – Crash reduction factors: Detailed results

Table A1: CRF results for treatment pairs

Treatment code	Treatment combination	Annual crash rate		Crash rate change	% change	Relative risk	95% confidence limits for relative risk		Total crashes
		Before	After				Lower limit	Upper limit	
1st T10 2nd T19	Seal/reseal linemarking	1.57	.83	-0.74	**-47**	0.5	.45	.63	664
1st T10 2nd T14	Seal/reseal Barriers/guardrails	3.88	3.86	-0.00	-.59	1.0	.84	1.18	638
1st T04 2nd T07	Modify signals Turning lanes	6.10	5.07	-1.03	**-17**	.80	.75	.92	1595
1st T02 2nd T07	Median Turning lanes	4.11	3.14	-0.97	**-24**	.80	.63	.92	493
1st T02 2nd T20	Median Priority signage	2.04	1.04	-1.00	**-49**	.50	.37	.72	186
1st T18 2nd T19	Warning signs Linemarking	1.57	1.23	-.034	-22	.80	.57	1.07	172
1st T12 2nd T10	Alter road width Seal/reseal	4.00	6.60	2.6	65	1.7	1.37	1.99	467
1st T02 2nd T05	Median Traffic calming	1.44	1.88	-.26	-18	.80	.57	1.18	143
1st T17 2nd T10	Clear hazards Seal/reseal	1.14	.84	-.30	-27	.70	.50	1.09	111
1st T19 2nd T20	Linemarking Priority signage	1.79	1.93	.14	8	1.10	.78	1.50	154
1st T15 2nd T10	Realign road Seal/reseal	1.69	.95	-.74	**-44**	.60	.35	.93	81
1st T07 2nd T08	Turning lane Ped. treatments	3.30	2.19	-1.11	**-34**	.70	.49	.90	195
1st T02 2nd T19	Median Linemarking	6.76	4.30	-2.46	**-36**	.60	.51	.79	374
1st T15 2nd T12	Realign road Alter road width	1.74	.83	-.91	**-52**	.50	.29	.79	68
1st T07 2nd T12	Turning lane Alter road width	2.48	1.02	-1.46	**-59**	.40	.26	.66	93

Table A2: CRF results for treatment triples

Treatment code	Treatment combination	Annual crash rate		crash rate change	% change	Relative risk	95% confidence limits for relative risk		Total crashes
		Before	After				Lower limit	Upper limit	
1st T02 2nd T07 3rd T08	Medians Turning lanes Ped. treatment	3.04	2.24	-.80	-26	.70	.49	1.13	113
1st T10 2nd T11 3rd T19	Seal/reseal Non-skid treatment Line marking	2.88	3.48	.60	21	1.20	.88	1.67	158
1st T10 2nd T17 3rd T19	Seal/reseal Clear hazards Line marking	3.12	2.28	.84	-27	.70	.51	1.05	145

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Modelling of Traffic Impacts of Black Spot Treatments

Tender Number: TRS06_034

Final Report

October 2008

CLIENT:

Bureau of Infrastructure, Transport and Regional Economics (BITRE)

Department of Infrastructure, Transport, Regional Development and Local Government

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1. INTRODUCTION

As part of its evaluation of the National Black Spot Program, BITRE has engaged John Piper Traffic Pty Ltd (JPT) to estimate the traffic impacts of completed Black Spot treatments for a number of case study sites.

This report details the method and results of that analysis.

2. BACKGROUND

BITRE is conducting an evaluation of the National Black Spot Program to “determine whether it continues to achieve good outcomes for road safety” (Parliamentary Secretary to the Minister for Transport and Regional Services, 2002). Two previous major evaluations of the program have been undertaken, involving the comparison of road crash data before and after implementation of black spot treatments to determine the effectiveness of treatments and the estimation of benefit–cost ratios.

With these previous evaluations, only benefits in the form of reductions in crashes were taken into account when estimating benefit–cost ratios. In this study, JPT was requested to estimate the time savings or costs of delays to road users that might result from the implementation of Black Spot treatments. It was recognized that to attempt this analysis for all treatments (approximately 2,600 were approved during the seven-year period 1996-97 to 2002-03, though not all of these were actually completed) would be prohibitively time consuming and that a small number of case studies should be examined, with the traffic impact results to provide indicative orders of magnitude for a number of types of Black Spot treatments.

The aaSIDRA software (**aa**Traffic **S**ignalised & unsignalised **I**ntersection **D**esign and **R**esearch **A**id – Akcelik & Associates) was selected as the traffic model appropriate to the study’s aims. aaSIDRA “uses detailed analytical traffic models coupled with an iterative approximation method to provide estimates of capacity and performance statistics (delay, queue length, stop rate, etc.)” (aaSIDRA User Guide). Since its first release in 1984, aaSIDRA has continued to be based on research carried out in Australia and elsewhere, and is recognised internationally by a number of authoritative references, including the US Highway Capacity Manual and various parts of the AustRoads “Guide to Traffic Engineering Practice”. This project has been undertaken over an eighteen month period due to the need to source data from many different Road Authorities and jurisdictions. Consequently, to ensure consistency of analysis outputs, the version of aaSIDRA in use at the commencement of the project was used throughout the duration of the study.

3. CASE STUDIES

As part of the wider overall evaluation of the Black Spot program, BITRE requested from the State and Territory road agencies data on all federally-funded treatments over the period 1996-97 to 2002-03. This data mostly comprised details of the treatments and the associated traffic levels and crash details.

The road agencies were also asked to suggest sites to be included in this study, bearing in mind the desire to analyse a number of different types of Black Spot treatments (roundabouts, new traffic signals, altered traffic signals…). It was suggested by BITRE that the numbers of these case study sites should be restricted, e.g., to a maximum of ten for each of the larger states, and that the candidates should also ideally include a variety of traffic levels and intersection layouts (crossroads, T-junctions…). For each of the suggested sites, BITRE and JPT developed a list of further specific data requirements which would be necessary input items in the aaSIDRA modelling of the case (refer Section 4).

It was also explained to the agencies that it was unlikely that analysis would be able to be undertaken for all of the suggested case studies, considering the desirability of including both a variety of treatment types and a spread of case studies across the states and territories.

Table 3.1 below summarises the case study sites that have been analysed:

State / Territory	Black Spot Ref. No.	Site Name	Treatment Details
SA	S00028	Adelaide Rd / Wellington Rd / Alexandrina Rd / Flaxley Rd	Installation of roundabout.
SA	S00004	Eastern Pde / Bedford St	Installation of traffic signals.
QLD	Q00569	Southport – Burleigh Rd / Benowa Rd	Extension of right turn lanes at traffic signals.
QLD	Q00768	Gold Coast Hwy / Kirribin St	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.
VIC	V01311	Dorset Rd / Eastfield Rd	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).
VIC	V01590	Mountain Hwy / High St / Valentine St	Modify traffic signals: two 3-aspect (full control) right turn arrows added.
VIC	V01145	Stud Rd / Boronia Rd	Modify traffic signals: one set of 2-aspect (partial control) right turn arrows added.
VIC	V01340	Burwood Hwy / Dawson St	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).
NSW	N00239	William St / Howick St	Installation of traffic signals.
NSW	N01073	Boundary St / Lang St	Installation of roundabout.
VIC	V00385	Warrandyte Rd / Wonga Rd	Modify traffic signals: one right turn arrow display altered from 2 to 3 aspects (“partial” to “full” control).
VIC	V03035	Dorset Rd / Francis Cr	Installation of traffic signals.
VIC	V01062	Boronia Rd / Forest Rd	Installation of roundabout.
NSW	N00995	Canley Vale Rd / Sackville St	Modify traffic signals: one right turn altered from “filter” to “partial” control and one right turn banned.
NSW	N00851	Pacific Hwy / Halls Rd	Installation of traffic signals.
NSW	N00114	Brisbane St / Tamworth St	Installation of roundabout.
NSW	N00228	Stewart Ave / Parkway Ave	Installation of traffic signals.
NSW	N00846	Pacific Hwy / Cook Dr / North Boambee Rd	Installation of traffic signals.

Table 3.1 – Selected Case Study Sites

4. AASIDRA ANALYSIS

To assess the impact of the Black Spot treatment in a given case study, a number of scenarios need to be examined. The site (intersection) layout prior to the implementation of the treatment needs to be modelled in aaSIDRA; with an unsignalised or roundabout intersection, this involves modelling the geometry, along with additional operational details such as cycle times and phasing being required in the case of traffic signal arrangements.

Traffic count data, in the form of left, through and right "turning movement" data applicable to the year of implementation is then added to the model in order to determine the operating characteristics of delays, queues, etc. The model allows "heavy" or commercial vehicle volumes to be entered separately if known, or an assumed percentage of the total flow can be applied. The effects of heavy vehicles in traffic streams are taken into account by aaSIDRA using their proportions to determine flows in PCUs (passenger car units) for use in its output parameter calculations.

Often turning movement data is only available for the weekday AM and PM peak hours. In order to more accurately model the operation of an intersection throughout all hours of a particular year, these volumes will have to be used to derive estimates of those occurring at other times on weekdays and throughout weekends. aaSIDRA provides for these variations in its "Annual Sums" facility by dividing the flows present throughout a day of the week into five different flow periods (AM Peak, PM Peak, Business Hours, Medium Off Peak and Light Off Peak) and then for work days, weekends and holidays separately, the model assigns the numbers of hours in each of these three types of day that each of the five flow periods is deemed to apply (refer to Figure A1 in Appendix A for details). These defaults are based on extensive research, but can be altered if required. aaSIDRA also suggests that in lieu of detailed observed traffic data:

- Business Hours flow rate = 71% of average flow rate of AM & PM Peaks
- Medium Off Peak flow rate = 53% of Business Hours flow rate
- Light Off Peak flow rate = 16% of Business Hours flow rate

(The above percentages and the default flow period hours have been used in this study)

Once five models have been created for the differing flow periods for the "before" layout at the time of implementation, corresponding models for the five periods (identical volumes) have to be set up for the "after" layout, i.e., as with geometry/phasing altered by the Black Spot treatment.

A sample of one of the output tables from aaSIDRA is shown in Figure A2 (Appendix A). This output table is referred to as a "Movement Summary" in the aaSIDRA documentation, and details various flow, capacity, delay and queue length results for each vehicle movement in the given scenario.

Agency guidelines have assigned a "notional life" or "typical treatment life" to each form of Black Spot treatment, and these have been used to determine the cost impacts of treatments in years following their implementation. Having set volumes for five different flow periods at the start, or "Year 0", of a treatment life, use is then made of annual percentage growth rates (from historical traffic data for the particular case) to derive flows at 10, 15 or 20 years following implementation. Applying these "end of life" volumes to both the "before" and "after" layouts will then result in a total of 20 aaSIDRA models for the one case study (5 No. flow periods X 2 No. analysis years X 2 No. layouts).

The extrapolating volume growth rates employed above have generally been linear, e.g., a total of 10% growth over 10 years rather than 1% per annum compounding for 10 years. In the majority of cases, only AM and PM Peak hour volume data was available, so that a common growth rate was used for a number of the five flow periods. Occasionally, however, the availability of more comprehensive data allowed differing growth rates to be adopted for all five periods.

Ten of the case studies involved "give way" or "stop" situations being replaced with roundabouts or traffic signals. In some of these cases, the traffic movements from the minor roads were suffering congestion problems, even in "Year 0". It would then not have been realistic to apply a growth factor to all traffic movements, since the "before" layout would not have been able to service any sizeable volume increases in the minor road movements.

In the "Annual Sums" facility, the output files from a number of individual runs can be combined to give total yearly estimates of cost, delay, fuel consumption, vehicle emissions, etc. – these are made using the assumed number of hours mentioned above for which the five flow periods apply throughout work days, weekends and holidays. In order to calculate these values, a number of cost parameters are used by the model – included below in Table 4.1 is a table of the default values (taken from the aaSIDRA User Guide). At the request of BITRE, the following changes to the default values were adopted in this study:

- Pump price of fuel = $1.12 per litre
- Fuel resource cost factor = 0.58
- Average income per hour = $34.35
- Time value factor = 0.5

(For details on how the BITRE values were obtained, see Appendix T)

The "Annual Sums" facility produces results tabled in a number of worksheets – two of these are reproduced as samples in Figures A3 and A4 (Appendix A). Note that, with the above changes set, all "$" amounts are in Year 2005 values.

The example in Figure A3 (Appendix A) details the calculated output parameters for the five defined flow periods and for the year overall – in this instance, the first option is the "before" layout and the second is the layout "after" implementation of the Black Spot treatment. For this example, the annual operating cost of the intersection has increased from $2,663,000 to $2,910,000, with associated increases in emissions, stops and delays. Figure A4 provides graphical representations of the totals summarised in Figure A3, with the results for the "before" and "after" layouts being presented in the first and second bars in each graph, respectively. The blank columns for the unused 3rd Option through to the 6th Option should be ignored.

Figure A3 details null values in the pedestrian flow, delay and stops results columns. Complete pedestrian volume data was rarely available, and this study has therefore not included any assessment of the impact on pedestrians of the various Black Spot treatments. The results in the "person delay" and "person stops" columns in the Annual Sums tables (such as Figure A3) are consequently equal to just the product of the corresponding vehicle delay/stops and the assumed average occupancy per vehicle.

Default values of cost model parameters for the standard aaSIDRA ("Australia"), New Zealand and US versions (updated April 2004)

Parameter	Symbol	Australia	New Zealand	USA
		$ (AUD)	$ (NZD)	$ (USD)
	(k_o)			
Pump price of fuel in "Cost Unit" per litre (or per gallon)	($\mathbf{P_p}$)	0.90 ($/L)	1.10 ($/L)	$ 0.45 ($/L) (1.80 $/gal)
Fuel resource cost factor	($\mathbf{f_r}$)	0.50	0.60	0.70
Running cost/fuel cost ratio	($\mathbf{f_c}$)	3.0	2.5	3.0
Parameters for time cost	***(k_t)***			
Average income (full time adult average hourly total earnings) in "Cost Unit" per hour	(**W**)	27.00 ($/h)	19.00 ($/h)	18.00 ($/h)
Time value factor as a proportion of average hourly income	($\mathbf{f_p}$)	0.60	0.60	0.40
Average occupancy in persons per vehicle	($\mathbf{f_o}$)	1.5	1.5	1.2
Light Vehicle Mass (average value in kg or lb)	($\mathbf{M_{vLV}}$)	1400	1400	1400 (3100 lb)
Heavy Vehicle Mass (average value in kg or lb)	($\mathbf{M_{vHV}}$)	11000	11000	11000 (24,000 lb)
Idling fuel consumption rate for Light Vehicles in millilitres per hour (or gallons per hour)	($\mathbf{f_{ILV}}$)	1350	1350	1350 (0.360 gal/h)
Idling fuel consumption rate for Heavy Vehicles in millilitres per hour (or gallons per hour)	($\mathbf{f_{IHV}}$)	2000	2000	2000 (0.530 gal/h)
Vehicle operating cost factor in "Cost Unit" per litre (or per gallon) of fuel	($\mathbf{k_o} = f_c\ f_r\ P_p$)	1.350 ($/L)	1.650 ($/L)	0.945 ($/L) (3.780 $/gal)
Time cost per ***person*** in "Cost Unit" per hour	(f_p W)	16.20 ($/h)	11.40 ($/h)	7.20 ($/h)
Time cost per ***vehicle*** in "Cost Unit" per hour	($\mathbf{k_t} = f_o\ f_p$ W)	24.30 ($/h)	17.10 ($/h)	8.64 ($/h)

Cost Unit can be stated using up to three characters ($, US$, USD, etc). In the case of inflated currencies, it can be specified as multiples of, for example 10^3, e.g. "Cost Unit" = LRk, where k is used for thousand.

Table 4.1 – aaSIDRA Cost Parameter Defaults
(from Table 6.3.1, aaSIDRA Output Guide – July 2005, Akcelik & Associates Pty Ltd)

The desired data was not always available, e.g. multiple historical volume collections, full documentation of layouts prior to treatment, etc.. In these cases, assumptions had to be made regarding such factors as volume growth rates and the arrangement of lanes at the intersection. This was in keeping with the overall aim of the study, which has been to examine case studies to enable qualitative assessment of the likely traffic impacts of various types of treatments, rather than to carry out aaSIDRA analysis as part of a detailed operational study of a specific intersection.

4.1 Model Output Terminology

Section 5 provides single page summaries of each case study analysed. Many model output parameters, such as dollars, litres, etc… require no explanation, however the following is provided regarding some of the more unfamiliar terms.

4.1.1 Traffic Flow

In aaSIDRA, “Flow” is the hourly rate of total traffic arrival (demand) at the intersection and is simply the sum of user specified volume data for all approaches.

4.1.2 Capacity

To quote from the aaSIDRA User Guide, “capacity is the maximum sustainable flow rate that can be achieved during a specified time period under given road, traffic and control conditions”. The vehicle capacity of an intersection will be equal to the sum of the capacities of all the individual approaches to the intersection, and as noted in the above definition, these approach capacities vary constantly, depending on, for example:

- At traffic signals, the ratio of available green signal time to the signal cycle time.
- At roundabouts, the circulating volume within the roundabout which must be “yielded” to.
- At a minor road “stop or give way” approach, the volume of traffic in the major road which must be “yielded” to.

The capacity of an intersection will therefore vary throughout the five assumed flow periods (defined on Page 3).

4.1.3 Delay

To fully explain the delay results produced by aaSIDRA, the following terms are worthy of mention:

“Stop-line delay” – is the difference between interrupted and uninterrupted travel times for a vehicle negotiating a given intersection. It can include stopped delay as well as, for instance, “queue move-up” delay at a congested intersection.

“Geometric delay” – is the delay experienced by a vehicle negotiating the intersection in the absence of any other vehicles, so that it includes deceleration and acceleration effects due to the physical (geometric) characteristics of the intersection.

“Intersection control delay” – is the sum of stop-line and geometric delays, so that it includes all deceleration, stopped and acceleration delays experienced in negotiating the intersection – in other references, this term has also been described as “overall delay with/including geometric delay”.

Intersection control delay is the default delay definition in aaSIDRA and has been adopted in this study. As seen in Figure A2 (Appendix A), aaSIDRA calculates average delays for each movement, i.e., an average result for all vehicles in a particular movement, both queued and unqueued. For each movement, the total delay is the product of average delay (seconds) and the total demand flow rate (vehicles per hour). aaSIDRA combines the results for all movements at an intersection to give a total in units of vehicle-hours per year or vehicle-hours per hour – Figure A3 (Appendix A) shows values obtained in one of the case studies.

aaSIDRA uses an uninterrupted “cruise” travel speed input parameter to set start and end point spatial limits for its delay calculations – this value applies to vehicles on all approaches and exits for the intersection and for the sake of simplicity is usually left set at its default of 60 kph.

5. CASE STUDIES

5.1 S00028 – Adelaide Rd / Wellington Rd / Alexandrina Rd / Flaxley Rd (Roundabout Installation)

5.1.1 Intersection Layouts

This site is located at Mount Barker, South Australia (Mount Barker District Council) and was treated in the 1996-97 financial year.

Prior to the Black Spot treatment, the intersection was a 4-way crossroad, with Adelaide and Wellington Roads being the main road legs (2 lanes in both directions), and where the Alexandrina and Flaxley Road single lane minor road approaches were slightly offset at their intersections with the main road (with "give way" lines at the intersection). The Black Spot treatment involved the installation of a roundabout along with a short length of two lane approach in Flaxley Road.

5.1.2 Traffic Volumes and Treatment Notional Life

Peak hour turning movement data was available from counts taken in 1996, 2000 and 2006, with annual growth being very consistent in both intervals between counts. A 20 year notional life was adopted for the installation of a roundabout and the 2006 volumes were further extrapolated to give 2016 estimates.

5.1.3 "Annual Sums" Results

Table 5.1 below lists some of the annual totals from the analysis:

Year / Layout	Cost ($/yr)	Fuel (l/yr)	CO_2 emissions (kg/yr)	Total Vehicle Delay (veh-hr/yr)
1996 "Before"	2,767,697	415,792	1,042,020	10,456
1996 "After"	3,010,860	474,520	1,189,312	14,390
2016 "Before"	5,336,958	715,380	1,792,040	49,271
2016 "After"	4,810,702	757,628	1,898,416	24,239

Table 5.1 – S00028 – Selected "Annual Sums" Results from aaSIDRA Analysis

Detailed summaries of all the "Annual Sums" figures are given in Figures B1 to B4 (Appendix B).

5.1.4 Discussion

The major change over the project's lifetime is that the roundabout vehicle operating costs and delay are lower in later years, principally because by 2016 the installation of the roundabout treatment will result in significantly lower congestion levels in the AM and PM Peaks. Not surprisingly in the early years of the project life, the roundabout will have higher operating costs and delay results, as main road vehicles will incur (slight) delays that were not present when they had the priority afforded with the "before" layout.

5.1.5 Additional Analysis

Please refer to Appendix U for details of additional analysis of this case requested by BITRE.

5.2 S00004 – Eastern Pde / Bedford St (Traffic Signals Installation)

5.2.1 Intersection Layouts

This site is located at Gillman, South Australia (Port Adelaide Enfield City Council) and was treated in the 1996-97 financial year.

Prior to the Black Spot treatment, the intersection was a 4-way crossroad, with Eastern Parade being the main road (2 lanes in both directions) and Bedford Street the minor road (one lane in both directions- with “stop” lines at the intersection). The Black Spot treatment involved the installation of traffic signals in a simple two-phase arrangement.

5.2.2 Traffic Volumes and Treatment Notional Life

Peak hour turning movement data was available from a count taken in 1991. Initially, a 15 year notional life was adopted for the installation of the signals, however even slight traffic growth rates after 1996 would have seen the “before” layout soon become “saturated” (demand reaching the capacity of the intersection) in the AM and PM peak periods – in this case it would have been unreasonable to assume that any further volume growth could have been accommodated. The two layouts were therefore analysed for estimated Year 2000 volumes to provide at least some comparison. As events would have it, the nearby Port River Expressway was opened in July 2005, leading to a substantial drop in traffic volumes at this intersection.

5.2.3 “Annual Sums” Results

Table 5.2 below lists some of the annual totals from the analysis:

Year / Layout	Cost ($/yr)	Fuel (l/yr)	CO_2 emissions (kg/yr)	Total Vehicle Delay (veh-hr/yr)
1996 “Before”	2,658,835	461,624	1,162,188	14,995
1996 “After”	2,768,944	497,744	1,252,840	16,586
2000 “Before”	3,191,896	527,576	1,328,364	24,640
2000 “After”	3,107,890	559,164	1,406,812	18,707

Table 5.2 – S00004 – Selected “Annual Sums” Results from aaSIDRA Analysis

Detailed summaries of all the “Annual Sums” figures are given in Figures C1 through C4 in Appendix C.

5.2.4 Discussion

The major change over the 4 year span is that the traffic signals vehicle operating costs and delay are lower in later years, because of the predicted severe congestion that would have been experienced in the AM and PM Peaks had the original layout been retained. As for Case Study 1, in the year of implementation, the traffic signals will have higher operating costs and delay results, as main road vehicles will incur delays that were not present when they had the priority afforded with the "before" layout.

5.3 Q00569 – Southport – Burleigh Rd / Benowa Rd (Right Turning Lane Extension)

5.3.1 Intersection Layouts

This site is located at Southport, Queensland (Gold Coast City Council) and was treated in the 1999-2000 financial year.

Prior to and following the Black Spot treatment, the intersection has been controlled by traffic signals (Benowa Road forms a T-junction by terminating at Southport-Burleigh Road). The Black Spot treatment involved lengthening the two right turn lanes from the north approach of Southport-Burleigh Road.

5.3.2 Traffic Volumes and Treatment Notional Life

Peak hour turning movement data was available from counts taken in 2001 and 2006. A 15 year notional life was adopted for the treatment and the 2006 volumes were further extrapolated to give 2016 estimates.

5.3.3 "Annual Sums" Results

Table 5.3 below lists some of the annual totals from the analysis:

Year / Layout	Cost ($/yr)	Fuel (l/yr)	CO_2 emissions (kg/yr)	Total Vehicle Delay (veh-hr/yr)
2001 "Before"	8,219,885	1,071,732	2,681,408	77,277
2001 "After"	8,067,131	1,053,692	2,635,676	72,725
2016 "Before"	9,733,023	1,259,688	3,151,540	98,466
2016 "After"	9,504,352	1,234,088	3,086,908	91,556

Table 5.3 – Q00569 – Selected "Annual Sums" Results from aaSIDRA Analysis

Detailed summaries of all the "Annual Sums" figures are given in Figures D1 through D4 in Appendix D.

5.3.4 Discussion

The lengthening of the dual right turn lanes results in savings in all major categories commencing immediately from implementation. Savings are not predicted for the Medium Off Peak and Light Off Peak periods, however the operation of the intersection is predicted to improve noticeably in the three heavier daily flow periods, even in 2001. BITRE records indicate that the project was aimed at treating "rear end" crashes, which would accord with aaSIDRA's modelling of the "before" layout in the 2001 PM Peak, where queues in the right turn lanes were predicted to frequently overflow into the adjacent through traffic lane.

5.4 Q00768 – Gold Coast Hwy / Kirribin St (Right Turning Lane Extension & Signal Modifications)

5.4.1 Intersection Layouts

This site is located at Bilinga, Queensland (Gold Coast City Council) and was treated in the 2001-2002 financial year.

Prior to and following the Black Spot treatment, the intersection has been controlled by traffic signals (the two roads form a 4-way crossroad junction). The Black Spot treatment involved lengthening the single right turn lanes on the north and south highway approaches. Prior to the treatment, these right turns were "partially" controlled, i.e., vehicles were provided with a green right turn signal phase, with the arrows then remaining "blank" in the highway through traffic phase, allowing additional vehicles to turn right through gaps in the opposing traffic. The treatment also included an operational change where the right turn arrows were held red for a short interval at the beginning of the highway through phase before again being set "blank".

5.4.2 Traffic Volumes and Treatment Notional Life

Peak hour turning movement data was available from counts taken in 2000 and 2005. A 10 year notional life was adopted for the treatment and the 2005 volumes were further extrapolated to give 2011 estimates.

5.4.3 "Annual Sums" Results

Table 5.4 below lists some of the annual totals from the analysis:

Year / Layout	Cost ($/yr)	Fuel (l/yr)	CO_2 emissions (kg/yr)	Total Vehicle Delay (veh-hr/yr)
2001 "Before"	10,433,876	1,512,480	3,794,040	102,768
2001 "After"	10,434,681	1,512,724	3,794,284	102,816
2011 "Before"	11,936,295	1,717,832	4,309,068	126,589
2011 "After"	11,937,100	1,717,832	4,309,068	126,614

Table 5.4 – Q00768 – Selected "Annual Sums" Results from aaSIDRA Analysis

Detailed summaries of all the "Annual Sums" figures are given in Figures E1 through E4 in Appendix E.

5.4.4 Discussion

Table 5.4 shows that there is predicted to be very little change in operation due to right turners from the highway approaches being held on a red signal at the start of the through phase. The only flow period where a change is predicted is the Low Off Peak in both 2001 and 2011 – in the other flow periods for the "Before" layout, the flows opposing the right turn movements are sizeable enough to prevent "filtering" right turn vehicles from proceeding early in the through phase anyway. Given the low right turn volumes used in the models, the lengthening of the right turn lanes was not predicted to result in any operational improvements.

5.5 V01311 – Dorset Rd / Eastfield Rd (Right Turning Lane Extension & Signal Modifications)

5.5.1 Intersection Layouts

This site is located at Croydon, Victoria (Maroondah City Council) and was treated in the 1999-2000 financial year.

Prior to and following the Black Spot treatment, the intersection has been controlled by traffic signals (the two roads form a 4-way crossroad junction). The Black Spot treatment involved lengthening the single right turn lane on the north Dorset Road approach. Before the treatment, the right turns from north and south in Dorset Road were "partially" controlled, i.e., vehicles were provided with a green right turn signal phase, with the arrows then remaining "blank" in the Dorset Road through traffic phase, allowing additional vehicles to turn right through gaps in the opposing traffic. The treatment also included an operational change where the right turn arrows were altered to "fully" controlled, i.e., they were held red throughout the Dorset Road through phase, so that right turn traffic could only proceed during their green right turn phase.

5.5.2 Traffic Volumes and Treatment Notional Life

Peak hour turning movement data was available from VicRoads' SCATS detector collections (November 2006), supplemented by on-site measurements of peak hour left turn volumes. SCATS detector collections from both 2003 and 2006 were also available for another nearby intersection, and these were used to help estimate 2000 and 2010 intersection volumes (A 10 year notional life was adopted for the treatment). It should be noted that the 2010 volumes are predicted to be less than the corresponding 2000 figures.

5.5.3 "Annual Sums" Results

Table 5.5 below lists some of the annual totals from the analysis:

Year / Layout	Cost ($/yr)	Fuel (l/yr)	CO_2 emissions (kg/yr)	Total Vehicle Delay (veh-hr/yr)
2000 "Before"	7,879,117	1,140,548	2,855,640	63,640
2000 "After"	8,124,673	1,158,216	2,900,616	71,766
2010 "Before"	7,602,495	1,100,568	2,755,692	61,009
2010 "After"	7,842,190	1,118,332	2,800,540	68,907

Table 5.5 – V01311 – Selected "Annual Sums" Results from aaSIDRA Analysis

Detailed summaries of all the "Annual Sums" figures are given in Figures F1 through F4 in Appendix F.

5.5.4 Discussion

Table 5.5 shows that the predicted annual cost impact of the change from partial to full control for the two right turn movements from Dorset Road is approximately $240,000, or a 3% increase. Likewise, Total Vehicle Delay results are predicted to increase by 13% in either analysis year.

5.6 V01590 – Mountain Hwy / High St / Valentine St (Traffic Signal Modifications)

5.6.1 Intersection Layouts

This site is located at Bayswater, Victoria (Knox City Council) and was treated in the 2001-2002 financial year.

Prior to and following the Black Spot treatment, the intersection has been controlled by traffic signals (High Street and Valentine Streets are the minor roads forming a 4-way crossroad junction with the two Mountain Highway approaches). Before the treatment, the right turns from east and west in Mountain Highway were “filter” turns only, i.e., vehicles were not provided with any right turn arrow displays and were required to seek gaps in the opposing traffic. The treatment involved an operational change where both right turn movements were altered to “fully” controlled, i.e., right turn vehicles were held with red turn arrows throughout the Mountain Highway through phase, so that they could only proceed during their (new) green right turn phase.

5.6.2 Traffic Volumes and Treatment Notional Life

Peak hour turning movement data was available from VicRoads’ SCATS detector collections (September 2002 and November 2006), supplemented by a count conducted in 2000. A 10 year notional life was adopted for the treatment and the volumes were further extrapolated to give 2012 estimates.

5.6.3 “Annual Sums” Results

Table 5.6 below lists some of the annual totals from the analysis:

Year / Layout	Cost ($/yr)	Fuel (l/yr)	CO_2 emissions (kg/yr)	Total Vehicle Delay (veh-hr/yr)
2002 “Before”	7,858,664	1,154,096	2,891,052	48,138
2002 “After”	8,865,265	1,255,848	3,145,808	79,325
2012 “Before”	8,135,780	1,195,520	2,995,100	50,027
2012 “After”	9,182,571	1,301,300	3,260,072	82,481

Table 5.6 – V01590 – Selected “Annual Sums” Results from aaSIDRA Analysis

Detailed summaries of all the “Annual Sums” figures are given in Figures G1 through G4 in Appendix G.

5.6.4 Discussion

Table 5.6 shows that the predicted annual cost impact of the change from “filter” to full control for the two right turn movements from Mountain Highway is approximately $1,000,000, or a 13% increase. Likewise, Total Vehicle Delay results are predicted to increase by 65% in either analysis year.

5.7 V01145 – Stud Rd / Boronia Rd (Traffic Signal Modifications)

5.7.1 *Intersection Layouts*

This site is located at Wantirna, Victoria (Knox City Council) and was treated in the 1999-2000 financial year.

Prior to and following the Black Spot treatment, the intersection has been controlled by traffic signals (Stud Road and Boronia Road form a 4-way crossroad junction). Before the treatment, the right turn from the north in Stud Road was a “filter” turn only, i.e., vehicles were not provided with any right turn arrow displays and were required to seek gaps in the opposing traffic. The treatment involved an operational change where the right turn movement was altered to “partially” controlled, i.e., vehicles were provided with a green right turn signal phase, with the arrows then remaining “blank” in the Stud Road through traffic phase, allowing additional vehicles to turn right through gaps in the opposing traffic.

5.7.2 *Traffic Volumes and Treatment Notional Life*

Peak hour turning movement data was available from VicRoads’ SCATS detector collections (September 1995 and November 2006), supplemented by on-site measurements of peak hour left turn volumes. A 10 year notional life was adopted for the treatment and the above volumes were used to derive 2000 and 2010 estimates.

5.7.3 *“Annual Sums” Results*

Table 5.7 below lists some of the annual totals from the analysis:

Year / Layout	Cost ($/yr)	Fuel (l/yr)	CO_2 emissions (kg/yr)	Total Vehicle Delay (veh-hr/yr)
2000 “Before”	15,941,948	2,028,104	5,080,064	223,367
2000 “After”	16,323,574	2,065,312	5,173,604	235,172
2010 “Before”	16,859,727	2,141,520	5,364,696	237,804
2010 “After”	17,362,019	2,187,228	5,479,548	253,562

Table 5.7 – V01145 – Selected “Annual Sums” Results from aaSIDRA Analysis

Detailed summaries of all the “Annual Sums” figures are given in Figures H1 through H4 in Appendix H.

5.7.4 *Discussion*

Table 5.7 shows that in the first year of implementation, the predicted cost impact of the change from “filter” to partial control for the right turn movement from Stud Road north is approximately $380,000, or a 2.4% increase. Likewise, Total Vehicle Delay is predicted to increase by 5%. After a further ten years, the corresponding results are predicted to be $500,000 (3%) and 6.6%.

5.8 V01340 – Burwood Hwy / Dawson St (Traffic Signal Modifications)

5.8.1 Intersection Layouts

This site is located at Upper Ferntree Gully, Victoria (Knox City Council) and was treated in the 1999-2000 financial year.

Prior to and following the Black Spot treatment, the intersection has been controlled by traffic signals (Dawson Street and the Upper Ferntree Gully railway station car park access road are the minor roads forming a 4-way crossroad junction with the two Burwood Highway approaches).

Before the treatment, the right turn from the west in Burwood Highway was "partially" controlled, i.e., vehicles were provided with a green right turn signal phase, with the arrows then remaining "blank" in the Burwood Highway through traffic phase, allowing additional vehicles to turn right through gaps in the opposing traffic. The right turn from the east in Burwood Highway was a "filter" turn only, i.e., vehicles were not provided with any right turn arrow displays and were required to seek gaps in the opposing traffic.

The treatment involved an operational change where both right turn movements were altered to "fully" controlled, i.e., they were both held red throughout the Burwood Highway through phase, so that right turn traffic from either direction could only proceed during the green right turn phase now servicing both movements.

5.8.2 Traffic Volumes and Treatment Notional Life

Peak hour turning movement data was available from VicRoads' SCATS detector collections (April 1994 and November 2006), supplemented by on-site observations of usage in shared lanes. A 10 year notional life was adopted for the treatment and the above volumes were used to derive 2000 and 2010 estimates. Full control of the right turn movement from the east was deleted from the "after" layout models since its minimal volume would result in its green arrows rarely operating to delay eastbound Burwood Highway through traffic.

5.8.3 "Annual Sums" Results

Table 5.8 below lists some of the annual totals from the analysis:

Year / Layout	Cost ($/yr)	Fuel (l/yr)	CO_2 emissions (kg/yr)	Total Vehicle Delay (veh-hr/yr)
2000 "Before"	6,915,009	973,068	2,436,380	55,671
2000 "After"	7,025,143	979,016	2,451,872	59,448
2010 "Before"	7,381,746	1,034,528	2,590,492	61,792
2010 "After"	7,491,633	1,039,836	2,604,264	65,644

Table 5.8 – V01340 – Selected "Annual Sums" Results from aaSIDRA Analysis

Detailed summaries of all the "Annual Sums" figures are given in Figures I1 through I4 in Appendix I.

5.8.4 Discussion

Table 5.8 shows that the predicted annual cost impact of the operational changes for the right turn movements from Burwood Highway is approximately $110,000, or a 1.5% increase. Likewise, Total Vehicle Delay results are predicted to increase by 6% in either analysis year.

5.9 N00239 – William St / Howick St (Traffic Signals Installation)

5.9.1 Intersection Layouts

This site is located at Bathurst, New South Wales (Bathurst Regional Council) and was treated in the 1999-2000 financial year.

Prior to the Black Spot treatment, the intersection was a 4-way crossroad, with William Street being the main road and Howick Street the minor road. The Black Spot treatment involved the installation of traffic signals in a three-phase arrangement.

5.9.2 Traffic Volumes and Treatment Notional Life

Peak hour turning movement data was available from RTA SCATS detector collections (June 2007). A 15 year notional life was adopted for the treatment and the above volumes were used to derive 1999 and 2014 estimates.

5.9.3 "Annual Sums" Results

Table 5.9 below lists some of the annual totals from the analysis:

Year / Layout	Cost ($/yr)	Fuel (l/yr)	CO_2 emissions (kg/yr)	Total Vehicle Delay (veh-hr/yr)
1999 "Before"	2,606,733	390,064	976,532	12,851
1999 "After"	3,144,743	426,692	1,067,752	31,540
2014 "Before"	2,854,696	427,876	1,071,332	14,824
2014 "After"	3,421,884	463,568	1,160,524	34,703

Table 5.9 – N00239 – Selected "Annual Sums" Results from aaSIDRA Analysis

Detailed summaries of all the "Annual Sums" figures are given in Figures J1 through J4 in Appendix J.

5.9.4 Discussion

The installation of traffic signals will result in higher operating costs and delays, as main road vehicles will incur delays that were not present when they had the priority afforded with the "before" layout. The aaSIDRA models for the "before" layout in the 2014 AM and PM Peaks did not predict severe congestion, so that even then the signalised layout is predicted to have significantly higher cost and delay results.

5.10 N01073 – Boundary St / Lang St (Roundabout Installation)

5.10.1 Intersection Layouts

This site is located at Kurri Kurri, New South Wales (Cessnock City Council) and was treated in the 2000-2001 financial year.

Prior to the Black Spot treatment, the intersection was a 4-way crossroad, with Boundary Street being the main road and Lang Street the minor road. The Black Spot treatment involved the installation of a roundabout (single lane approaches and single lane circulating flow).

5.10.2 Traffic Volumes and Treatment Notional Life

Peak hour turning movement data was available from a turning movement count conducted in July 2000. A 15 year notional life was adopted for the treatment and the above volumes were used to derive 2016 estimates.

5.10.3 "Annual Sums" Results

Table 5.10 below lists some of the annual totals from the analysis:

Year / Layout	Cost ($/yr)	Fuel (l/yr)	CO_2 emissions (kg/yr)	Total Vehicle Delay (veh-hr/yr)
2001 "Before"	861,600	131,812	330,564	2,448
2001 "After"	930,791	148,864	372,924	4,226
2016 "Before"	1,054,975	161,924	406,096	3,141
2016 "After"	1,130,796	180,604	453,344	5,155

Table 5.10 – N01073 – Selected "Annual Sums" Results from aaSIDRA Analysis

Detailed summaries of all the "Annual Sums" figures are given in Figures K1 through K4 in Appendix K.

5.10.4 Discussion

The installation of the roundabout will result in higher operating costs and delays, as main road vehicles will incur delays that were not present when they had the priority afforded with the "before" layout. The aaSIDRA models for the "before" layout in the 2016 AM and PM Peaks predicted that there would still have been plentiful spare capacity available, so that even then the roundabout is predicted to have higher cost and delay results.

5.11 V00385 – Warrandyte Rd / Wonga Rd (Traffic Signal Modifications)

5.11.1 Intersection Layouts

This site is located at Ringwood North, Victoria (Maroondah City Council) and was treated in the 1997-1998 financial year.

Prior to and following the Black Spot treatment, the intersection has been controlled by traffic signals (Wonga Road forms a 3-way 'Y' junction with the two slightly angled Warrandyte Road approaches). Before the treatment, the right turn from Warrandyte Road south into Wonga Road was "partially" controlled, i.e., vehicles were provided with a green right turn signal phase, with the arrows then remaining "blank" in the Warrandyte Road through traffic phase, allowing additional vehicles to turn right through gaps in the opposing traffic. The treatment involved an operational change where the right turn arrows were altered to "fully" controlled, i.e., they were held red throughout the Warrandyte Road through phase, so that right turn traffic could only proceed during their green right turn phase.

5.11.2 Traffic Volumes and Treatment Notional Life

Peak hour turning movement data was available from VicRoads' SCATS detector collections (November 2006). A 10 year notional life was adopted for the treatment and the above volumes were used to derive 1998 and 2008 estimates.

5.11.3 "Annual Sums" Results

Table 5.11 below lists some of the annual totals from the analysis:

Year / Layout	Cost ($/yr)	Fuel (l/yr)	CO_2 emissions (kg/yr)	Total Vehicle Delay (veh-hr/yr)
1998 "Before"	5,175,487	739,020	1,849,832	40,024
1998 "After"	5,437,151	759,940	1,901,852	48,559
2008 "Before"	5,773,441	822,964	2,060,044	45,896
2008 "After"	6,072,523	846,792	2,119,676	55,647

Table 5.11 – V00385 – Selected "Annual Sums" Results from aaSIDRA Analysis

Detailed summaries of all the "Annual Sums" figures are given in Figures L1 through L4 in Appendix L.

5.11.4 Discussion

Table 5.11 shows that the predicted annual cost impact of the operational change for the right turn movement from Warrandyte Road south will range between $260,000 and $300,000 over the notional life (a 5% increase). Likewise, Total Vehicle Delay results are predicted to increase by 21% in either analysis year.

5.12 V03035 – Dorset Rd / Francis Cr (Traffic Signals Installation)

5.12.1 Intersection Layouts

This site is located at Ferntree Gully, Victoria (Knox City Council) and was treated in the 2003-2004 financial year.

Prior to the Black Spot treatment, the intersection was a T-junction, with Dorset Road being the main road (2 lanes in both directions) and Francis Crescent the terminating minor road (one lane for right turning traffic and another short lane for left turning traffic). The Black Spot treatment involved the installation of traffic signals in a simple three-phase arrangement.

5.12.2 Traffic Volumes and Treatment Notional Life

Peak hour turning movement data was available from VicRoads' SCATS detector collections (November 2006), supplemented by a count conducted in August 2003 (immediately prior to the implementation of the treatment). A 15 year notional life was adopted for the treatment and the volumes were further extrapolated to give 2018 estimates.

5.12.3 "Annual Sums" Results

Table 5.12 below lists some of the annual totals from the analysis:

Year / Layout	Cost ($/yr)	Fuel (l/yr)	CO_2 emissions (kg/yr)	Total Vehicle Delay (veh-hr/yr)
2003 "Before"	5,615,298	755,292	1,890,548	18,909
2003 "After"	6,439,715	950,240	2,380,344	33,345
2018 "Before"	6,845,298	883,736	2,212,032	34,247
2018 "After"	8,465,170	1,286,632	3,222,964	61,436

Table 5.12 – V03035 – Selected "Annual Sums" Results from aaSIDRA Analysis

Detailed summaries of all the "Annual Sums" figures are given in Figures M1 through M4 in Appendix M.

5.12.4 Discussion

The installation of the traffic signals will result in higher operating costs and delays, as main road vehicles will incur delays that were not present when they had the priority afforded with the "before" layout – such increases are not surprising given how much more heavily trafficked is Dorset Road compared to Francis Crescent.

5.13 V01062 – Boronia Rd / Forest Rd (Roundabout Installation)

5.13.1 Intersection Layouts

This site is located at Boronia, Victoria (Knox City Council) and was treated in the 1998-99 financial year.

Prior to the Black Spot treatment, the intersection was a T-junction, with Boronia Road being the main road and Forest Road the terminating minor road. The Black Spot treatment involved the installation of a roundabout.

5.13.2 Traffic Volumes and Treatment Notional Life

Peak hour turning movement data was available from counts taken in May 1997 and July 2003. A 20 year notional life was adopted for the installation of a roundabout and the volumes were further extrapolated to give 2018 estimates.

5.13.3 "Annual Sums" Results

Table 5.13 below lists some of the annual totals from the analysis:

Year / Layout	Cost ($/yr)	Fuel (l/yr)	CO_2 emissions (kg/yr)	Total Vehicle Delay (veh-hr/yr)
1998 "Before"	3,428,557	517,212	1,295,556	16,414
1998 "After"	3,690,809	563,548	1,410,144	20,250
2018 "Before"	3,893,087	610,148	1,529,836	19,564
2018 "After"	4,085,013	622,332	1,557,712	22,839

Table 5.13 – V01062 – Selected "Annual Sums" Results from aaSIDRA Analysis

Detailed summaries of all the "Annual Sums" figures are given in Figures N1 through N4 in Appendix N.

5.13.4 Discussion

In the early years of the project life, the roundabout will have higher operating costs and delay results, as main road vehicles will incur (slight) delays that were not present when they had the priority afforded with the "before" layout. Later in the project's lifetime, the differences in these results for the two layouts reduce, due to the higher congestion levels which would have been experienced in the AM and PM Peaks had the roundabout not been installed.

5.14 N00995 – Canley Vale Rd / Sackville St (Traffic Signal Modifications)

5.14.1 Intersection Layouts

This site is located at Canley Vale, New South Wales (Fairfield City Council) and was treated in the 2000-2001 financial year.

Prior to and following the Black Spot treatment, the intersection has been controlled by traffic signals (Canley Vale Road and Sackville Street form a 4-way crossroad junction). Before the treatment, the right turn from the east in Canley Vale Road was a “filter” turn only, i.e., vehicles were not provided with any right turn arrow displays and were required to seek gaps in the opposing traffic during the Canley Road through phase. The treatment involved an operational change where the right turn movement was altered to “partially” controlled, i.e., vehicles were provided with a new right turn phase following the Canley Road through phase. Right turning traffic could still complete a “filter” turn during this through phase, following an interval where they would be held by a new red turn arrow (conditional on pedestrians crossing the north leg of the intersection). In order to safely operate the new “lagging” right turn phase, the right turn movement from the west Canley Vale Road approach was banned as part of the treatment.

5.14.2 Traffic Volumes and Treatment Notional Life

Peak hour turning movement data was available from a count taken in October 2000. A 15 year notional life was adopted for the treatment and the volumes were extrapolated to give 2016 estimates.

5.14.3 “Annual Sums” Results

Table 5.14 below lists some of the annual totals from the analysis:

Year / Layout	Cost ($/yr)	Fuel (l/yr)	CO_2 emissions (kg/yr)	Total Vehicle Delay (veh-hr/yr)
2001 “Before”	6,773,092	990,436	2,480,908	56,392
2001 “After”	6,834,850	996,364	2,495,792	58,235
2016 “Before”	7,942,234	1,160,648	2,907,960	67,732
2016 “After”	8,003,962	1,165,488	2,919,464	69,773

Table 5.14 – N00995 – Selected “Annual Sums” Results from aaSIDRA Analysis

Detailed summaries of all the “Annual Sums” figures are given in Figures O1 through O4 in Appendix O.

5.14.4 Discussion

With the additional signal phase operating, it is not surprising that the treatment is predicted to result in slight increases in the various output parameters. The degree of change is however much more modest than would be expected for a new traffic signal installation at an intersection, and this is somewhat due to the fact that the new right turn phase is only enabled when traffic densities reach a certain threshold, rather than at all hours of a given day.

5.15 N00851 – Pacific Highway / Halls Rd (Traffic Signals Installation)

5.15.1 Intersection Layouts

This site is located at Coffs Harbour, New South Wales (Coffs Harbour City Council) and was treated in the 1999-2000 financial year.

Prior to the Black Spot treatment, the intersection was a T-junction, with Pacific Highway being the main road (2 lanes in both directions) and Halls Road the terminating minor road (one lane each for right turning and left turning traffic). The Black Spot treatment involved the installation of traffic signals at this intersection, as well as other roadworks at the adjacent Pacific Highway intersection with Thompsons Road – the effects of the latter were not analysed in this study.

5.15.2 Traffic Volumes and Treatment Notional Life

Peak hour turning movement data was available from RTA SCATS detector collections (June 2007), along with 1998, 2001 & 2004 AADT figures for a nearby Pacific Highway intersection. A 15 year notional life was adopted for the treatment and the above volumes were used to derive 2000 and 2015 estimates.

5.15.3 "Annual Sums" Results

Table 5.15 below lists some of the annual totals from the analysis:

Year / Layout	Cost ($/yr)	Fuel (l/yr)	CO_2 emissions (kg/yr)	Total Vehicle Delay (veh-hr/yr)
2000 "Before"	2,873,749	388,008	971,184	5,312
2000 "After"	3,504,259	486,920	1,219,216	22,088
2015 "Before"	3,706,330	503,252	1,260,364	5,773
2015 "After"	4,595,512	639,976	1,602,100	29,696

Table 5.15 – N00851 – Selected "Annual Sums" Results from aaSIDRA Analysis

Detailed summaries of all the "Annual Sums" figures are given in Figures P1 through P4 in Appendix P.

5.15.4 Discussion

The installation of the traffic signals will result in higher operating costs and delays, as main road vehicles will incur delays that were not present when they had the priority afforded with the "before" layout.

5.16 N00114 – Brisbane Street / Tamworth Street (Roundabout Installation)

5.16.1 Intersection Layouts

This site is located at Dubbo, New South Wales (Dubbo City Council) and was treated in the 1998-1999 financial year.

Prior to the Black Spot treatment, the intersection was a 4-way crossroad, with Brisbane Street being the main road and Tamworth Street the minor road. The Black Spot treatment involved the installation of a roundabout (single lane approaches and single lane circulating flow).

5.16.2 Traffic Volumes and Treatment Notional Life

Current peak hour turning movement data was estimated from AADT figures provided by Dubbo City Council. A 15 year notional life was adopted for the treatment and the current volumes were used to derive 1998 and 2013 estimates.

5.16.3 "Annual Sums" Results

Table 5.16 below lists some of the annual totals from the analysis:

Year / Layout	Cost ($/yr)	Fuel (l/yr)	CO_2 emissions (kg/yr)	Total Vehicle Delay (veh-hr/yr)
1998 "Before"	907,584	137,320	344,468	4,216
1998 "After"	930,596	142,932	358,436	4,388
2013 "Before"	932,506	141,400	353,792	4,327
2013 "After"	955,966	146,988	368,296	4,522

Table 5.16 – N00114 – Selected "Annual Sums" Results from aaSIDRA Analysis

Detailed summaries of all the "Annual Sums" figures are given in Figures Q1 through Q4 in Appendix Q.

5.16.4 Discussion

The installation of the roundabout will result in higher operating costs and delays, as main road vehicles will incur delays that were not present when they had the priority afforded with the "before" layout. The aaSIDRA models for the "before" layout in the 2013 AM and PM Peaks predicted that there would still have been plentiful spare capacity available, so that even then the roundabout is predicted to have higher cost and delay results.

5.17 N00228 – Stewart Avenue / Parkway Avenue (Traffic Signals Installation)

5.17.1 Intersection Layouts

This site is located at Hamilton South, New South Wales (Newcastle City Council) and was treated in the 2001-2002 financial year.

Prior to the Black Spot treatment, the intersection was a 4-way crossroad, with Stewart Avenue being the main road and Parkway Avenue the minor road. The Black Spot treatment involved the installation of traffic signals in a four-phase arrangement.

5.17.2 Traffic Volumes and Treatment Notional Life

Peak hour turning movement data was available from RTA SCATS detector collections (May 2007) along with AADT figures covering the period 1980 to 2004 for a nearby counting station in Stewart Avenue. A 15 year notional life was adopted for the treatment and the above volumes were used to derive 2001 and 2016 estimates.

Even slight traffic growth rates for Parkway Avenue after 2001 would have seen the "before" layout soon become "saturated" (demand reaching the capacity of the intersection) in the AM and PM peak periods – in this case it would have been unreasonable to assume that any further volume growth in Parkway Avenue could have been accommodated in those two flow periods. In 2016, the "after" layout has therefore been analysed for slightly higher (1.7% per day or year) total volumes than the "before" layout.

5.17.3 "Annual Sums" Results

Table 5.17 below lists some of the annual totals from the analysis:

Year / Layout	Cost ($/yr)	Fuel (l/yr)	CO_2 emissions (kg/yr)	Total Vehicle Delay (veh-hr/yr)
2001 "Before"	5,668,102	771,428	1,931,496	40,150
2001 "After"	6,859,434	941,640	2,357,996	71,690
2016 "Before"	6,280,909	844,572	2,114,708	47,445
2016 "After"	7,664,082	1,051,140	2,632,320	81,074

Table 5.17 – N00228 – Selected "Annual Sums" Results from aaSIDRA Analysis

Detailed summaries of all the "Annual Sums" figures are given in Figures R1 through R4 in Appendix R.

5.17.4 Discussion

The installation of the traffic signals will result in higher operating costs and delays, as main road vehicles will incur delays that were not present when they had the priority afforded with the "before" layout. The gap between "before" and "after" results is widening in 2016 mostly because of the assumption (above) that the "before" layout would not have permitted any further volume growth on the Parkway Avenue approaches to the intersection.

5.18 N00846 – Pacific Hwy / Cook Dr / North Boambee Rd (Traffic Signals Installation)

5.18.1 Intersection Layouts

This site is located at Coffs Harbour, New South Wales (Coffs Harbour City Council) and was treated in the 1999-2000 financial year.

Prior to the Black Spot treatment, the intersection comprised two closely-spaced T-junctions, with Pacific Highway being the main road (2 lanes in both directions) and Cook Drive and North Boambee Road the terminating minor roads – Cook Drive intersects the highway from the south, while North Boambee Road intersects the highway from the north, approximately 70 metres to the west of the Cook Drive intersection. The Black Spot treatment involved the installation of traffic signals at both intersections (being operated by the one controller unit).

5.18.2 Traffic Volumes and Treatment Notional Life

Peak hour turning movement data was available from RTA SCATS detector collections (June 2007), along with 1998, 2001 & 2004 AADT figures for a nearby Pacific Highway intersection. A 15 year notional life was adopted for the treatment and the above volumes were used to derive 1999 and 2014 estimates.

5.18.3 "Annual Sums" Results

Table 5.18 below lists some of the annual totals from the analysis:

Year / Layout	Cost ($/yr)	Fuel (l/yr)	CO_2 emissions (kg/yr)	Total Vehicle Delay (veh-hr/yr)
1999 "Before"	6,472,264	947,948	2,376,196	21,637
1999 "After"	7,236,832	1,075,684	2,696,772	51,278
2014 "Before"	11,930,292	1,432,292	3,590,756	144,900
2014 "After"	9,914,495	1,467,132	3,667,420	78,289

Table 5.18 – N00846 – Selected "Annual Sums" Results from aaSIDRA Analysis

Detailed summaries of all the "Annual Sums" figures are given in Figures S1 through S4 in Appendix S.

5.18.4 Discussion

Initially, the installation of the traffic signals will result in higher operating costs and delays, as main road vehicles will incur delays that were not present when they had the priority afforded with the "before" layout. By 2014, however, the increasing peak hour congestion associated with the "before" layout would result in the "after" layout producing superior overall cost and delay results (even though the "after" layout would by then also be predicted to experience peak hour congestion).

APPENDIX A

SAMPLE AASIDRA SUMMARIES

Annual sums for aaSIDRA results © **Akcelik & Associates Pty Ltd 2000-2004** **Version 4, September 2004**

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aaSIDRA

Defaults

Cost unit =	($/h)	<< type $/h, DM/h, TL/h, etc
Fuel unit =	(L/h)	<< type L/h or ga/h
Cost unit =	($/y)	<< type $/y, DM/y, TL/y, etc
Fuel unit =	(L/y)	<< type L/y or ga/y

For determining Total hours per flow period per year using the table below, first establish the flow periods for an average work day, then find the weekend flow periods with similar flow rates.

Your defaults

Flow Period Ref. No.	Flow Period Description	Total Hours per year
0	Zero Flow period	0
1	AM Peak	480
2	PM Peak	480
3	Business Hours	3160
4	Medium Off-Peak	2200
5	Light Off-Peak	2440
	Sum of above =	8760
	Check: Hours per year = 365 x 24 =	8760
	Difference	0

<< use this information to adjust the hours

To RESET the table to Standard Defaults, click the button below

Calculation of Total hours per period per year

Flow Period Ref. No.	Flow Period Description	Work Days	Weekends	Holidays	Total hours per year	Work Day Hours	Weekend Day Hours
	No. of days per year >>	240	104	21	8760		
0	Zero Flow period	0	0	0	0		-
1	AM Peak	2	0	0	480	07-09	-
2	PM Peak	2	0	0	480	16-18	-
3	Business Hours	9	8	8	3160	06-07, 09-16, 18-19	10-18
4	Medium Off-Peak	5	8	8	2200	05-06, 19-23	07-10, 18-23
5	Light Off-Peak	6	8	8	2440	23-05	23-07
	Total hours per day >>	24	24	24	8760		

Number of hours per period shown in red

Standard defaults

Flow Period Ref. No.	Flow Period Description	Total Hours per year
0	Zero Flow period	0
1	AM Peak	480
2	PM Peak	480
3	Business Hours	3160
4	Medium Off-Peak	2200
5	Light Off-Peak	2440
	Sum of above =	8760
	Check: Hours per year = 365 x 24 =	8760

For Standard defaults

Average hours in the AADT	Percentage of Hourly Flow Rate in AADT	Percentage of Total Flow in AADT
0.0	0.0%	0.0%
1.3	8.0%	10.5%
1.3	9.0%	11.8%
8.7	6.0%	52.0%
6.0	3.2%	19.1%
6.7	1.0%	6.5%
24		100%

Business Hours flow rate =
71 % of the average flow rate for AM and PM Peak flow rates
MOP flow rate = 53 % of the Business Hours flow rate
LOP flow rate = 16 % of the Business Hours flow rate

Figure A1 – aaSIDRA "Annual Sums" Flow Period Defaults

Adelaide / Wellington / Alexandrina / Flaxley

"Before" Give Way Intersection - 1996 AM Peak

Give-way

Vehicle Movements

Mov No	Turn	Dem Flow (veh/h)	%HV	Deg of Satn (v/c)	Aver Delay (sec)	Level of Service	95% Back of Queue (m)	Prop. Queued	Eff. Stop Rate	Aver Speed (km/h)
Wellington Road										
1	L	26	19.2	0.136	8.9	LOS A	0	0.00	0.67	49.0
2	T	462	5.0	0.136	0.9	LOS A	11	0.24	0.00	56.8
3	R	11	18.2	0.136	10.6	LOS B	11	0.48	0.69	46.9
Approach		**499**	**6.0**	**0.136**	**1.5**	**LOS A**	**11**	**0.24**	**0.05**	**56.0**
Alexandrina Road										
4	L	8	0.0	0.055	17.0	LOS C	2	0.61	0.70	40.9
5	T	11	12.9	0.292	29.3	LOS D	11	0.80	0.96	33.4
5	R	51	12.9	0.292	29.3	LOS D	11	0.80	0.96	33.4
Approach		**70**	**11.4**	**0.293**	**27.9**	**LOS D**	**11**	**0.78**	**0.93**	**34.1**
Adelaide Road										
7	L	117	10.3	0.193	8.6	LOS A	0	0.00	0.67	49.0
8	T	278	2.9	0.193	0.4	LOS A	9	0.07	0.00	59.0
9	R	150	7.3	0.193	11.1	LOS B	9	0.51	0.77	46.2
Approach		**545**	**5.7**	**0.193**	**5.1**	**LOS A**	**9**	**0.18**	**0.36**	**52.7**
Flaxley Road										
10	L	274	3.3	0.406	13.3	LOS B	20	0.60	0.94	44.0
11	T	37	5.5	0.329	34.0	LOS D	12	0.88	1.00	31.1
11	R	18	5.5	0.329	34.0	LOS D	12	0.88	1.00	31.1
Approach		**329**	**3.6**	**0.406**	**16.7**	**LOS C**	**20**	**0.65**	**0.95**	**41.2**
All Vehicles		**1443**	**5.6**	**0.406**	**7.6**	**Not Applicable**	**20**	**0.33**	**0.41**	**49.3**

Figure A2 – Sample aaSIDRA Output Table (Movement Summary)

Annual sums for aaSIDRA results © Akcelik & Associates Pty Ltd 2000-2004 Version 4, September 2004

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Calculation of ANNUAL SUMS

See "Combined Cases" sheet for calculating weighted average of Options A to F as cases (event scenarios)

Design Option / Case: A

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	302,074	47,376	118,704	180	7,973	265	692,640	0	1,038,720	1,706,400	1,464	0	2,194	285,600	0	428,640	7.6	0.41
2	PM Peak	480	312,101	47,232	118,224	183	7,800	263	725,280	0	1,087,680	1,770,720	1,574	0	2,366	283,680	0	425,760	7.8	0.39
3	Business Hours	3160	1,379,150	215,828	540,676	818	35,613	1,204	3,311,680	0	4,967,520	18,517,600	5,277	0	7,900	1,181,840	0	1,772,760	5.7	0.36
4	Medium Off-Peak	2200	500,610	78,760	197,560	297	12,870	438	1,225,400	0	1,839,200	15,521,000	1,628	0	2,442	393,800	0	589,600	4.8	0.32
5	Light Off-Peak	2440	169,141	26,596	66,856	100	4,270	146	419,680	0	629,520	17,507,000	512	0	756	129,320	0	192,760	4.3	0.31
Total per year >>			2,663,076	415,792	1,042,020	1,578	68,526	2,317	6,374,680	0	9,562,640	55,022,720	10,456	0	15,658	2,274,240	0	3,409,520	5.9	0.36
Total per day >>			7,296	1,139	2,855	4	188	6	17,465	0	26,199	150,747	29	0	43	6,231	0	9,341		
Percentage of "Period 1" to daily total >>			9%	9%	9%	9%	9%	9%	8%	NA	8%	2%	11%	NA	11%	10%	NA	10%		
Percentage of "Period 2" to daily total >>			9%	9%	9%	9%	9%	9%	9%	NA	9%	2%	11%	NA	11%	9%	NA	9%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Design Option / Case: B

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	321,653	53,472	134,016	212	10,781	328	692,640	0	1,038,720	1,865,760	1,733	0	2,602	447,360	0	671,520	9.0	0.65
2	PM Peak	480	334,157	53,760	134,640	218	10,781	327	725,280	0	1,087,680	2,195,520	1,886	0	2,827	472,320	0	708,480	9.4	0.65
3	Business Hours	3160	1,514,462	248,060	621,256	992	49,580	1,514	3,311,680	0	4,967,520	16,469,920	7,900	0	11,850	2,000,280	0	2,998,840	8.6	0.60
4	Medium Off-Peak	2200	553,256	90,860	227,480	361	17,996	552	1,225,400	0	1,839,200	11,732,600	2,728	0	4,092	690,800	0	1,034,000	8.0	0.56
5	Light Off-Peak	2440	187,221	30,744	77,104	122	6,051	185	419,680	0	629,520	13,639,600	878	0	1,342	231,800	0	346,480	7.7	0.55
Total per year >>			2,910,748	476,896	1,194,496	1,905	95,189	2,907	6,374,680	0	9,562,640	45,903,400	15,126	0	22,713	3,842,560	0	5,759,320	8.6	0.60
Total per day >>			7,975	1,307	3,273	5	261	8	17,465	0	26,199	125,763	41	0	62	10,528	0	15,779		
Percentage of "Period 1" to daily total >>			8%	9%	9%	8%	9%	9%	8%	NA	8%	3%	9%	NA	9%	9%	NA	9%		
Percentage of "Period 2" to daily total >>			9%	9%	9%	9%	9%	9%	9%	NA	9%	4%	9%	NA	9%	9%	NA	9%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Figure A3 – Sample aaSIDRA "Annual Sums" Output

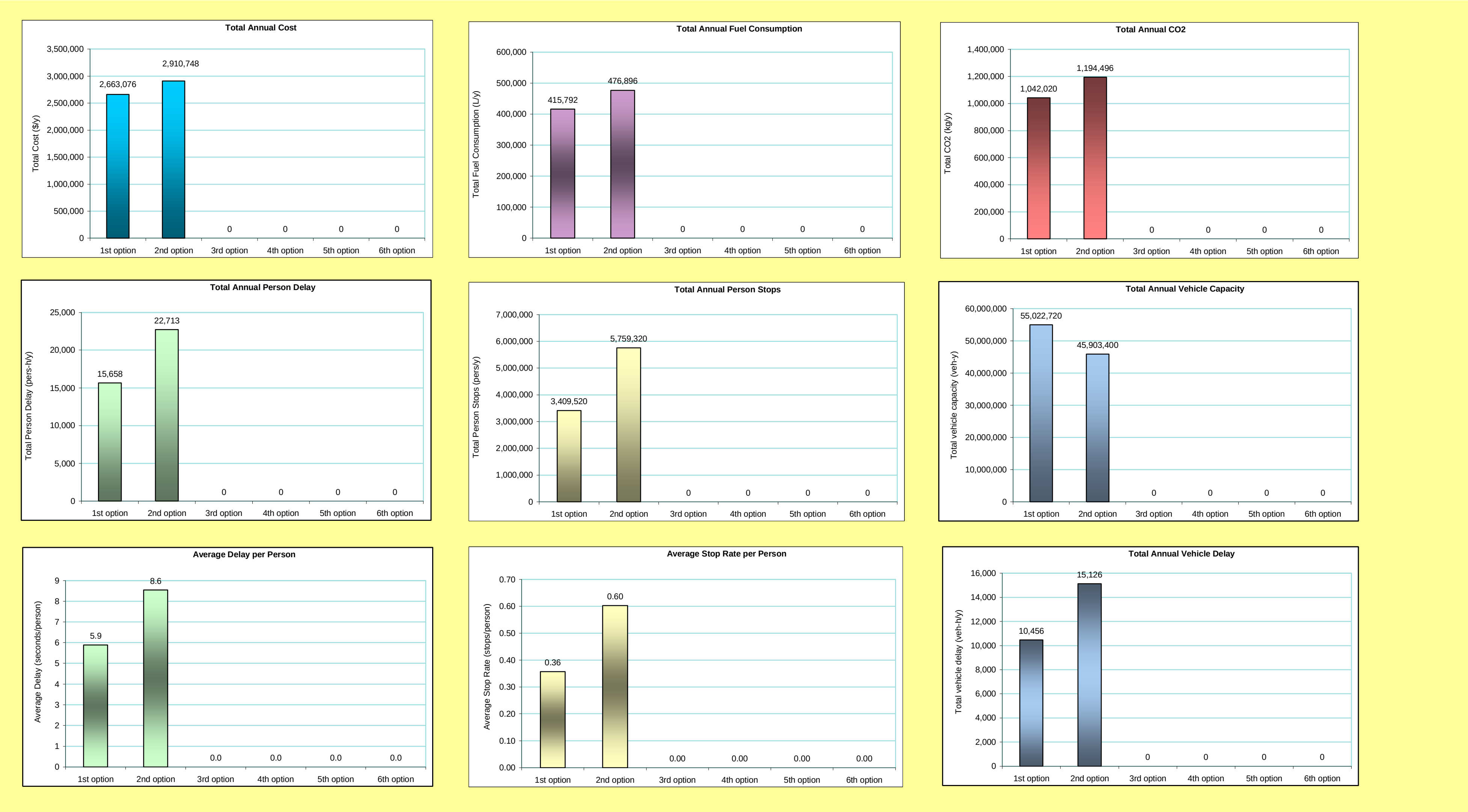

Figure A4 – Sample aaSIDRA “Annual Sums” – “Comparisons” Output

APPENDICES B TO S

CASE STUDY AASIDRA SUMMARIES

Annual sums for aaSIDRA results © Akcelik & Associates Pty Ltd 2000-2004 Version 4, September 2004

Calculation of ANNUAL SUMS

See "Combined Cases" sheet for calculating weighted average of Options A to F as cases (event scenarios)

Design Option / Case: A

Default values set in Defaults sheet

Flow Period Ref. No.	Flow Period Description	Total Hours per year	Total per YEAR: Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Average: Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	313,958	47,376	118,704	180	7,973	265	692,640	0	1,038,720	1,706,400	1,464	0	2,194	285,600	0	428,640	7.6	0.41
2	PM Peak	480	324,192	47,232	118,224	183	7,800	263	725,280	0	1,087,680	1,770,720	1,574	0	2,366	283,680	0	425,760	7.8	0.39
3	Business Hours	3160	1,433,376	215,828	540,676	818	35,613	1,204	3,311,680	0	4,967,520	18,517,600	5,277	0	7,900	1,181,840	0	1,772,760	5.7	0.36
4	Medium Off-Peak	2200	520,344	78,760	197,560	297	12,870	438	1,225,400	0	1,839,200	15,521,000	1,628	0	2,442	393,800	0	589,600	4.8	0.32
5	Light Off-Peak	2440	175,826	26,596	66,856	100	4,270	146	419,680	0	629,520	17,507,000	512	0	756	129,320	0	192,760	4.3	0.31
Total per year >>			2,767,697	415,792	1,042,020	1,578	68,526	2,317	6,374,680	0	9,562,640	55,022,720	10,456	0	15,658	2,274,240	0	3,409,520	5.9	0.36
Total per day >>			7,583	1,139	2,855	4	188	6	17,465	0	26,199	150,747	29	0	43	6,231	0	9,341		
Percentage of "Period 1" to daily total >>			9%	9%	9%	9%	9%	9%	8%	NA	8%	2%	11%	NA	11%	10%	NA	10%		
Percentage of "Period 2" to daily total >>			9%	9%	9%	9%	9%	9%	9%	NA	9%	2%	11%	NA	11%	9%	NA	9%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Design Option / Case: B

Default values set in Defaults sheet

Flow Period Ref. No.	Flow Period Description	Total Hours per year	Total per YEAR: Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Average: Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	331,704	53,136	133,152	210	10,675	326	692,640	0	1,038,720	2,593,440	1,603	0	2,400	422,400	0	633,600	8.3	0.61
2	PM Peak	480	344,630	53,424	133,824	216	10,690	325	725,280	0	1,087,680	2,847,840	1,757	0	2,635	451,680	0	677,760	8.7	0.62
3	Business Hours	3160	1,566,317	246,796	618,412	986	49,201	1,504	3,311,680	0	4,967,520	21,105,640	7,489	0	11,250	1,930,760	0	2,897,720	8.2	0.58
4	Medium Off-Peak	2200	573,716	90,420	226,820	359	17,908	550	1,225,400	0	1,839,200	14,979,800	2,662	0	3,982	682,000	0	1,020,800	7.8	0.56
5	Light Off-Peak	2440	194,492	30,744	77,104	122	6,027	185	419,680	0	629,520	17,382,560	878	0	1,318	231,800	0	346,480	7.5	0.55
Total per year >>			3,010,860	474,520	1,189,312	1,893	94,501	2,891	6,374,680	0	9,562,640	58,909,280	14,390	0	21,584	3,718,640	0	5,576,360	8.1	0.58
Total per day >>			8,249	1,300	3,258	5	259	8	17,465	0	26,199	161,395	39	0	59	10,188	0	15,278		
Percentage of "Period 1" to daily total >>			8%	9%	9%	8%	9%	9%	8%	NA	8%	3%	8%	NA	8%	9%	NA	9%		
Percentage of "Period 2" to daily total >>			9%	9%	9%	9%	9%	9%	9%	NA	9%	4%	9%	NA	9%	9%	NA	9%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Figure B1 – Case Study 1 (S00028) – 1996 aaSIDRA "Annual Sums"

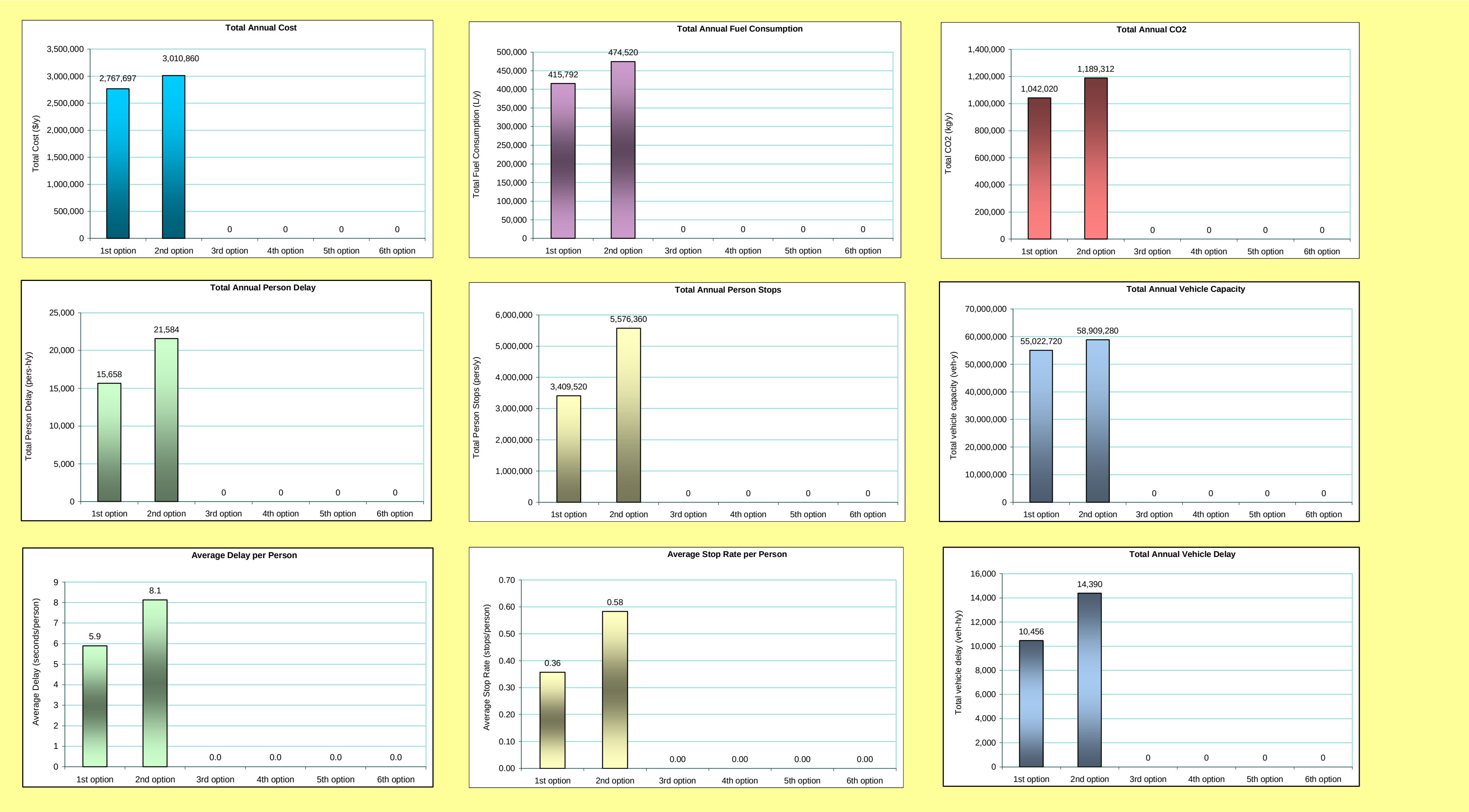

Figure B2 – Case Study 1 (S00028) – 1996 aaSIDRA "Annual Sums Comparisons"

JPT

Annual sums for aaSIDRA results © Akcelik & Associates Pty Ltd 2000-2004 Version 4, September 2004

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Calculation of ANNUAL SUMS

See "Combined Cases" sheet for calculating weighted average of Options A to F as cases (event scenarios)

Design Option / Case: A

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	1,226,568	120,432	301,776	532	18,038	569	1,191,840	0	1,787,520	1,044,960	25,834	0	38,750	1,715,040	0	2,572,800	78.0	1.44
2	PM Peak	480	593,189	75,264	188,496	304	11,962	398	1,044,960	0	1,567,680	1,044,960	6,605	0	9,912	515,520	0	773,280	22.8	0.49
3	Business Hours	3160	2,410,164	352,340	882,272	1,359	58,650	1,959	5,232,960	0	7,849,440	9,849,720	13,146	0	19,750	2,177,240	0	3,267,440	9.1	0.42
4	Medium Off-Peak	2200	831,952	125,620	314,820	475	20,680	702	1,936,000	0	2,904,000	13,802,800	2,882	0	4,334	668,800	0	1,003,200	5.4	0.35
5	Light Off-Peak	2440	275,086	41,724	104,676	156	6,734	232	653,920	0	980,880	18,326,840	805	0	1,220	202,520	0	305,000	4.5	0.31
Total per year >>			5,336,958	715,380	1,792,040	2,826	116,064	3,860	10,059,680	0	15,089,520	44,069,280	49,271	0	73,966	5,279,120	0	7,921,720	17.6	0.52
Total per day >>			14,622	1,960	4,910	8	318	11	27,561	0	41,341	120,738	135	0	203	14,463	0	21,703		
Percentage of "Period 1" to daily total >>			17%	13%	13%	14%	12%	11%	9%	NA	9%	2%	40%	NA	40%	25%	NA	25%		
Percentage of "Period 2" to daily total >>			8%	8%	8%	8%	8%	8%	8%	NA	8%	2%	10%	NA	10%	7%	NA	7%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Design Option / Case: B

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	585,355	93,408	234,048	372	19,027	576	1,191,840	0	1,787,520	2,072,640	3,182	0	4,771	852,960	0	1,279,680	9.6	0.72
2	PM Peak	480	503,304	77,904	195,120	316	15,710	476	1,044,960	0	1,567,680	2,794,080	2,746	0	4,118	704,160	0	1,056,480	9.5	0.67
3	Business Hours	3160	2,505,185	394,368	988,132	1,580	79,253	2,414	5,232,960	0	7,849,440	20,619,000	12,608	0	18,897	3,295,880	0	4,945,400	8.7	0.63
4	Medium Off-Peak	2200	912,736	143,880	360,580	574	28,622	876	1,936,000	0	2,904,000	14,781,800	4,312	0	6,468	1,108,800	0	1,663,200	8.0	0.57
5	Light Off-Peak	2440	304,122	48,068	120,536	190	9,467	290	653,920	0	980,880	17,001,920	1,391	0	2,074	358,680	0	539,240	7.6	0.55
Total per year >>			4,810,702	757,628	1,898,416	3,033	152,080	4,632	10,059,680	0	15,089,520	57,269,440	24,239	0	36,328	6,320,480	0	9,484,000	8.7	0.63
Total per day >>			13,180	2,076	5,201	8	417	13	27,561	0	41,341	156,903	66	0	100	17,316	0	25,984		
Percentage of "Period 1" to daily total >>			9%	9%	9%	9%	10%	9%	9%	NA	9%	3%	10%	NA	10%	10%	NA	10%		
Percentage of "Period 2" to daily total >>			8%	8%	8%	8%	8%	8%	8%	NA	8%	4%	9%	NA	9%	8%	NA	8%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Figure B3 – Case Study 1 (S00028) – 2016 aaSIDRA "Annual Sums"

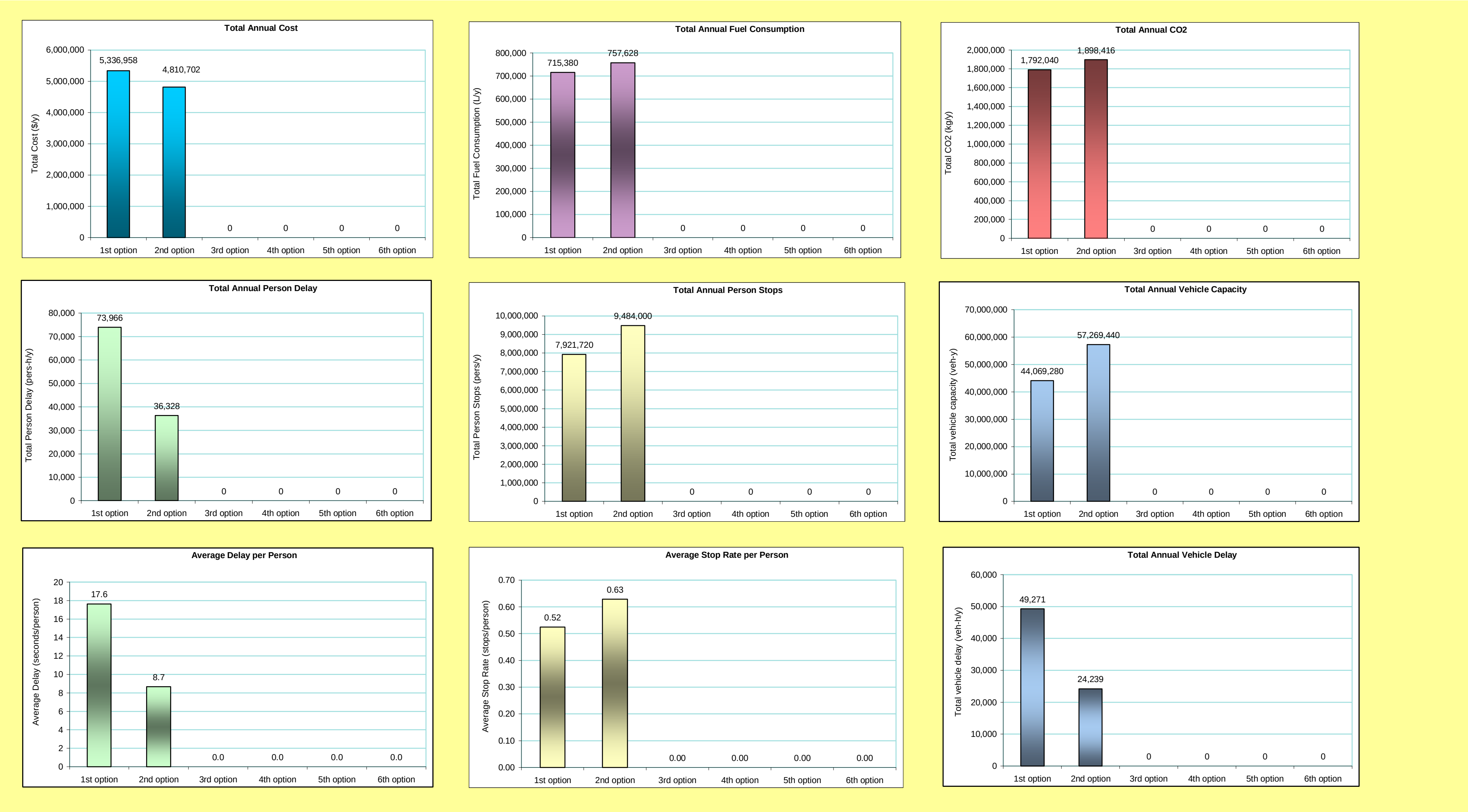

Figure B4 – Case Study 1 (S00028) – 2016 aaSIDRA "Annual Sums Comparisons"

Annual sums for aaSIDRA results © Akcelik & Associates Pty Ltd 2000-2004 Version 4, September 2004

Calculation of ANNUAL SUMS

See "Combined Cases" sheet for calculating weighted average of Options A to F as cases (event scenarios)

Design Option / Case: A

Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Average Person delay	Average Person stops
Default values set in Defaults sheet			Total per YEAR																Average	
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	335,131	56,592	142,944	193	10,066	319	511,680	0	767,520	545,280	3,264	0	4,901	254,400	0	382,080	23.0	0.50
2	PM Peak	480	333,898	51,792	130,032	198	9,643	300	620,160	0	930,240	816,480	2,645	0	3,965	334,560	0	502,080	15.3	0.54
3	Business Hours	3160	1,353,807	239,528	602,928	841	44,050	1,394	2,648,080	0	3,972,120	8,146,480	6,699	0	10,049	1,185,000	0	1,775,920	9.1	0.45
4	Medium Off-Peak	2200	475,618	84,920	214,060	293	15,136	486	974,600	0	1,463,000	9,785,600	1,826	0	2,728	404,800	0	609,400	6.7	0.42
5	Light Off-Peak	2440	160,381	28,792	72,224	98	4,929	161	336,720	0	505,080	15,713,600	561	0	830	139,080	0	209,840	5.9	0.42
Total per year >>			2,658,835	461,624	1,162,188	1,622	83,824	2,660	5,091,240	0	7,637,960	35,007,440	14,995	0	22,472	2,317,840	0	3,479,320	10.6	0.46
Total per day >>			7,284	1,265	3,184	4	230	7	13,949	0	20,926	95,911	41	0	62	6,350	0	9,532		
Percentage of "Period 1" to daily total >>			10%	9%	9%	9%	9%	9%	8%	NA	8%	1%	17%	NA	17%	8%	NA	8%		
Percentage of "Period 2" to daily total >>			10%	9%	9%	9%	9%	9%	9%	NA	9%	2%	13%	NA	13%	11%	NA	11%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Design Option / Case: B

Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Average Person delay	Average Person stops
Default values set in Defaults sheet			Total per YEAR																Average	
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	297,134	58,176	146,928	201	11,914	365	511,680	0	767,520	1,221,600	1,680	0	2,520	348,000	0	522,240	11.8	0.68
2	PM Peak	480	324,538	53,616	134,640	208	10,848	328	620,160	0	930,240	1,447,200	2,150	0	3,226	432,000	0	648,000	12.5	0.70
3	Business Hours	3160	1,440,518	259,120	651,908	942	52,172	1,596	2,648,080	0	3,972,120	10,965,200	8,627	0	12,924	1,731,680	0	2,600,680	11.7	0.65
4	Medium Off-Peak	2200	525,536	94,380	237,380	341	18,788	576	974,600	0	1,463,000	7,748,400	3,080	0	4,620	600,600	0	899,800	11.4	0.62
5	Light Off-Peak	2440	181,219	32,452	81,984	117	6,466	198	336,720	0	505,080	8,859,640	1,049	0	1,586	192,760	0	287,920	11.3	0.57
Total per year >>			2,768,944	497,744	1,252,840	1,809	100,187	3,063	5,091,240	0	7,637,960	30,242,040	16,586	0	24,876	3,305,040	0	4,958,640	11.7	0.65
Total per day >>			7,586	1,364	3,432	5	274	8	13,949	0	20,926	82,855	45	0	68	9,055	0	13,585		
Percentage of "Period 1" to daily total >>			8%	9%	9%	8%	9%	9%	8%	NA	8%	3%	8%	NA	8%	8%	NA	8%		
Percentage of "Period 2" to daily total >>			9%	8%	8%	9%	8%	8%	9%	NA	9%	4%	10%	NA	10%	10%	NA	10%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Figure C1 – Case Study 2 (S00004) – 1996 aaSIDRA "Annual Sums"

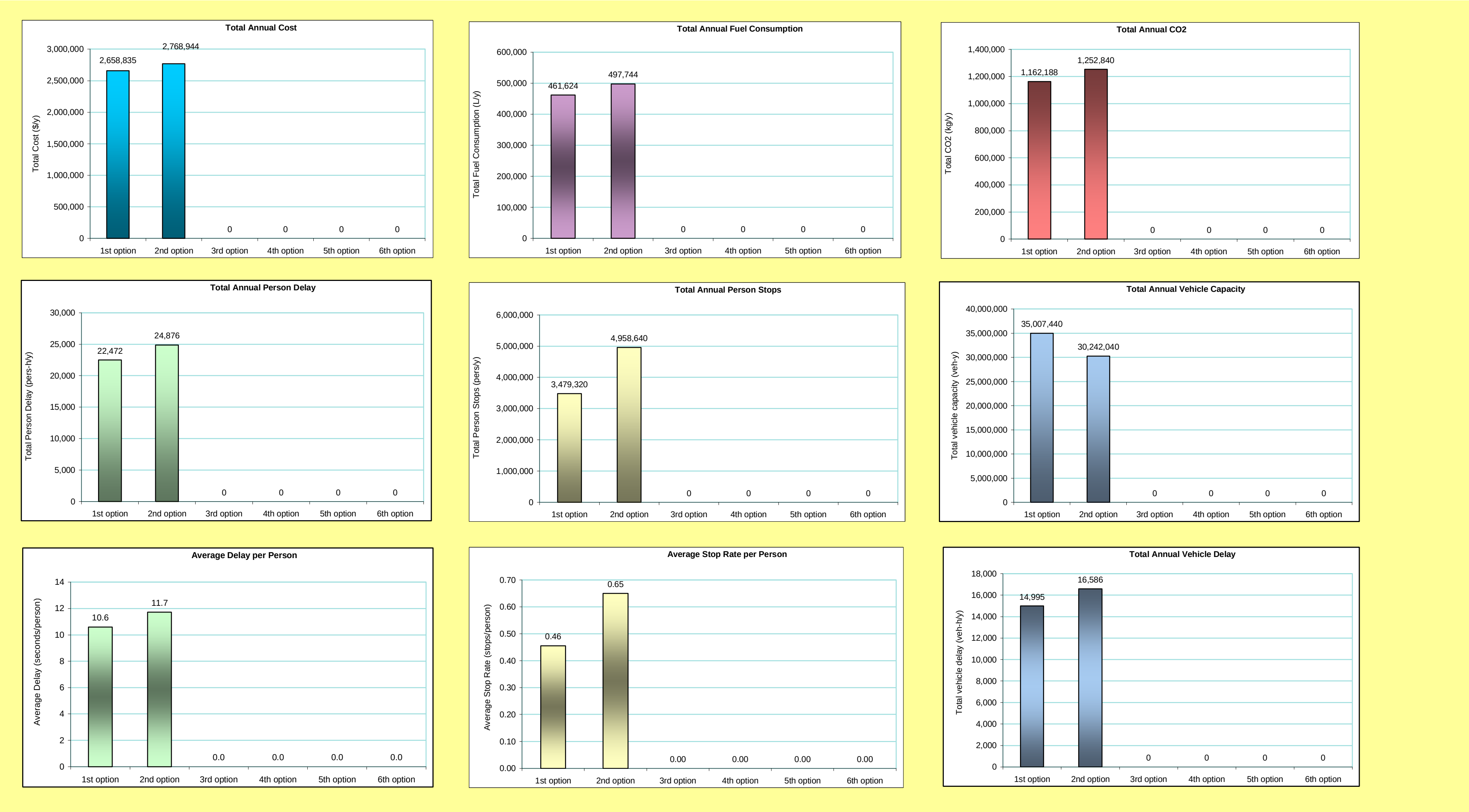

Figure C2 – Case Study 2 (S00004) – 1996 aaSIDRA "Annual Sums Comparisons"

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Annual sums for aaSIDRA results © **Akcelik & Associates Pty Ltd 2000-2004** **Version 4, September 2004**

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Calculation of ANNUAL SUMS

See "Combined Cases" sheet for calculating weighted average of Options A to F as cases (event scenarios)

Design Option / Case: A

Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
Default values set in Defaults sheet			Total per YEAR																Average	
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	411,595	62,688	158,400	220	10,819	343	532,800	0	799,200	503,520	5,510	0	8,270	310,080	0	465,600	37.3	0.58
2	PM Peak	480	519,178	66,000	165,696	267	11,539	357	694,560	0	1,041,600	660,480	7,930	0	11,899	547,200	0	820,800	41.1	0.79
3	Business Hours	3160	1,548,937	271,444	683,508	957	50,212	1,583	2,970,400	0	4,455,600	6,989,920	8,500	0	12,766	1,355,640	0	2,035,040	10.3	0.46
4	Medium Off-Peak	2200	533,236	95,480	240,240	330	17,094	548	1,086,800	0	1,630,200	9,097,000	2,090	0	3,146	457,600	0	686,400	6.9	0.42
5	Light Off-Peak	2440	178,950	31,964	80,520	107	5,490	178	375,760	0	563,640	15,559,880	610	0	927	153,720	0	231,800	5.9	0.41
Total per year >>			3,191,896	527,576	1,328,364	1,883	95,155	3,009	5,660,320	0	8,490,240	32,810,800	24,640	0	37,009	2,824,240	0	4,239,640	15.7	0.50
Total per day >>			8,745	1,445	3,639	5	261	8	15,508	0	23,261	89,893	68	0	101	7,738	0	11,615		
Percentage of "Period 1" to daily total >>			10%	9%	9%	9%	9%	9%	7%	NA	7%	1%	17%	NA	17%	8%	NA	8%		
Percentage of "Period 2" to daily total >>			12%	10%	9%	11%	9%	9%	9%	NA	9%	2%	24%	NA	24%	15%	NA	15%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Design Option / Case: B

Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
Default values set in Defaults sheet			Total per YEAR																Average	
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	334,589	65,520	165,456	227	13,478	412	573,600	0	860,160	1,222,080	1,915	0	2,870	397,440	0	595,680	12.0	0.69
2	PM Peak	480	364,704	60,336	151,440	234	12,245	370	694,560	0	1,041,600	1,454,400	2,434	0	3,653	492,000	0	737,760	12.6	0.71
3	Business Hours	3160	1,619,437	291,352	733,120	1,062	58,839	1,798	2,970,400	0	4,455,600	10,946,240	9,733	0	14,631	1,968,680	0	2,954,600	11.8	0.66
4	Medium Off-Peak	2200	587,202	105,600	265,540	383	21,054	647	1,086,800	0	1,630,200	7,730,800	3,454	0	5,170	675,400	0	1,014,200	11.4	0.62
5	Light Off-Peak	2440	201,959	36,356	91,256	132	7,174	222	375,760	0	563,640	8,718,120	1,171	0	1,757	217,160	0	324,520	11.2	0.58
Total per year >>			3,107,890	559,164	1,406,812	2,037	112,790	3,449	5,701,120	0	8,551,200	30,071,640	18,707	0	28,081	3,750,680	0	5,626,760	11.8	0.66
Total per day >>			8,515	1,532	3,854	6	309	9	15,620	0	23,428	82,388	51	0	77	10,276	0	15,416		
Percentage of "Period 1" to daily total >>			8%	9%	9%	8%	9%	9%	8%	NA	8%	3%	8%	NA	8%	8%	NA	8%		
Percentage of "Period 2" to daily total >>			9%	8%	8%	9%	8%	8%	9%	NA	9%	4%	10%	NA	10%	10%	NA	10%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Figure C3 – Case Study 2 (S00004) – 2000 aaSIDRA "Annual Sums"

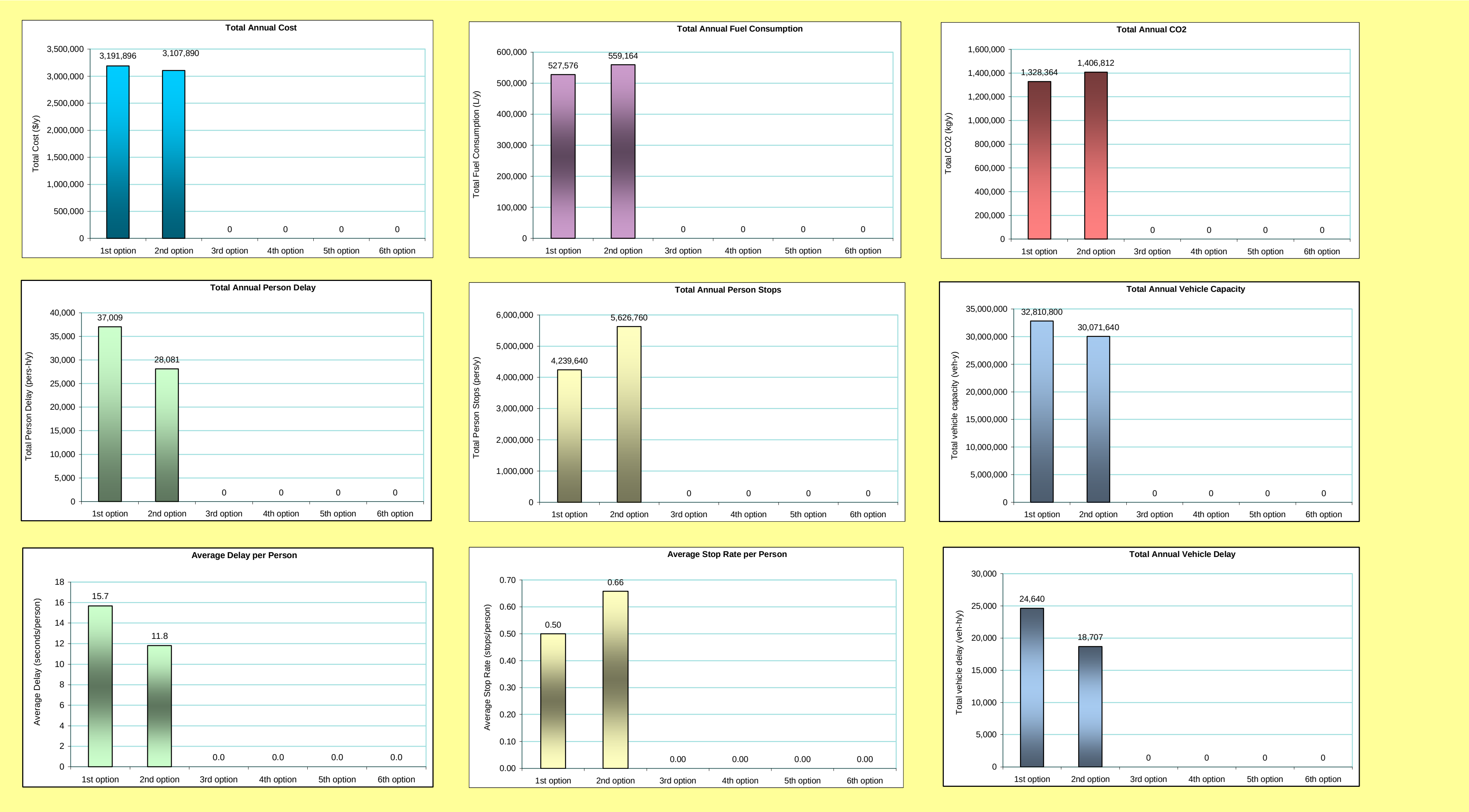

Figure C4 – Case Study 2 (S0004) – 2000 aaSIDRA "Annual Sums Comparisons"

Annual sums for aaSIDRA results © Akcelik & Associates Pty Ltd 2000-2004 Version 4, September 2004

Calculation of ANNUAL SUMS

See "Combined Cases" sheet for calculating weighted average of Options A to F as cases (event scenarios)

Design Option / Case: A

Default values set in Defaults sheet			Total per YEAR																	Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX		Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)		(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	847,939	106,896	267,312	446	17,539	576		1,590,720	0	2,386,080	2,626,080	8,650	0	12,979	887,520	0	1,331,040	19.6	0.56
2	PM Peak	480	1,142,558	141,312	353,472	611	24,974	775		1,931,520	0	2,897,280	2,678,400	14,045	0	21,062	1,341,120	0	2,011,680	26.2	0.69
3	Business Hours	3160	4,290,585	548,892	1,373,336	2,288	91,008	2,980		8,228,640	0	12,342,960	15,916,920	41,428	0	62,126	4,376,600	0	6,566,480	18.1	0.53
4	Medium Off-Peak	2200	1,457,610	206,800	517,220	867	38,896	1,201		3,038,200	0	4,558,400	6,492,200	10,032	0	15,048	1,903,000	0	2,853,400	11.9	0.63
5	Light Off-Peak	2440	481,192	67,832	170,068	283	12,420	390		1,022,360	0	1,532,320	7,293,160	3,123	0	4,709	556,320	0	836,920	11.1	0.55
Total per year >>			8,219,885	1,071,732	2,681,408	4,495	184,837	5,923		15,811,440	0	23,717,040	35,006,760	77,277	0	115,924	9,064,560	0	13,599,520	17.6	0.57
Total per day >>			22,520	2,936	7,346	12	506	16		43,319	0	64,978	95,909	212	0	318	24,834	0	37,259		
Percentage of "Period 1" to daily total >>			8%	8%	8%	8%	7%	7%		8%	NA	8%	6%	9%	NA	9%	7%	NA	7%		
Percentage of "Period 2" to daily total >>			11%	10%	10%	10%	10%	10%		9%	NA	9%	6%	14%	NA	14%	11%	NA	11%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Design Option / Case: B

Default values set in Defaults sheet			Total per YEAR																	Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX		Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)		(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	816,974	103,680	259,344	428	16,550	555		1,590,720	0	2,386,080	2,324,640	7,694	0	11,539	821,280	0	1,231,680	17.4	0.52
2	PM Peak	480	1,119,235	137,232	343,200	588	23,314	741		1,931,520	0	2,897,280	2,655,360	13,450	0	20,174	1,213,440	0	1,820,160	25.1	0.63
3	Business Hours	3160	4,192,119	538,148	1,345,844	2,221	87,374	2,904		8,228,640	0	12,342,960	19,901,680	38,426	0	57,670	4,145,920	0	6,218,880	16.8	0.50
4	Medium Off-Peak	2200	1,457,610	206,800	517,220	867	38,896	1,201		3,038,200	0	4,558,400	6,492,200	10,032	0	15,048	1,903,000	0	2,853,400	11.9	0.63
5	Light Off-Peak	2440	481,192	67,832	170,068	283	12,420	390		1,022,360	0	1,532,320	7,293,160	3,123	0	4,709	556,320	0	836,920	11.1	0.55
Total per year >>			8,067,131	1,053,692	2,635,676	4,387	178,554	5,792		15,811,440	0	23,717,040	38,667,040	72,725	0	109,141	8,639,960	0	12,961,040	16.6	0.55
Total per day >>			22,102	2,887	7,221	12	489	16		43,319	0	64,978	105,937	199	0	299	23,671	0	35,510		
Percentage of "Period 1" to daily total >>			8%	7%	7%	7%	7%	7%		8%	NA	8%	5%	8%	NA	8%	7%	NA	7%		
Percentage of "Period 2" to daily total >>			11%	10%	10%	10%	10%	10%		9%	NA	9%	5%	14%	NA	14%	11%	NA	11%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Figure D1 – Case Study 3 (Q00569) – 2001 aaSIDRA "Annual Sums"

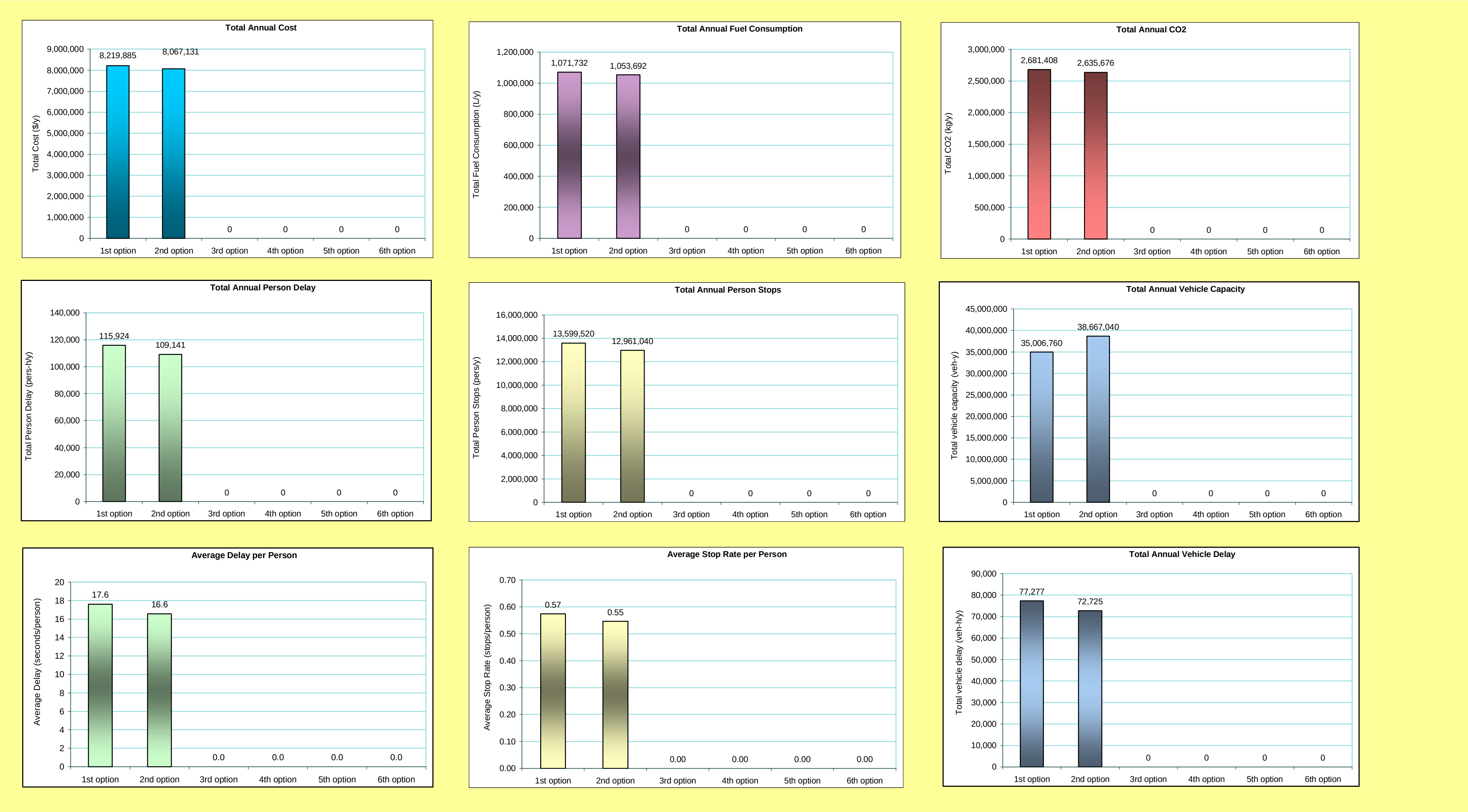

Figure D2 – Case Study 3 (Q00569) – 2001 aaSIDRA “Annual Sums Comparisons”

Annual sums for aaSIDRA results **© Akcelik & Associates Pty Ltd 2000-2004** **Version 4, September 2004**

Calculation of ANNUAL SUMS

See "Combined Cases" sheet for calculating weighted average of Options A to F as cases (event scenarios)

Design Option / Case: A

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	1,083,893	133,584	334,128	570	22,680	723	1,880,640	0	2,820,960	2,467,680	12,830	0	19,243	1,206,240	0	1,809,120	24.6	0.64
2	PM Peak	480	1,350,240	165,120	412,992	726	30,139	912	2,150,400	0	3,225,600	2,635,200	18,053	0	27,082	1,685,760	0	2,528,640	30.2	0.78
3	Business Hours	3160	5,058,402	643,376	1,609,704	2,702	108,578	3,508	9,416,800	0	14,125,200	15,683,080	52,014	0	77,989	5,365,680	0	8,051,680	19.9	0.57
4	Medium Off-Peak	2200	1,674,970	237,820	594,880	1,001	45,100	1,386	3,460,600	0	5,192,000	6,256,800	11,836	0	17,754	2,230,800	0	3,346,200	12.3	0.64
5	Light Off-Peak	2440	565,519	79,788	199,836	332	14,664	459	1,195,600	0	1,793,400	6,927,160	3,733	0	5,612	666,120	0	997,960	11.3	0.56
Total per year >>			9,733,023	1,259,688	3,151,540	5,330	221,161	6,988	18,104,040	0	27,157,160	33,969,920	98,466	0	147,680	11,154,600	0	16,733,600	19.6	0.62
Total per day >>			26,666	3,451	8,634	15	606	19	49,600	0	74,403	93,068	270	0	405	30,561	0	45,845		
Percentage of "Period 1" to daily total >>			8%	8%	8%	8%	8%	8%	8%	NA	8%	6%	10%	NA	10%	8%	NA	8%		
Percentage of "Period 2" to daily total >>			11%	10%	10%	10%	10%	10%	9%	NA	9%	6%	14%	NA	14%	11%	NA	11%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Design Option / Case: B

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	1,028,458	128,352	321,072	539	21,178	691	1,880,640	0	2,820,960	2,574,720	11,083	0	16,622	1,094,880	0	1,642,560	21.2	0.58
2	PM Peak	480	1,294,651	157,392	393,648	681	27,283	853	2,150,400	0	3,225,600	2,718,720	16,493	0	24,739	1,470,720	0	2,206,080	27.6	0.68
3	Business Hours	3160	4,940,755	630,736	1,577,472	2,629	104,438	3,419	9,416,800	0	14,125,200	19,155,920	48,411	0	72,617	5,103,400	0	7,653,520	18.5	0.54
4	Medium Off-Peak	2200	1,674,970	237,820	594,880	1,001	45,100	1,386	3,460,600	0	5,192,000	6,256,800	11,836	0	17,754	2,230,800	0	3,346,200	12.3	0.64
5	Light Off-Peak	2440	565,519	79,788	199,836	332	14,664	459	1,195,600	0	1,793,400	6,927,160	3,733	0	5,612	666,120	0	997,960	11.3	0.56
Total per year >>			9,504,352	1,234,088	3,086,908	5,182	212,663	6,808	18,104,040	0	27,157,160	37,633,320	91,556	0	137,344	10,565,920	0	15,846,320	18.2	0.58
Total per day >>			26,039	3,381	8,457	14	583	19	49,600	0	74,403	103,105	251	0	376	28,948	0	43,415		
Percentage of "Period 1" to daily total >>			8%	8%	8%	8%	8%	8%	8%	NA	8%	5%	9%	NA	9%	8%	NA	8%		
Percentage of "Period 2" to daily total >>			10%	10%	10%	10%	10%	10%	9%	NA	9%	5%	14%	NA	14%	11%	NA	11%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Figure D3 – Case Study 3 (Q00569) – 2016 aaSIDRA "Annual Sums"

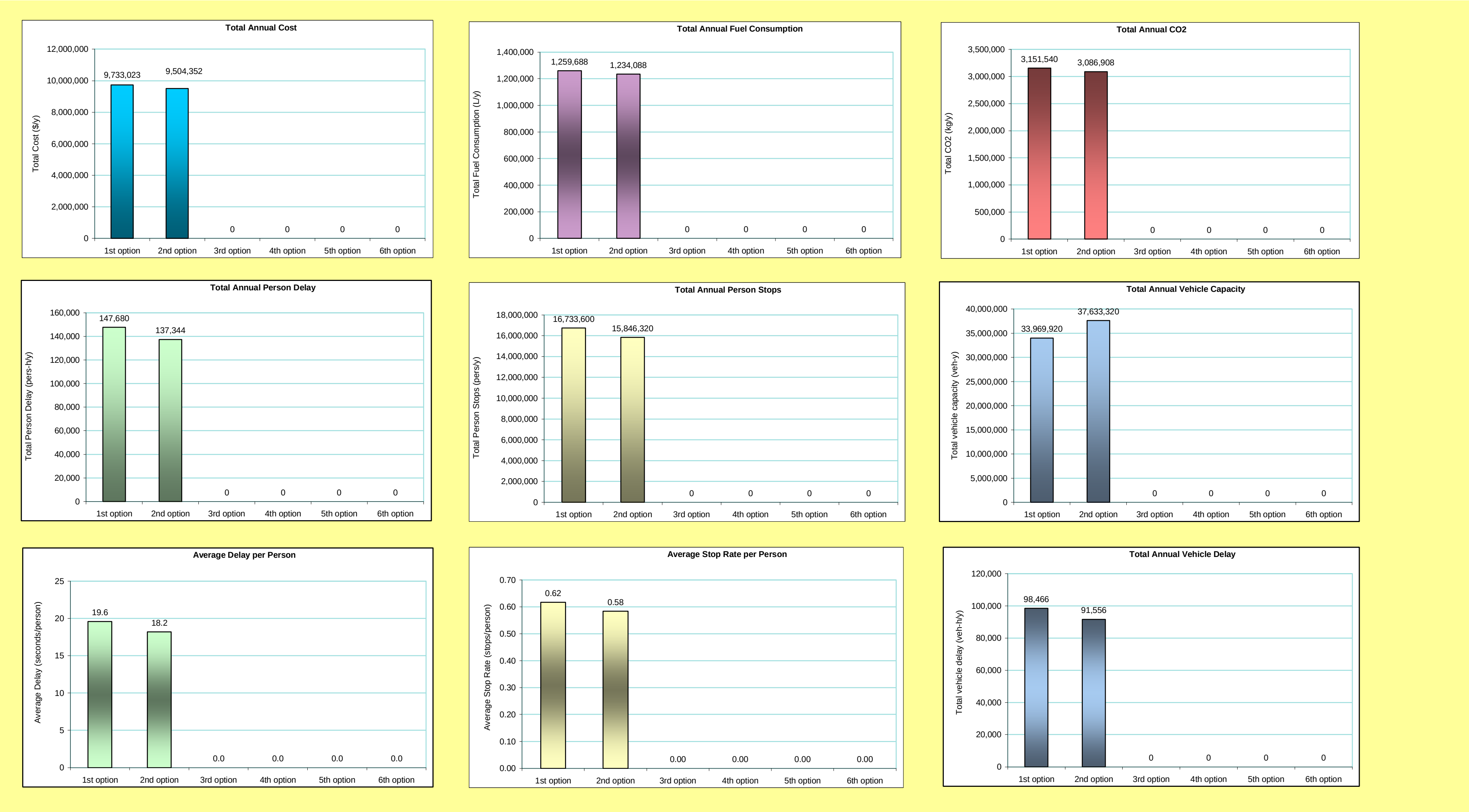

Figure D4 – Case Study 3 (Q00569) – 2016 aaSIDRA “Annual Sums Comparisons”

Annual sums for aaSIDRA results © Akcelik & Associates Pty Ltd 2000-2004 **Version 4, September 2004**

Calculation of ANNUAL SUMS

See "Combined Cases" sheet for calculating weighted average of Options A to F as cases (event scenarios)

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aaSIDRA

Design Option / Case: A

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	1,203,830	170,928	428,640	684	31,622	973	2,002,560	0	3,003,840	2,274,240	13,118	0	19,675	1,485,120	0	2,227,680	23.6	0.74
2	PM Peak	480	1,241,856	177,216	444,528	708	33,014	1,014	2,047,680	0	3,071,520	2,374,080	13,627	0	20,443	1,540,320	0	2,310,720	24.0	0.75
3	Business Hours	3160	5,385,841	767,248	1,924,756	2,999	134,426	4,263	9,467,360	0	14,201,040	14,539,160	53,341	0	80,011	5,912,360	0	8,866,960	20.3	0.62
4	Medium Off-Peak	2200	1,942,402	296,560	743,820	1,179	57,926	1,758	3,491,400	0	5,236,000	5,761,800	16,874	0	25,300	2,519,000	0	3,779,600	17.4	0.72
5	Light Off-Peak	2440	659,947	100,528	252,296	400	19,691	598	1,178,520	0	1,766,560	4,445,680	5,807	0	8,735	785,680	0	1,178,520	17.8	0.67
Total per year >>			10,433,876	1,512,480	3,794,040	5,971	276,680	8,606	18,187,520	0	27,278,960	29,394,960	102,768	0	154,165	12,242,480	0	18,363,480	20.3	0.67
Total per day >>			28,586	4,144	10,395	16	758	24	49,829	0	74,737	80,534	282	0	422	33,541	0	50,311		
Percentage of "Period 1" to daily total >>			9%	9%	9%	9%	9%	9%	8%	NA	8%	6%	10%	NA	10%	9%	NA	9%		
Percentage of "Period 2" to daily total >>			9%	9%	9%	9%	9%	9%	9%	NA	9%	6%	10%	NA	10%	10%	NA	10%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Design Option / Case: B

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	1,203,830	170,928	428,640	684	31,622	973	2,002,560	0	3,003,840	2,274,240	13,118	0	19,675	1,485,120	0	2,227,680	23.6	0.74
2	PM Peak	480	1,241,856	177,216	444,528	708	33,014	1,014	2,047,680	0	3,071,520	2,374,080	13,627	0	20,443	1,540,320	0	2,310,720	24.0	0.75
3	Business Hours	3160	5,385,841	767,248	1,924,756	2,999	134,426	4,263	9,467,360	0	14,201,040	14,539,160	53,341	0	80,011	5,912,360	0	8,866,960	20.3	0.62
4	Medium Off-Peak	2200	1,942,402	296,560	743,820	1,179	57,926	1,758	3,491,400	0	5,236,000	5,761,800	16,874	0	25,300	2,519,000	0	3,779,600	17.4	0.72
5	Light Off-Peak	2440	660,752	100,772	252,540	400	19,691	598	1,178,520	0	1,766,560	4,445,680	5,856	0	8,760	785,680	0	1,178,520	17.9	0.67
Total per year >>			10,434,681	1,512,724	3,794,284	5,971	276,680	8,606	18,187,520	0	27,278,960	29,394,960	102,816	0	154,189	12,242,480	0	18,363,480	20.3	0.67
Total per day >>			28,588	4,144	10,395	16	758	24	49,829	0	74,737	80,534	282	0	422	33,541	0	50,311		
Percentage of "Period 1" to daily total >>			9%	9%	9%	9%	9%	9%	8%	NA	8%	6%	10%	NA	10%	9%	NA	9%		
Percentage of "Period 2" to daily total >>			9%	9%	9%	9%	9%	9%	9%	NA	9%	6%	10%	NA	10%	10%	NA	10%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Figure E1 – Case Study 4 (Q00768) – 2001 aaSIDRA "Annual Sums"

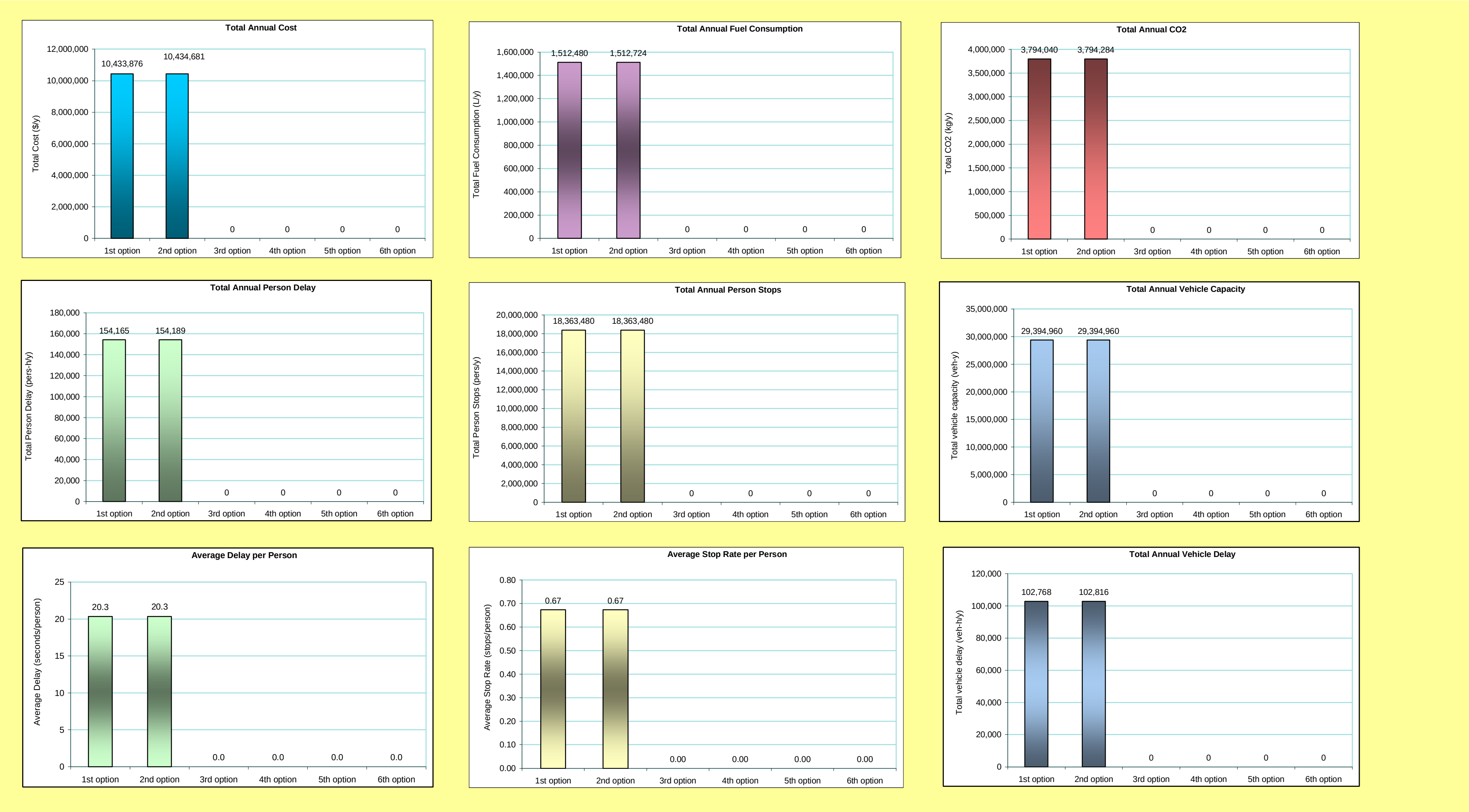

Figure E2 – Case Study 4 (Q00768) – 2001 aaSIDRA "Annual Sums Comparisons"

Annual sums for aaSIDRA results © **Akcelik & Associates Pty Ltd 2000-2004** **Version 4, September 2004**

Calculation of ANNUAL SUMS

See "Combined Cases" sheet for calculating weighted average of Options A to F as cases (event scenarios)

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aaSIDRA

Design Option / Case: A

Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
Default values set in Defaults sheet			Total per YEAR																Average	
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	1,504,435	205,248	514,704	849	39,571	1,183	2,202,240	0	3,303,360	2,349,600	20,074	0	30,115	1,932,480	0	2,898,720	32.8	0.88
2	PM Peak	480	1,502,784	209,520	525,600	860	40,762	1,219	2,252,160	0	3,378,240	2,436,960	19,147	0	28,723	1,973,280	0	2,960,160	30.6	0.88
3	Business Hours	3160	6,042,994	862,048	2,162,388	3,400	154,650	4,844	10,409,040	0	15,613,560	14,387,480	61,904	0	92,872	6,936,200	0	10,405,880	21.4	0.67
4	Medium Off-Peak	2200	2,143,614	327,800	822,360	1,307	64,658	1,954	3,821,400	0	5,733,200	6,072,000	18,876	0	28,314	2,838,000	0	4,257,000	17.8	0.74
5	Light Off-Peak	2440	742,468	113,216	284,016	451	22,228	673	1,322,480	0	1,983,720	4,428,600	6,588	0	9,882	895,480	0	1,344,440	17.9	0.68
Total per year >>			11,936,295	1,717,832	4,309,068	6,867	321,870	9,873	20,007,320	0	30,012,080	29,674,640	126,589	0	189,907	14,575,440	0	21,866,200	22.8	0.73
Total per day >>			32,702	4,706	11,806	19	882	27	54,815	0	82,225	81,300	347	0	520	39,933	0	59,907		
Percentage of "Period 1" to daily total >>			10%	9%	9%	9%	9%	9%	8%	NA	8%	6%	12%	NA	12%	10%	NA	10%		
Percentage of "Period 2" to daily total >>			10%	9%	9%	10%	10%	9%	9%	NA	9%	6%	12%	NA	12%	10%	NA	10%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Design Option / Case: B

Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
Default values set in Defaults sheet			Total per YEAR																Average	
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	1,504,435	205,248	514,704	849	39,571	1,183	2,202,240	0	3,303,360	2,349,600	20,074	0	30,115	1,932,480	0	2,898,720	32.8	0.88
2	PM Peak	480	1,502,784	209,520	525,600	860	40,762	1,219	2,252,160	0	3,378,240	2,436,960	19,147	0	28,723	1,973,280	0	2,960,160	30.6	0.88
3	Business Hours	3160	6,042,994	862,048	2,162,388	3,400	154,650	4,844	10,409,040	0	15,613,560	14,387,480	61,904	0	92,872	6,936,200	0	10,405,880	21.4	0.67
4	Medium Off-Peak	2200	2,143,614	327,800	822,360	1,307	64,658	1,954	3,821,400	0	5,733,200	6,072,000	18,876	0	28,314	2,838,000	0	4,257,000	17.8	0.74
5	Light Off-Peak	2440	743,273	113,216	284,016	451	22,228	673	1,322,480	0	1,983,720	4,428,600	6,612	0	9,906	895,480	0	1,344,440	18.0	0.68
Total per year >>			11,937,100	1,717,832	4,309,068	6,867	321,870	9,873	20,007,320	0	30,012,080	29,674,640	126,614	0	189,931	14,575,440	0	21,866,200	22.8	0.73
Total per day >>			32,704	4,706	11,806	19	882	27	54,815	0	82,225	81,300	347	0	520	39,933	0	59,907		
Percentage of "Period 1" to daily total >>			10%	9%	9%	9%	9%	9%	8%	NA	8%	6%	12%	NA	12%	10%	NA	10%		
Percentage of "Period 2" to daily total >>			10%	9%	9%	10%	10%	9%	9%	NA	9%	6%	11%	NA	11%	10%	NA	10%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Figure E3 – Case Study 4 (Q00768) – 2011 aaSIDRA "Annual Sums"

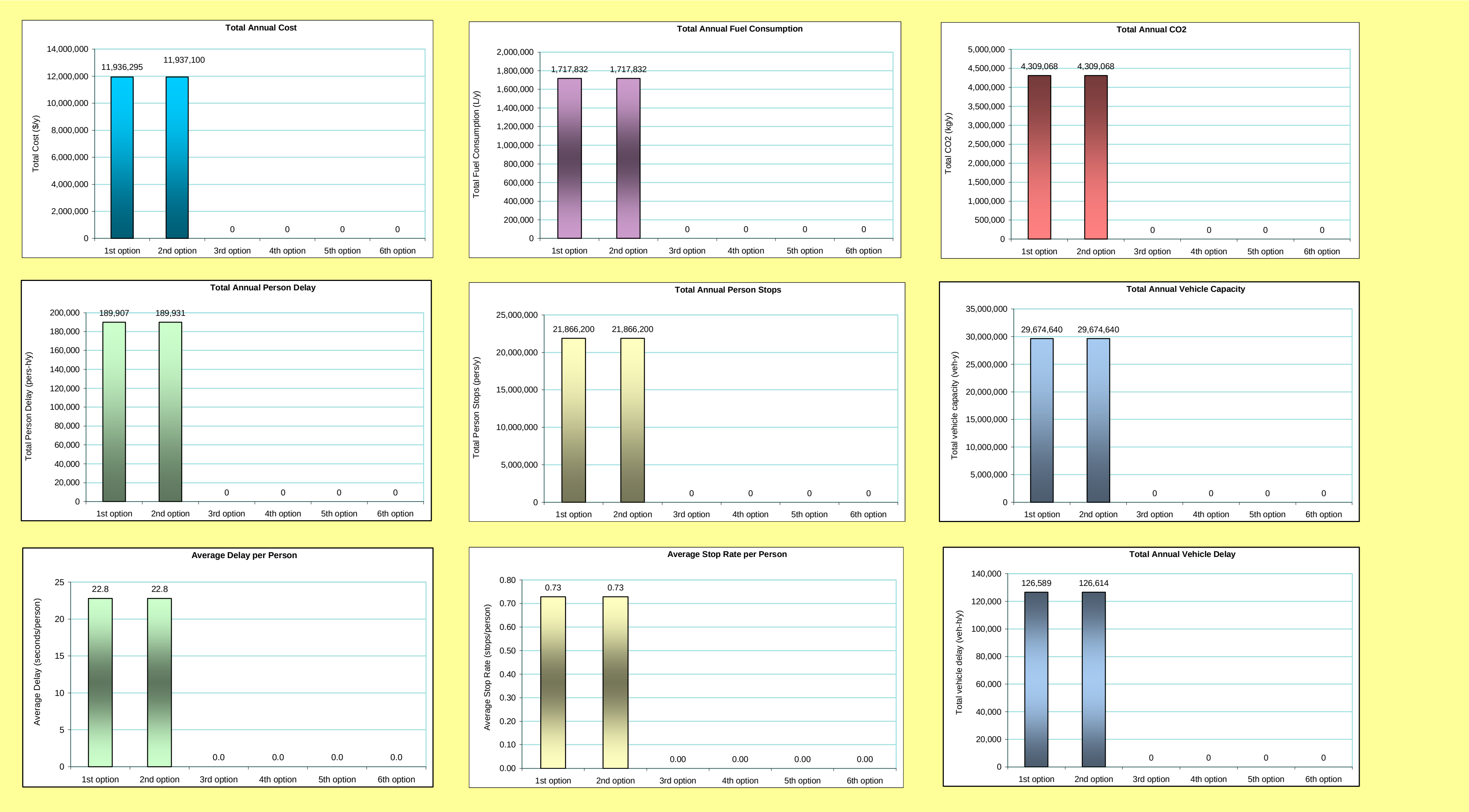

Figure E4 – Case Study 4 (Q00768) – 2011 aaSIDRA "Annual Sums Comparisons"

Annual sums for aaSIDRA results © **Akcelik & Associates Pty Ltd 2000-2004** **Version 4, September 2004**

Calculation of ANNUAL SUMS

See "Combined Cases" sheet for calculating weighted average of Options A to F as cases (event scenarios)

Design Option / Case: A

Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay (Average)	Person stops (Average)
Default values set in Defaults sheet			Total per YEAR																Average	
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	853,186	121,008	302,976	498	22,834	700	1,589,280	0	2,383,680	2,279,040	7,690	0	11,534	1,097,280	0	1,645,920	17.4	0.69
2	PM Peak	480	975,922	137,040	343,152	565	25,757	790	1,789,440	0	2,684,160	2,353,920	9,182	0	13,776	1,256,160	0	1,884,480	18.5	0.70
3	Business Hours	3160	4,073,335	591,236	1,480,460	2,417	112,117	3,444	7,890,520	0	11,837,360	15,951,680	32,548	0	48,822	5,223,480	0	7,836,800	14.8	0.66
4	Medium Off-Peak	2200	1,465,178	215,380	539,220	873	40,524	1,254	2,930,400	0	4,395,600	9,935,200	10,560	0	15,818	1,801,800	0	2,701,600	13.0	0.61
5	Light Off-Peak	2440	511,497	75,884	189,832	310	14,518	444	1,019,920	0	1,529,880	8,603,440	3,660	0	5,490	607,560	0	910,120	12.9	0.59
Total per year >>			7,879,117	1,140,548	2,855,640	4,664	215,749	6,633	15,219,560	0	22,830,680	39,123,280	63,640	0	95,440	9,986,280	0	14,978,920	15.0	0.66
Total per day >>			21,587	3,125	7,824	13	591	18	41,697	0	62,550	107,187	174	0	261	27,360	0	41,038		
Percentage of "Period 1" to daily total >>			8%	8%	8%	8%	8%	8%	8%	NA	8%	4%	9%	NA	9%	8%	NA	8%		
Percentage of "Period 2" to daily total >>			9%	9%	9%	9%	9%	9%	9%	NA	9%	5%	11%	NA	11%	10%	NA	10%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Design Option / Case: B

Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay (Average)	Person stops (Average)
Default values set in Defaults sheet			Total per YEAR																Average	
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	905,846	124,896	312,720	520	23,640	720	1,589,280	0	2,383,680	2,159,040	9,427	0	14,141	1,153,440	0	1,729,920	21.4	0.73
2	PM Peak	480	1,012,094	139,776	349,968	581	26,338	804	1,789,440	0	2,684,160	2,256,960	10,363	0	15,542	1,300,320	0	1,950,240	20.8	0.73
3	Business Hours	3160	4,197,365	600,716	1,504,160	2,471	114,234	3,495	7,890,520	0	11,837,360	15,430,280	36,656	0	54,952	5,337,240	0	8,004,280	16.7	0.68
4	Medium Off-Peak	2200	1,491,160	216,700	542,960	882	40,678	1,258	2,930,400	0	4,395,600	9,935,200	11,440	0	17,160	1,806,200	0	2,710,400	14.1	0.62
5	Light Off-Peak	2440	518,207	76,128	190,808	310	14,567	447	1,019,920	0	1,529,880	8,603,440	3,880	0	5,832	607,560	0	912,560	13.7	0.60
Total per year >>			8,124,673	1,158,216	2,900,616	4,764	219,456	6,723	15,219,560	0	22,830,680	38,384,920	71,766	0	107,627	10,204,760	0	15,307,400	17.0	0.67
Total per day >>			22,259	3,173	7,947	13	601	18	41,697	0	62,550	105,164	197	0	295	27,958	0	41,938		
Percentage of "Period 1" to daily total >>			8%	8%	8%	8%	8%	8%	8%	NA	8%	4%	10%	NA	10%	9%	NA	9%		
Percentage of "Period 2" to daily total >>			9%	9%	9%	9%	9%	9%	9%	NA	9%	4%	11%	NA	11%	10%	NA	10%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Figure F1 – Case Study 5 (V01311) – 2000 aaSIDRA "Annual Sums"

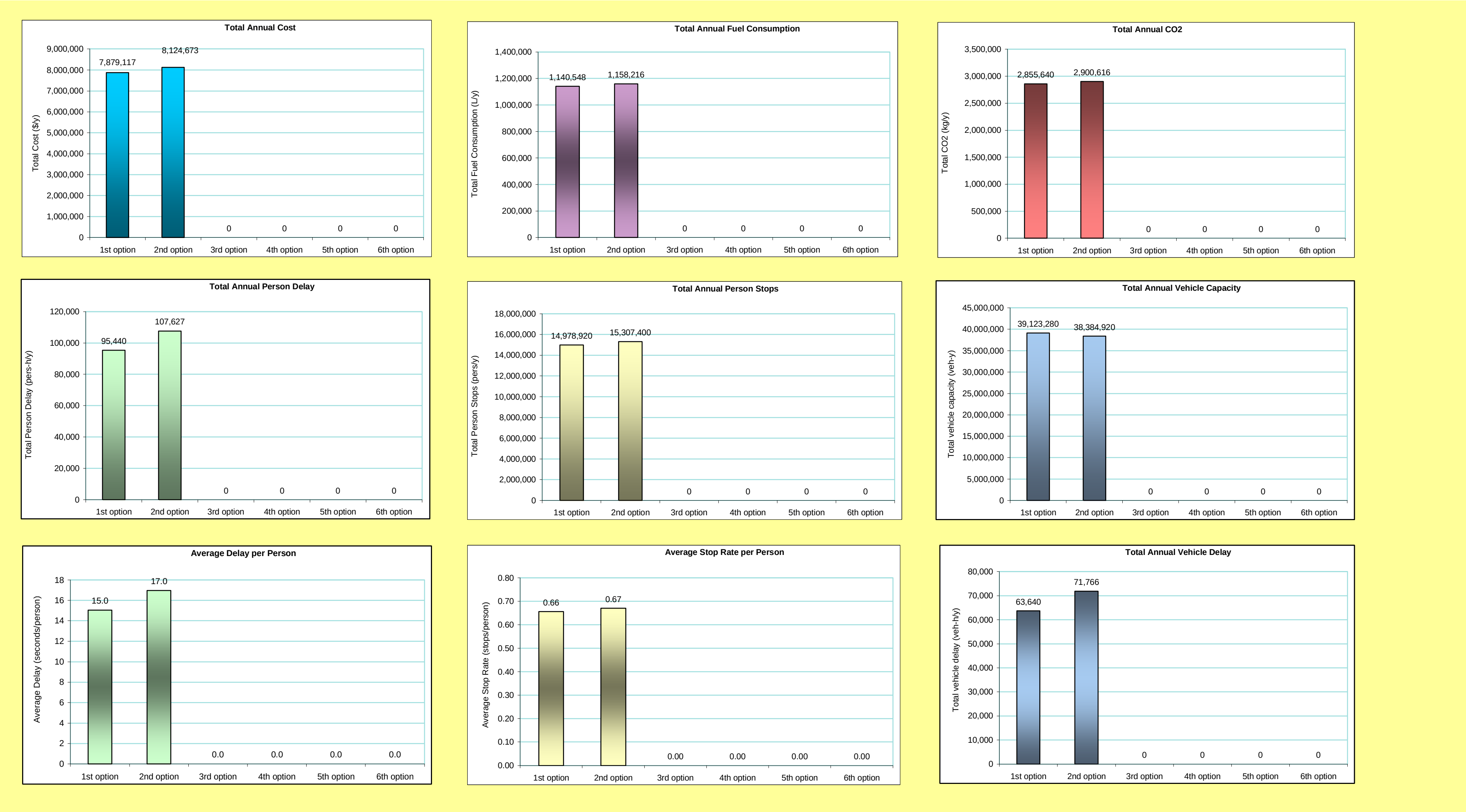

Figure F2 – Case Study 5 (V01311) – 2000 aaSIDRA "Annual Sums Comparisons"

Annual sums for aaSIDRA results © **Akcelik & Associates Pty Ltd 2000-2004** **Version 4, September 2004**

Calculation of ANNUAL SUMS

See "Combined Cases" sheet for calculating weighted average of Options A to F as cases (event scenarios)

Design Option / Case: A

Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
Default values set in Defaults sheet			Total per YEAR																Average	
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	819,096	116,352	291,312	477	21,778	672	1,543,200	0	2,314,560	2,296,800	7,190	0	10,786	1,040,160	0	1,560,000	16.8	0.67
2	PM Peak	480	933,763	131,376	328,944	540	24,437	755	1,737,120	0	2,605,440	2,380,800	8,515	0	12,778	1,180,800	0	1,771,200	17.7	0.68
3	Business Hours	3160	3,944,881	572,592	1,433,692	2,338	108,325	3,334	7,659,840	0	11,489,760	15,999,080	31,347	0	46,989	5,030,720	0	7,546,080	14.7	0.66
4	Medium Off-Peak	2200	1,424,148	209,000	523,380	851	39,578	1,221	2,824,800	0	4,237,200	9,669,000	10,516	0	15,774	1,762,200	0	2,642,200	13.4	0.62
5	Light Off-Peak	2440	480,607	71,248	178,364	290	13,615	417	958,920	0	1,439,600	8,598,560	3,440	0	5,148	566,080	0	851,560	12.9	0.59
Total per year >>			7,602,495	1,100,568	2,755,692	4,497	207,732	6,398	14,723,880	0	22,086,560	38,944,240	61,009	0	91,475	9,579,960	0	14,371,040	14.9	0.65
Total per day >>			20,829	3,015	7,550	12	569	18	40,339	0	60,511	106,697	167	0	251	26,246	0	39,373		
Percentage of "Period 1" to daily total >>			8%	8%	8%	8%	8%	8%	8%	NA	8%	4%	9%	NA	9%	8%	NA	8%		
Percentage of "Period 2" to daily total >>			9%	9%	9%	9%	9%	9%	9%	NA	9%	5%	11%	NA	11%	9%	NA	9%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Design Option / Case: B

Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
Default values set in Defaults sheet			Total per YEAR																Average	
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	868,474	119,952	300,336	498	22,517	689	1,543,200	0	2,314,560	2,175,840	8,827	0	13,243	1,088,640	0	1,632,480	20.6	0.71
2	PM Peak	480	971,424	134,496	336,816	557	25,210	772	1,737,120	0	2,605,440	2,256,480	9,730	0	14,597	1,231,200	0	1,847,040	20.2	0.71
3	Business Hours	3160	4,067,268	582,072	1,457,392	2,395	110,442	3,384	7,659,840	0	11,489,760	15,427,120	35,360	0	53,056	5,144,480	0	7,719,880	16.6	0.67
4	Medium Off-Peak	2200	1,448,172	210,320	526,900	858	39,732	1,225	2,824,800	0	4,237,200	9,669,000	11,330	0	17,006	1,766,600	0	2,648,800	14.4	0.63
5	Light Off-Peak	2440	486,853	71,492	179,096	293	13,664	420	958,920	0	1,439,600	8,598,560	3,660	0	5,466	568,520	0	851,560	13.7	0.59
Total per year >>			7,842,190	1,118,332	2,800,540	4,601	211,564	6,491	14,723,880	0	22,086,560	38,127,000	68,907	0	103,368	9,799,440	0	14,699,760	16.8	0.67
Total per day >>			21,485	3,064	7,673	13	580	18	40,339	0	60,511	104,458	189	0	283	26,848	0	40,273		
Percentage of "Period 1" to daily total >>			8%	8%	8%	8%	8%	8%	8%	NA	8%	4%	10%	NA	10%	8%	NA	8%		
Percentage of "Period 2" to daily total >>			9%	9%	9%	9%	9%	9%	9%	NA	9%	5%	11%	NA	11%	10%	NA	10%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Figure F3 – Case Study 5 (V01311) – 2010 aaSIDRA "Annual Sums"

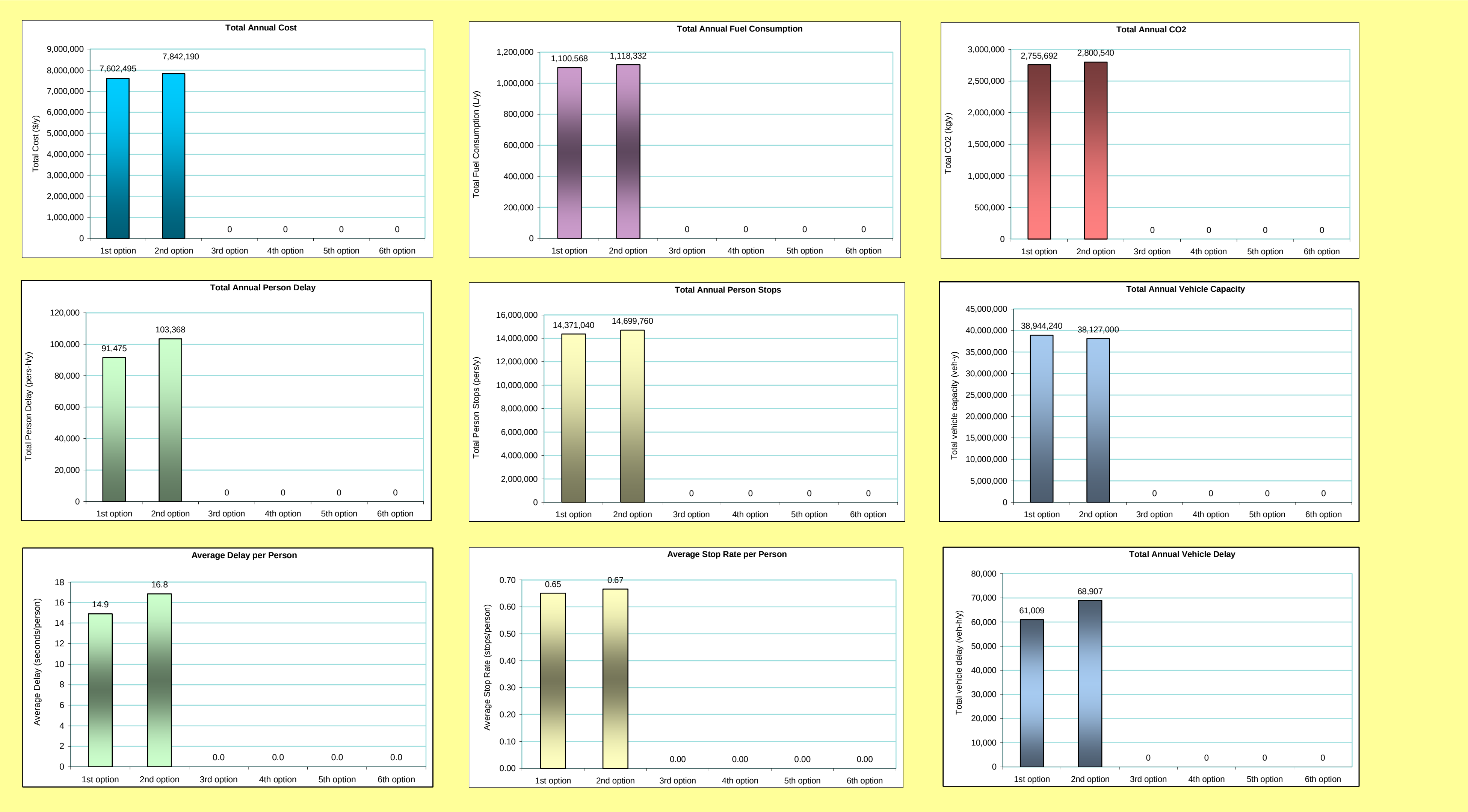

Figure F4 – Case Study 5 (V01311) – 2010 aaSIDRA "Annual Sums Comparisons"

Annual sums for aaSIDRA results © **Akcelik & Associates Pty Ltd 2000-2004** **Version 4, September 2004**

Calculation of ANNUAL SUMS

See "Combined Cases" sheet for calculating weighted average of Options A to F as cases (event scenarios)

Design Option / Case: A

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/h)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	796,114	116,160	290,976	448	19,258	639	1,697,760	0	2,546,880	3,912,480	4,752	0	7,128	844,320	0	1,266,240	10.1	0.50
2	PM Peak	480	987,686	141,648	354,864	556	24,163	785	1,992,960	0	2,989,440	3,574,080	7,234	0	10,853	1,097,280	0	1,645,440	13.1	0.55
3	Business Hours	3160	4,163,142	603,876	1,512,692	2,357	102,416	3,350	8,620,480	0	12,930,720	22,404,400	27,745	0	41,586	4,487,200	0	6,733,960	11.6	0.52
4	Medium Off-Peak	2200	1,419,110	216,040	540,980	829	36,872	1,212	3,187,800	0	4,782,800	14,526,600	6,138	0	9,218	1,524,600	0	2,288,000	6.9	0.48
5	Light Off-Peak	2440	492,612	76,372	191,540	300	13,981	444	1,080,920	0	1,622,600	11,816,920	2,269	0	3,416	558,760	0	836,920	7.6	0.52
Total per year >>			7,858,664	1,154,096	2,891,052	4,492	196,690	6,430	16,579,920	0	24,872,440	56,234,480	48,138	0	72,200	8,512,160	0	12,770,560	10.5	0.51
Total per day >>			21,531	3,162	7,921	12	539	18	45,424	0	68,144	154,067	132	0	198	23,321	0	34,988		
Percentage of "Period 1" to daily total >>			8%	8%	8%	8%	7%	8%	8%	NA	8%	5%	8%	NA	8%	8%	NA	8%		
Percentage of "Period 2" to daily total >>			10%	9%	9%	9%	9%	9%	9%	NA	9%	5%	11%	NA	11%	10%	NA	10%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Design Option / Case: B

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/h)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	907,238	127,776	320,016	514	22,771	719	1,697,760	0	2,546,880	3,232,320	8,165	0	12,250	1,051,680	0	1,577,760	17.3	0.62
2	PM Peak	480	1,123,099	154,800	387,744	630	27,912	871	1,992,960	0	2,989,440	3,074,400	11,472	0	17,208	1,319,520	0	1,979,520	20.7	0.66
3	Business Hours	3160	4,675,599	652,540	1,634,984	2,632	116,067	3,659	8,620,480	0	12,930,720	19,067,440	43,861	0	65,791	5,267,720	0	7,903,160	18.3	0.61
4	Medium Off-Peak	2200	1,607,034	238,260	596,640	955	44,198	1,377	3,187,800	0	4,782,800	10,564,400	11,704	0	17,556	1,933,800	0	2,901,800	13.2	0.61
5	Light Off-Peak	2440	552,294	82,472	206,424	332	15,714	483	1,080,920	0	1,622,600	8,442,400	4,124	0	6,198	646,600	0	968,680	13.8	0.60
Total per year >>			8,865,265	1,255,848	3,145,808	5,063	226,662	7,109	16,579,920	0	24,872,440	44,380,960	79,325	0	119,002	10,219,320	0	15,330,920	17.2	0.62
Total per day >>			24,288	3,441	8,619	14	621	19	45,424	0	68,144	121,592	217	0	326	27,998	0	42,003		
Percentage of "Period 1" to daily total >>			8%	8%	8%	8%	8%	8%	8%	NA	8%	6%	8%	NA	8%	8%	NA	8%		
Percentage of "Period 2" to daily total >>			10%	9%	9%	9%	9%	9%	9%	NA	9%	5%	11%	NA	11%	10%	NA	10%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Figure G1 – Case Study 6 (V01590) – 2002 aaSIDRA "Annual Sums"

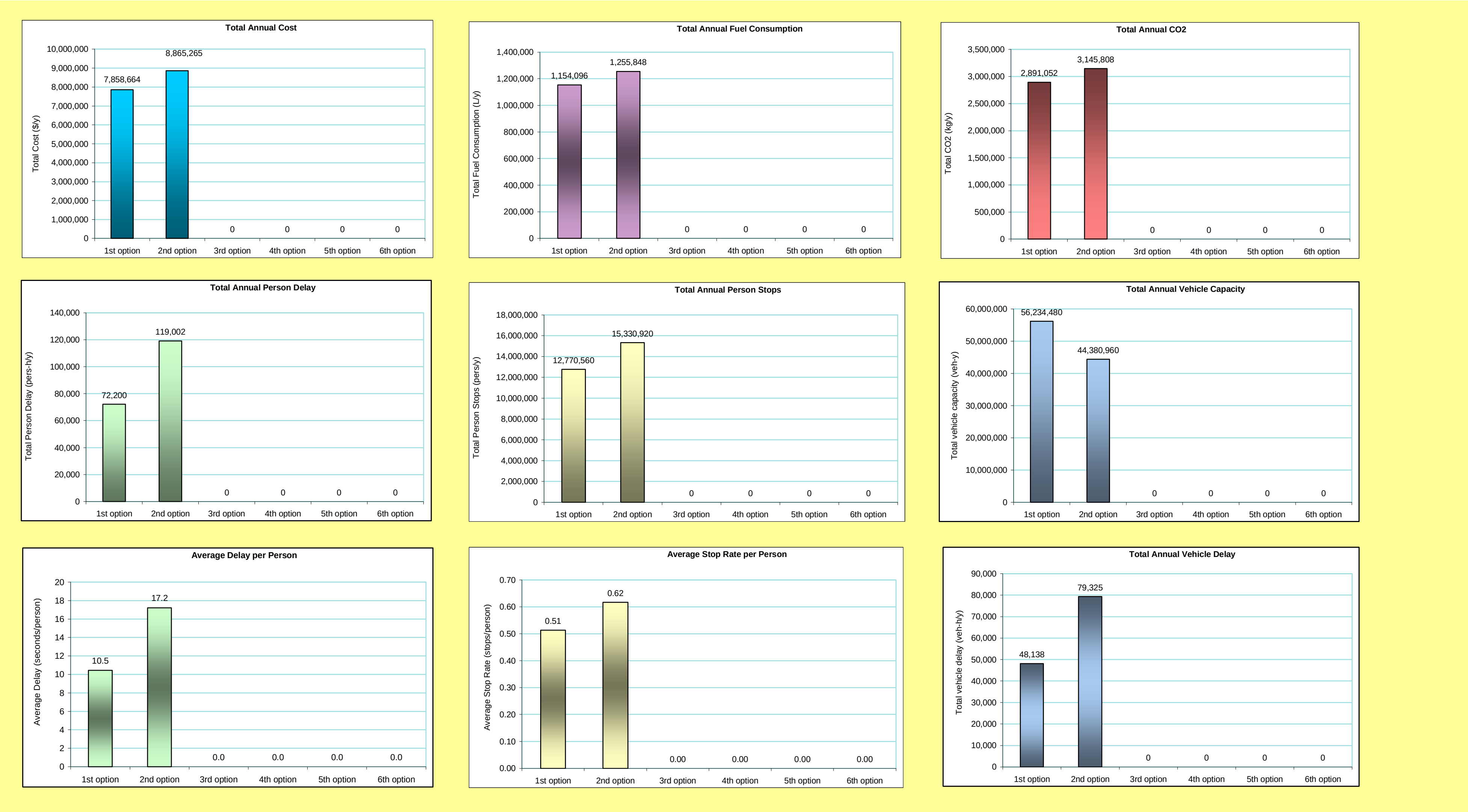

Figure G2 – Case Study 6 (V01590) – 2002 aaSIDRA “Annual Sums Comparisons”

Annual sums for aaSIDRA results © Akcelik & Associates Pty Ltd 2000-2004 Version 4, September 2004

Calculation of ANNUAL SUMS

See "Combined Cases" sheet for calculating weighted average of Options A to F as cases (event scenarios)

Design Option / Case: A

Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
Default values set in Defaults sheet			Total per YEAR																Average	
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	821,237	119,904	300,336	463	19,958	660	1,747,680	0	2,621,760	3,924,480	4,934	0	7,402	878,880	0	1,318,560	10.2	0.50
2	PM Peak	480	1,020,840	146,496	367,008	576	25,118	814	2,052,960	0	3,079,680	3,574,080	7,541	0	11,309	1,146,720	0	1,719,840	13.2	0.56
3	Business Hours	3160	4,295,830	623,468	1,561,672	2,433	106,050	3,460	8,879,600	0	13,319,400	22,394,920	28,756	0	43,134	4,664,160	0	6,996,240	11.7	0.53
4	Medium Off-Peak	2200	1,473,736	224,400	562,100	862	38,368	1,261	3,308,800	0	4,963,200	14,559,600	6,380	0	9,570	1,592,800	0	2,389,200	6.9	0.48
5	Light Off-Peak	2440	524,136	81,252	203,984	320	14,884	471	1,149,240	0	1,725,080	11,799,840	2,416	0	3,636	597,800	0	895,480	7.6	0.52
Total per year >>			8,135,780	1,195,520	2,995,100	4,655	204,378	6,666	17,138,280	0	25,709,120	56,252,920	50,027	0	75,050	8,880,360	0	13,319,320	10.5	0.52
Total per day >>			22,290	3,275	8,206	13	560	18	46,954	0	70,436	154,118	137	0	206	24,330	0	36,491		
Percentage of "Period 1" to daily total >>			8%	8%	8%	8%	7%	8%	8%	NA	8%	5%	8%	NA	7%	8%	NA	8%		
Percentage of "Period 2" to daily total >>			10%	9%	9%	9%	9%	9%	9%	NA	9%	5%	11%	NA	11%	10%	NA	10%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Design Option / Case: B

Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
Default values set in Defaults sheet			Total per YEAR																Average	
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	936,595	131,952	330,576	531	23,621	744	1,747,680	0	2,621,760	3,242,400	8,477	0	12,710	1,095,840	0	1,644,000	17.5	0.63
2	PM Peak	480	1,161,902	160,224	401,328	654	29,040	903	2,052,960	0	3,079,680	3,074,880	11,952	0	17,923	1,380,000	0	2,070,240	21.0	0.67
3	Business Hours	3160	4,827,090	674,028	1,688,388	2,721	120,238	3,786	8,879,600	0	13,319,400	19,061,120	45,472	0	68,193	5,476,280	0	8,216,000	18.4	0.62
4	Medium Off-Peak	2200	1,669,822	247,500	620,180	992	46,024	1,432	3,308,800	0	4,963,200	10,588,600	12,188	0	18,282	2,021,800	0	3,031,600	13.3	0.61
5	Light Off-Peak	2440	587,162	87,596	219,600	354	16,738	512	1,149,240	0	1,725,080	8,427,760	4,392	0	6,588	690,520	0	1,037,000	13.7	0.60
Total per year >>			9,182,571	1,301,300	3,260,072	5,252	235,661	7,377	17,138,280	0	25,709,120	44,394,760	82,481	0	123,696	10,664,440	0	15,998,840	17.3	0.62
Total per day >>			25,158	3,565	8,932	14	646	20	46,954	0	70,436	121,629	226	0	339	29,218	0	43,832		
Percentage of "Period 1" to daily total >>			8%	8%	8%	8%	8%	8%	8%	NA	8%	6%	8%	NA	8%	8%	NA	8%		
Percentage of "Period 2" to daily total >>			10%	9%	9%	9%	9%	9%	9%	NA	9%	5%	11%	NA	11%	10%	NA	10%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Figure G3 – Case Study 6 (V01590) – 2012 aaSIDRA "Annual Sums"

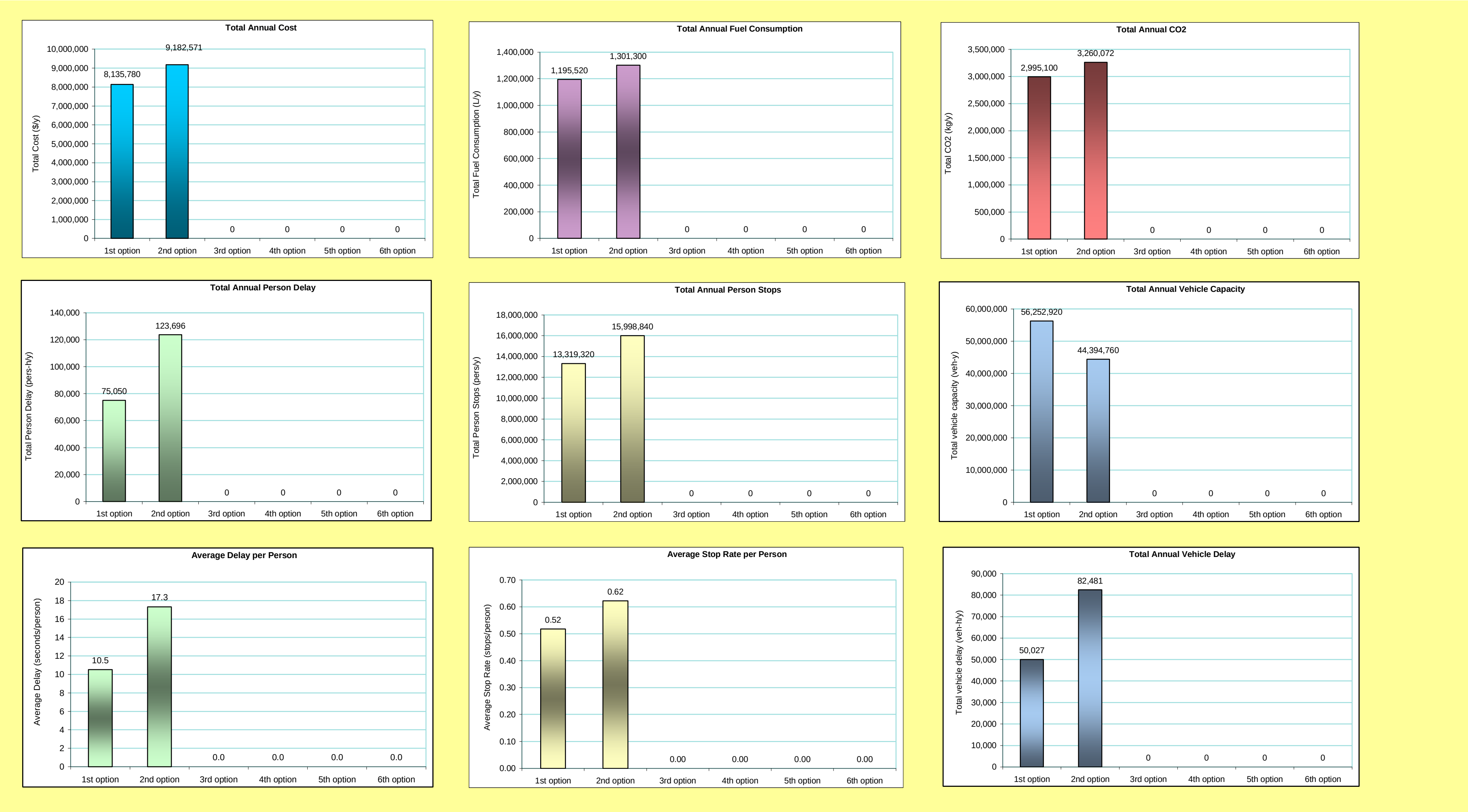

Figure G4 – Case Study 6 (V01590) – 2012 aaSIDRA "Annual Sums Comparisons"

Annual sums for aaSIDRA results © Akcelik & Associates Pty Ltd 2000-2004 **Version 4, September 2004**

Calculation of ANNUAL SUMS

See "Combined Cases" sheet for calculating weighted average of Options A to F as cases (event scenarios)

Design Option / Case: A

Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
Default values set in Defaults sheet			Total per YEAR																Average	
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	1,989,072	241,872	605,856	1,040	44,501	1,337	2,650,080	0	3,975,360	3,216,000	31,570	0	47,352	2,181,120	0	3,271,680	42.9	0.82
2	PM Peak	480	1,912,478	234,048	586,224	1,004	42,989	1,294	2,590,560	0	3,886,080	3,336,000	29,866	0	44,803	2,046,720	0	3,070,560	41.5	0.79
3	Business Hours	3160	8,497,524	1,062,392	2,661,036	4,494	192,728	5,878	12,254,480	0	18,381,720	19,866,920	123,556	0	185,334	8,712,120	0	13,069,760	36.3	0.71
4	Medium Off-Peak	2200	2,698,828	368,280	922,680	1,522	69,102	2,110	4,518,800	0	6,778,200	12,504,800	30,470	0	45,694	3,005,200	0	4,507,800	24.3	0.67
5	Light Off-Peak	2440	844,045	121,512	304,268	498	23,448	712	1,522,560	0	2,283,840	8,278,920	7,906	0	11,883	958,920	0	1,437,160	18.7	0.63
Total per year >>			15,941,948	2,028,104	5,080,064	8,558	372,768	11,331	23,536,480	0	35,305,200	47,202,640	223,367	0	335,066	16,904,080	0	25,356,960	34.2	0.72
Total per day >>			43,677	5,556	13,918	23	1,021	31	64,484	0	96,727	129,322	612	0	918	46,313	0	69,471		
Percentage of "Period 1" to daily total >>			9%	9%	9%	9%	9%	9%	9%	NA	9%	5%	11%	NA	11%	10%	NA	10%		
Percentage of "Period 2" to daily total >>			9%	9%	9%	9%	9%	9%	8%	NA	8%	5%	10%	NA	10%	9%	NA	9%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Design Option / Case: B

Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
Default values set in Defaults sheet			Total per YEAR																Average	
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	2,059,882	247,728	620,592	1,073	45,946	1,370	2,650,080	0	3,975,360	3,083,520	33,806	0	50,712	2,283,840	0	3,425,760	45.9	0.86
2	PM Peak	480	1,999,867	241,152	604,128	1,044	44,693	1,333	2,590,560	0	3,886,080	3,095,040	32,659	0	48,984	2,160,000	0	3,240,000	45.4	0.83
3	Business Hours	3160	8,613,054	1,074,716	2,692,004	4,563	196,552	5,963	12,254,480	0	18,381,720	20,094,440	127,064	0	190,611	8,908,040	0	13,363,640	37.3	0.73
4	Medium Off-Peak	2200	2,787,158	377,520	945,780	1,575	71,896	2,174	4,518,800	0	6,778,200	10,159,600	33,176	0	49,764	3,152,600	0	4,727,800	26.4	0.70
5	Light Off-Peak	2440	863,614	124,196	311,100	512	24,424	734	1,522,560	0	2,283,840	8,278,920	8,467	0	12,688	1,005,280	0	1,507,920	20.0	0.66
Total per year >>			16,323,574	2,065,312	5,173,604	8,768	383,511	11,574	23,536,480	0	35,305,200	44,711,520	235,172	0	352,759	17,509,760	0	26,265,120	36.0	0.74
Total per day >>			44,722	5,658	14,174	24	1,051	32	64,484	0	96,727	122,497	644	0	966	47,972	0	71,959		
Percentage of "Period 1" to daily total >>			10%	9%	9%	9%	9%	9%	9%	NA	9%	5%	11%	NA	11%	10%	NA	10%		
Percentage of "Period 2" to daily total >>			9%	9%	9%	9%	9%	9%	8%	NA	8%	5%	11%	NA	11%	9%	NA	9%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Figure H1 – Case Study 7 (V01145) – 2000 aaSIDRA "Annual Sums"

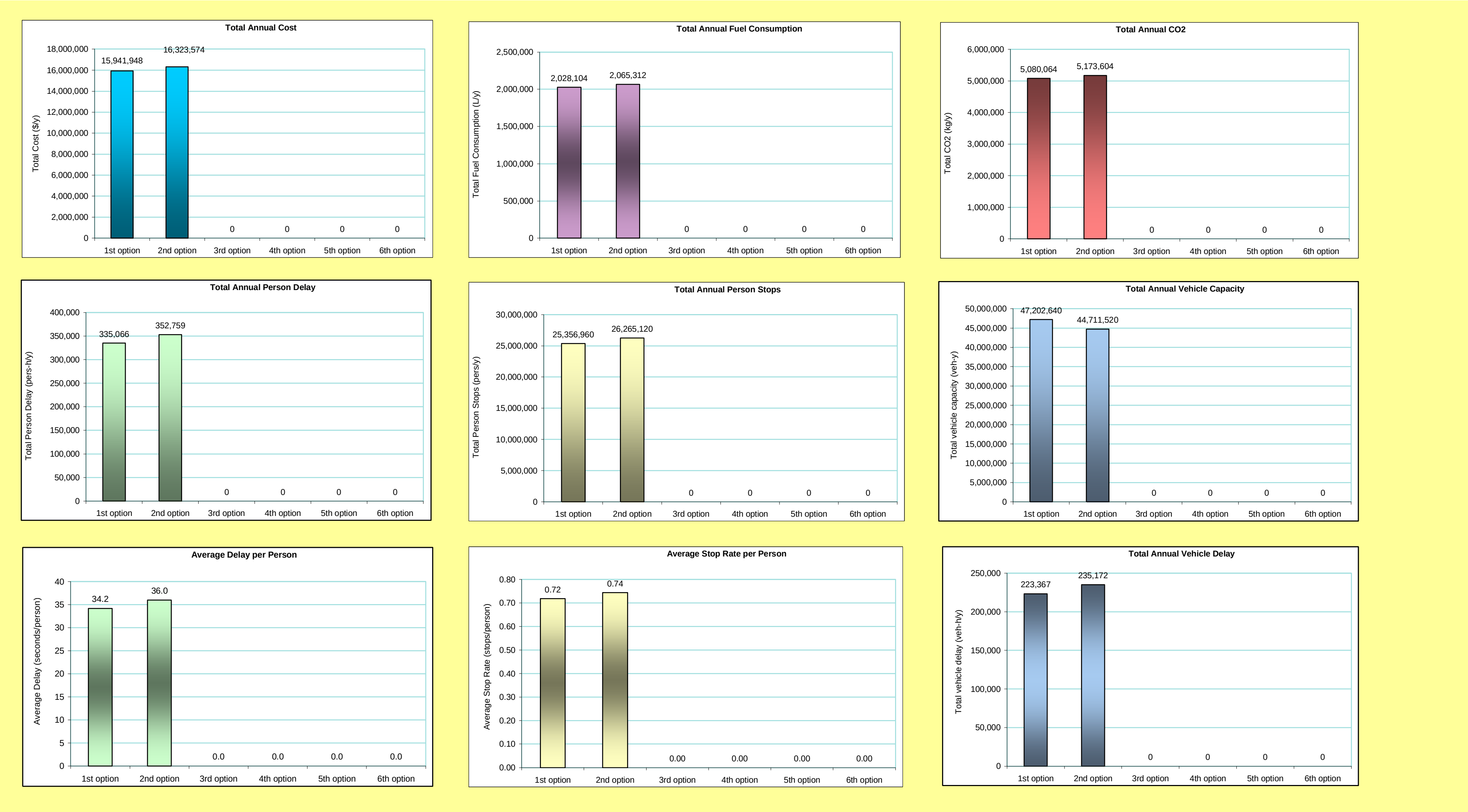

Figure H2 – Case Study 7 (V01145) – 2000 aaSIDRA "Annual Sums Comparisons"

Annual sums for aaSIDRA results © Akcelik & Associates Pty Ltd 2000-2004 **Version 4, September 2004**

Calculation of ANNUAL SUMS

See "Combined Cases" sheet for calculating weighted average of Options A to F as cases (event scenarios)

Design Option / Case: A

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	2,147,174	258,336	647,136	1,117	47,650	1,426	2,783,040	0	4,174,560	3,162,240	35,030	0	52,546	2,386,560	0	3,579,840	45.3	0.86
2	PM Peak	480	2,036,611	248,208	621,744	1,068	45,768	1,373	2,719,680	0	4,079,520	3,377,280	32,256	0	48,389	2,207,040	0	3,310,560	42.7	0.81
3	Business Hours	3160	8,926,210	1,116,744	2,797,548	4,727	203,093	6,187	12,864,360	0	19,298,120	20,195,560	129,781	0	194,688	9,233,520	0	13,850,280	36.3	0.72
4	Medium Off-Peak	2200	2,854,764	389,400	975,700	1,610	73,128	2,233	4,771,800	0	7,158,800	12,491,600	32,318	0	48,466	3,192,200	0	4,787,200	24.4	0.67
5	Light Off-Peak	2440	894,968	128,832	322,568	527	24,864	756	1,612,840	0	2,420,480	8,330,160	8,418	0	12,615	1,017,480	0	1,527,440	18.8	0.63
Total per year >>			16,859,727	2,141,520	5,364,696	9,050	394,502	11,976	24,751,720	0	37,131,480	47,556,840	237,804	0	356,703	18,036,800	0	27,055,320	34.6	0.73
Total per day >>			46,191	5,867	14,698	25	1,081	33	67,813	0	101,730	130,293	652	0	977	49,416	0	74,124		
Percentage of "Period 1" to daily total >>			10%	9%	9%	9%	9%	9%	9%	NA	9%	5%	11%	NA	11%	10%	NA	10%		
Percentage of "Period 2" to daily total >>			9%	9%	9%	9%	9%	9%	8%	NA	8%	5%	10%	NA	10%	9%	NA	9%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Design Option / Case: B

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	2,248,430	266,352	667,200	1,162	49,488	1,468	2,783,040	0	4,174,560	3,083,520	38,261	0	57,389	2,524,320	0	3,786,240	49.5	0.91
2	PM Peak	480	2,177,366	259,344	649,728	1,131	48,336	1,433	2,719,680	0	4,079,520	3,098,880	36,763	0	55,142	2,388,480	0	3,582,720	48.7	0.88
3	Business Hours	3160	9,082,314	1,131,596	2,834,836	4,813	207,233	6,279	12,864,360	0	19,298,120	20,217,680	134,711	0	202,050	9,429,440	0	14,147,320	37.7	0.73
4	Medium Off-Peak	2200	2,938,298	398,420	998,140	1,661	75,944	2,295	4,771,800	0	7,158,800	10,828,400	34,848	0	52,272	3,339,600	0	5,011,600	26.3	0.70
5	Light Off-Peak	2440	915,610	131,516	329,644	544	25,913	778	1,612,840	0	2,420,480	8,330,160	8,979	0	13,469	1,068,720	0	1,605,520	20.0	0.66
Total per year >>			17,362,019	2,187,228	5,479,548	9,311	406,914	12,253	24,751,720	0	37,131,480	45,558,640	253,562	0	380,322	18,750,560	0	28,133,400	36.9	0.76
Total per day >>			47,567	5,992	15,012	26	1,115	34	67,813	0	101,730	124,818	695	0	1,042	51,371	0	77,078		
Percentage of "Period 1" to daily total >>			10%	9%	9%	9%	9%	9%	9%	NA	9%	5%	11%	NA	11%	10%	NA	10%		
Percentage of "Period 2" to daily total >>			10%	9%	9%	9%	9%	9%	8%	NA	8%	5%	11%	NA	11%	10%	NA	10%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Figure H3 – Case Study 7 (V01145) – 2010 aaSIDRA "Annual Sums"

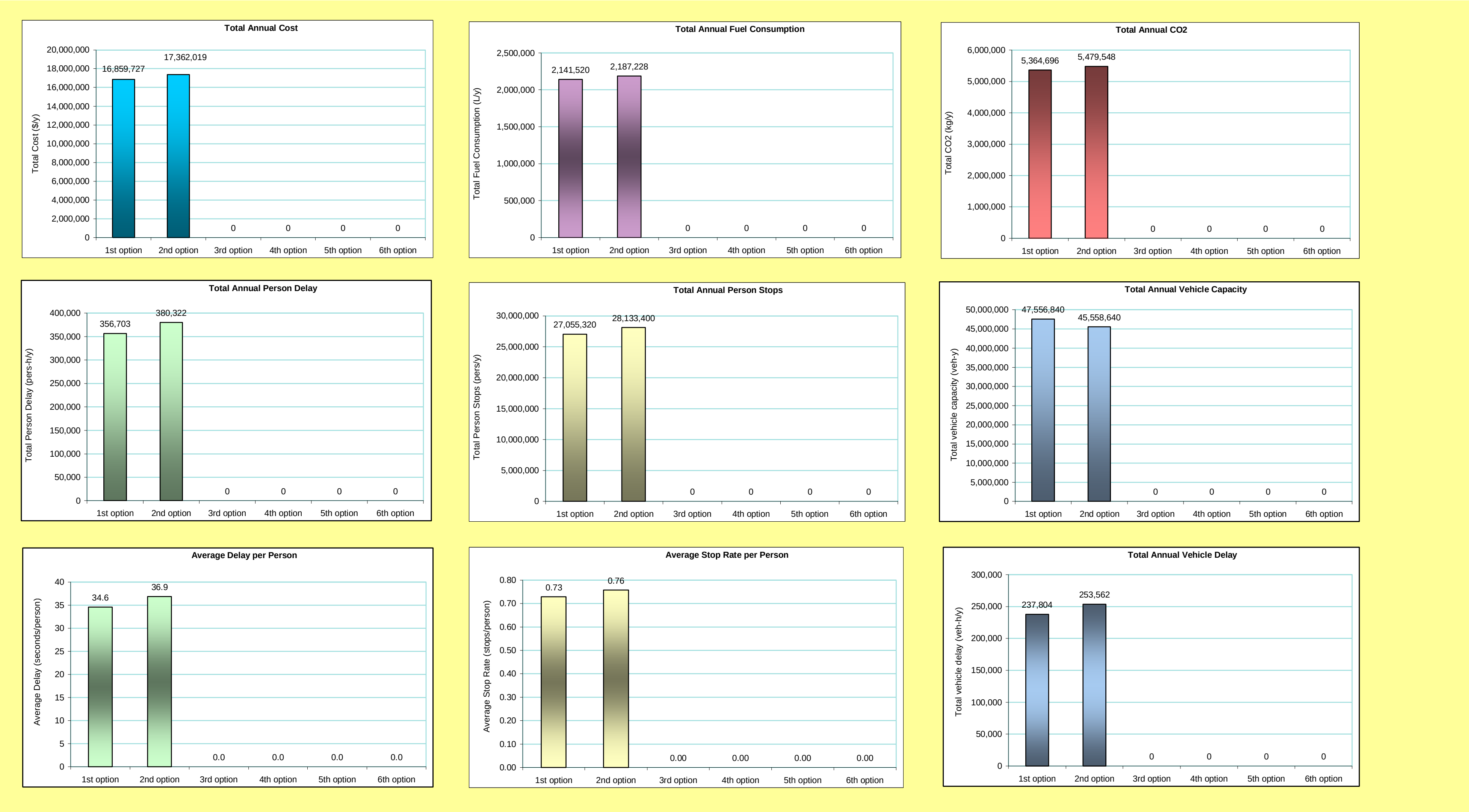

Figure H4 – Case Study 7 (V01145) – 2010 aaSIDRA "Annual Sums Comparisons"

Annual sums for aaSIDRA results © **Akcelik & Associates Pty Ltd 2000-2004** **Version 4, September 2004**

Calculation of ANNUAL SUMS

akcelik & associates
aaTraffic
aaSIDRA

See "Combined Cases" sheet for calculating weighted average of Options A to F as cases (event scenarios)

Design Option / Case: A

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	847,877	115,680	289,728	486	21,994	665	1,447,680	0	2,171,520	1,663,200	9,302	0	13,954	1,125,120	0	1,687,680	23.1	0.78
2	PM Peak	480	829,157	116,496	291,744	475	21,120	661	1,581,120	0	2,371,680	2,727,840	7,234	0	10,848	1,005,120	0	1,507,680	16.5	0.64
3	Business Hours	3160	3,570,642	503,704	1,261,156	2,022	88,164	2,822	7,087,880	0	10,630,240	13,294,120	28,187	0	42,281	4,029,000	0	6,041,920	14.3	0.57
4	Medium Off-Peak	2200	1,227,182	172,040	430,760	667	27,192	926	2,622,400	0	3,933,600	10,892,200	7,898	0	11,858	1,108,800	0	1,663,200	10.9	0.42
5	Light Off-Peak	2440	440,152	65,148	162,992	264	12,249	378	893,040	0	1,339,560	4,199,240	3,050	0	4,563	512,400	0	768,600	12.3	0.57
Total per year >>			6,915,009	973,068	2,436,380	3,913	170,718	5,453	13,632,120	0	20,446,600	32,776,600	55,671	0	83,503	7,780,440	0	11,669,080	14.7	0.57
Total per day >>			18,945	2,666	6,675	11	468	15	37,348	0	56,018	89,799	153	0	229	21,316	0	31,970		
Percentage of "Period 1" to daily total >>			9%	9%	9%	9%	10%	9%	8%	NA	8%	4%	13%	NA	13%	11%	NA	11%		
Percentage of "Period 2" to daily total >>			9%	9%	9%	9%	9%	9%	9%	NA	9%	6%	10%	NA	10%	10%	NA	10%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Design Option / Case: B

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	862,267	116,448	291,648	490	22,061	666	1,447,680	0	2,171,520	1,648,320	9,797	0	14,698	1,134,240	0	1,701,600	24.4	0.78
2	PM Peak	480	840,101	117,072	293,184	478	21,158	662	1,581,120	0	2,371,680	2,727,840	7,613	0	11,424	1,006,080	0	1,509,600	17.3	0.64
3	Business Hours	3160	3,626,100	506,548	1,268,424	2,041	88,354	2,828	7,087,880	0	10,630,240	13,294,120	30,115	0	45,188	4,032,160	0	6,048,240	15.3	0.57
4	Medium Off-Peak	2200	1,254,352	173,800	435,380	678	27,522	933	2,622,400	0	3,933,600	10,665,600	8,800	0	13,222	1,126,400	0	1,689,600	12.1	0.43
5	Light Off-Peak	2440	442,323	65,148	163,236	266	12,249	378	893,040	0	1,339,560	4,199,240	3,123	0	4,685	512,400	0	768,600	12.6	0.57
Total per year >>			7,025,143	979,016	2,451,872	3,953	171,344	5,468	13,632,120	0	20,446,600	32,535,120	59,448	0	89,216	7,811,280	0	11,717,640	15.7	0.57
Total per day >>			19,247	2,682	6,717	11	469	15	37,348	0	56,018	89,137	163	0	244	21,401	0	32,103		
Percentage of "Period 1" to daily total >>			9%	9%	9%	9%	10%	9%	8%	NA	8%	4%	13%	NA	13%	11%	NA	11%		
Percentage of "Period 2" to daily total >>			9%	9%	9%	9%	9%	9%	9%	NA	9%	6%	10%	NA	10%	10%	NA	10%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Figure I1– Case Study 8 (V01340) – 2000 aaSIDRA "Annual Sums"

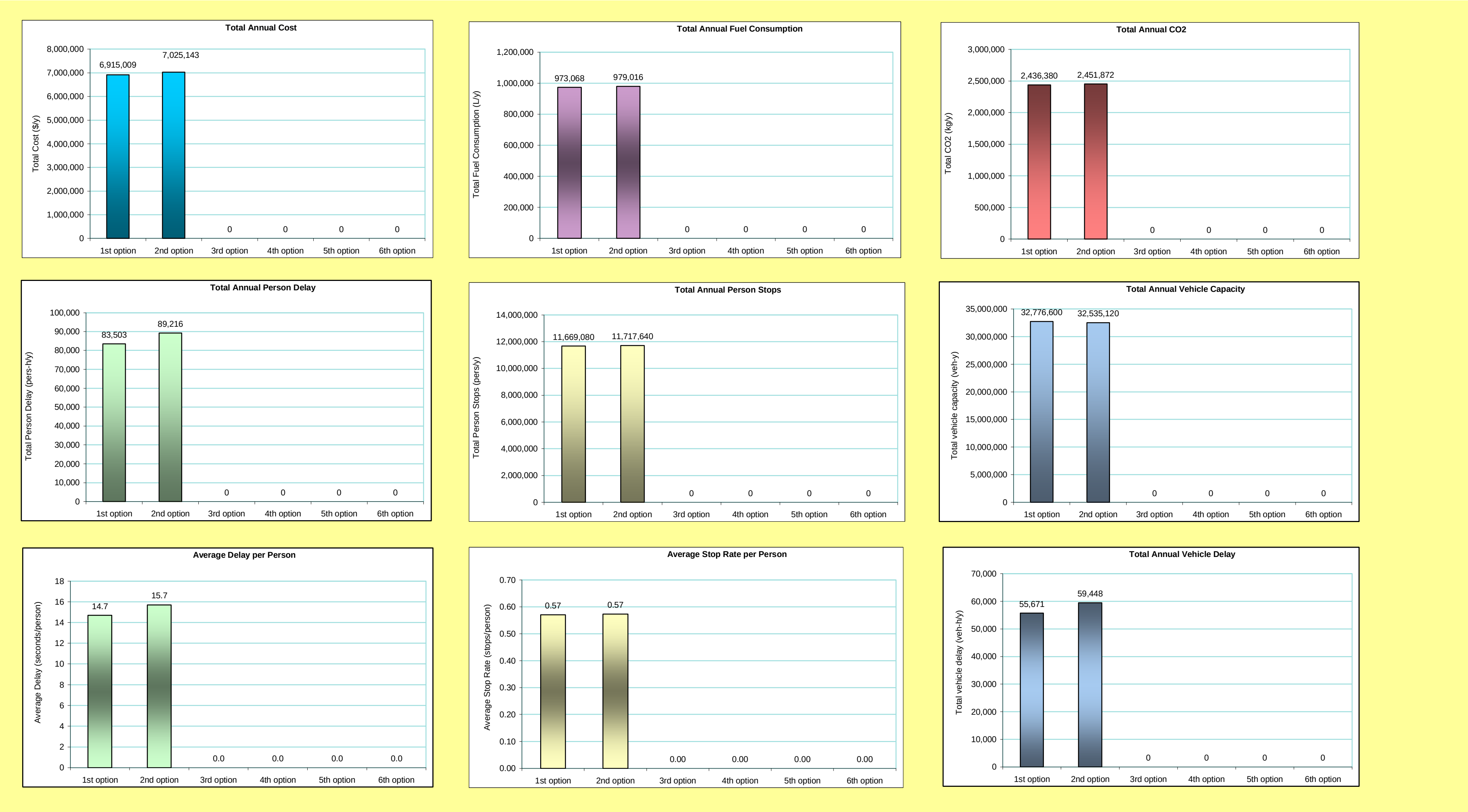

Figure I2– Case Study 8 (V01340) – 2000 aaSIDRA "Annual Sums Comparisons"

Annual sums for aaSIDRA results © Akcelik & Associates Pty Ltd 2000-2004 **Version 4, September 2004**

Calculation of ANNUAL SUMS

See "Combined Cases" sheet for calculating weighted average of Options A to F as cases (event scenarios)

Design Option / Case: A

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	976,987	129,120	323,328	553	25,090	743	1,518,240	0	2,277,120	1,661,280	12,490	0	18,734	1,320,960	0	1,981,440	29.6	0.87
2	PM Peak	480	875,429	123,072	308,208	503	22,464	701	1,659,840	0	2,489,760	2,725,920	7,728	0	11,592	1,077,120	0	1,615,680	16.8	0.65
3	Business Hours	3160	3,762,170	530,880	1,329,412	2,136	93,410	2,980	7,441,800	0	11,161,120	13,287,800	29,925	0	44,904	4,294,440	0	6,443,240	14.5	0.58
4	Medium Off-Peak	2200	1,299,144	182,160	456,060	708	28,842	981	2,772,000	0	4,158,000	10,854,800	8,404	0	12,606	1,183,600	0	1,773,200	10.9	0.43
5	Light Off-Peak	2440	468,016	69,296	173,484	281	13,030	403	949,160	0	1,424,960	4,191,920	3,245	0	4,856	546,560	0	819,840	12.3	0.58
Total per year >>			7,381,746	1,034,528	2,590,492	4,182	182,835	5,807	14,341,040	0	21,510,960	32,721,720	61,792	0	92,692	8,422,680	0	12,633,400	15.5	0.59
Total per day >>			20,224	2,834	7,097	11	501	16	39,291	0	58,934	89,649	169	0	254	23,076	0	34,612		
Percentage of "Period 1" to daily total >>			10%	9%	9%	10%	10%	10%	8%	NA	8%	4%	15%	NA	15%	12%	NA	12%		
Percentage of "Period 2" to daily total >>			9%	9%	9%	9%	9%	9%	9%	NA	9%	6%	10%	NA	10%	10%	NA	10%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Design Option / Case: B

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	993,158	129,984	325,488	558	25,166	745	1,518,240	0	2,277,120	1,644,960	13,046	0	19,565	1,334,880	0	2,002,560	30.9	0.88
2	PM Peak	480	886,934	123,696	309,696	506	22,507	702	1,659,840	0	2,489,760	2,725,920	8,126	0	12,192	1,078,560	0	1,618,080	17.6	0.65
3	Business Hours	3160	3,820,693	534,040	1,337,312	2,155	93,631	2,986	7,441,800	0	11,161,120	13,287,800	31,979	0	47,969	4,300,760	0	6,452,720	15.5	0.58
4	Medium Off-Peak	2200	1,320,440	182,820	458,040	713	28,754	979	2,772,000	0	4,158,000	10,709,600	9,174	0	13,750	1,172,600	0	1,760,000	11.9	0.42
5	Light Off-Peak	2440	470,408	69,296	173,728	281	13,030	403	949,160	0	1,424,960	4,191,920	3,318	0	4,978	546,560	0	819,840	12.6	0.58
Total per year >>			7,491,633	1,039,836	2,604,264	4,213	183,088	5,815	14,341,040	0	21,510,960	32,560,200	65,644	0	98,453	8,433,360	0	12,653,200	16.5	0.59
Total per day >>			20,525	2,849	7,135	12	502	16	39,291	0	58,934	89,206	180	0	270	23,105	0	34,666		
Percentage of "Period 1" to daily total >>			10%	10%	10%	10%	10%	10%	8%	NA	8%	4%	15%	NA	15%	12%	NA	12%		
Percentage of "Period 2" to daily total >>			9%	9%	9%	9%	9%	9%	9%	NA	9%	6%	9%	NA	9%	10%	NA	10%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Figure I3 – Case Study 8 (V01340) – 2010 aaSIDRA "Annual Sums"

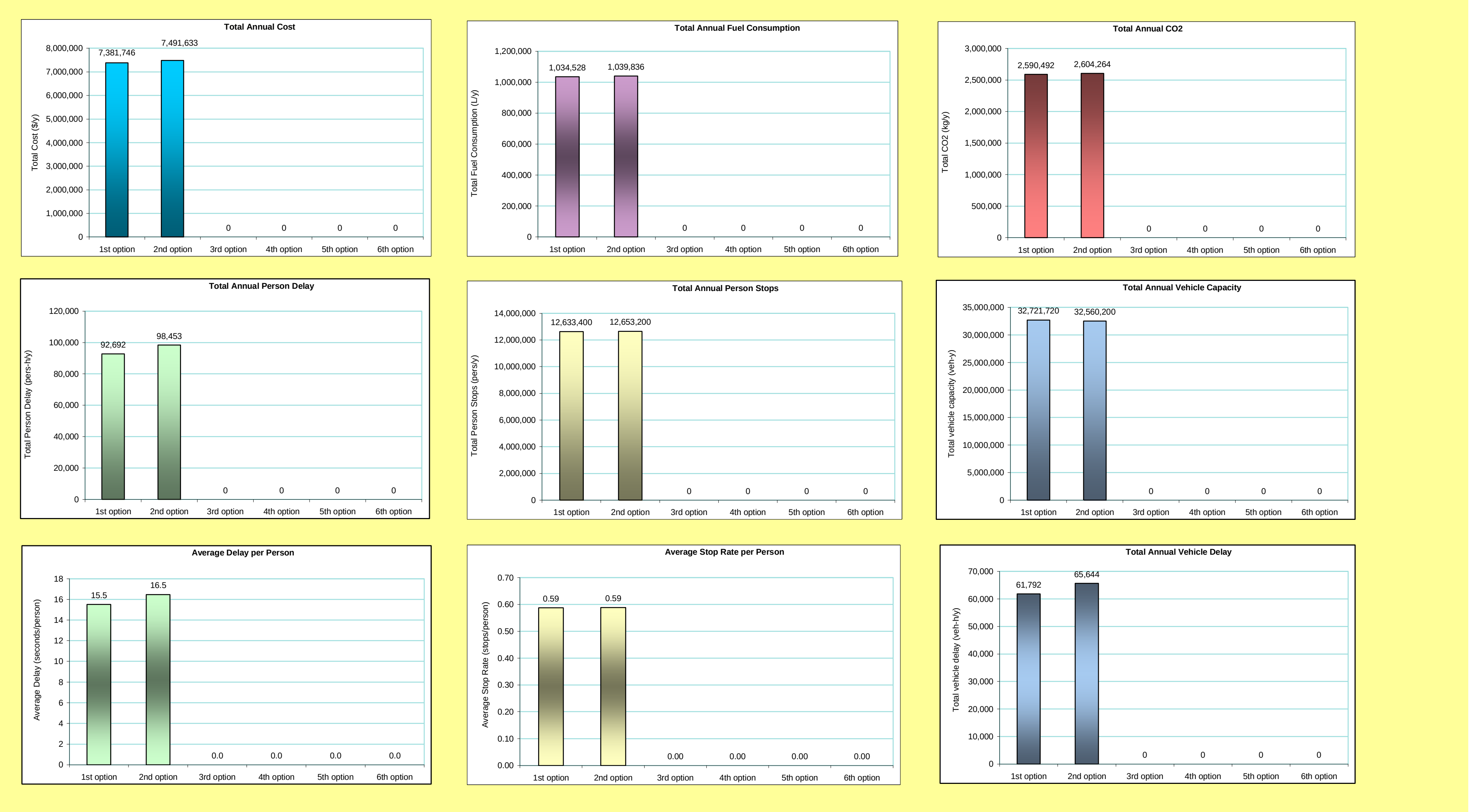

Figure I4 – Case Study 8 (V01340) – 2010 aaSIDRA "Annual Sums Comparisons"

Annual sums for aaSIDRA results © **Akcelik & Associates Pty Ltd 2000-2004** **Version 4, September 2004**

Calculation of ANNUAL SUMS

See "Combined Cases" sheet for calculating weighted average of Options A to F as cases (event scenarios)

Design Option / Case: A

Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
Default values set in Defaults sheet			Total per YEAR																Average	
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	190,507	28,704	71,856	117	5,482	170	423,360	0	635,040	2,280,480	854	0	1,282	200,160	0	300,480	7.3	0.47
2	PM Peak	480	305,002	45,360	113,520	188	8,832	269	649,440	0	974,400	1,351,680	1,723	0	2,582	334,080	0	500,640	9.5	0.51
3	Business Hours	3160	1,721,031	257,224	644,008	1,062	49,770	1,526	3,741,440	0	5,612,160	10,845,120	8,785	0	13,177	1,861,240	0	2,790,280	8.5	0.50
4	Medium Off-Peak	2200	346,786	51,700	129,580	209	9,526	301	798,600	0	1,199,000	13,235,200	1,342	0	2,024	345,400	0	519,200	6.1	0.43
5	Light Off-Peak	2440	43,408	7,076	17,568	27	1,244	39	97,600	0	146,400	14,413,080	146	0	220	41,480	0	63,440	5.4	0.43
Total per year >>			2,606,733	390,064	976,532	1,603	74,854	2,306	5,710,440	0	8,567,000	42,125,560	12,851	0	19,285	2,782,360	0	4,174,040	8.1	0.49
Total per day >>			7,142	1,069	2,675	4	205	6	15,645	0	23,471	115,412	35	0	53	7,623	0	11,436		
Percentage of "Period 1" to daily total >>			6%	6%	6%	6%	6%	6%	6%	NA	6%	4%	5%	NA	5%	5%	NA	5%		
Percentage of "Period 2" to daily total >>			9%	9%	9%	9%	9%	9%	9%	NA	9%	2%	10%	NA	10%	9%	NA	9%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Design Option / Case: B

Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
Default values set in Defaults sheet			Total per YEAR																Average	
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	228,461	31,728	79,392	136	6,278	186	422,880	0	634,560	1,254,240	2,184	0	3,274	298,560	0	447,360	18.6	0.70
2	PM Peak	480	363,442	49,008	122,544	211	9,480	283	648,480	0	972,480	1,287,360	3,830	0	5,741	459,840	0	690,240	21.3	0.71
3	Business Hours	3160	2,074,382	280,924	702,784	1,204	54,257	1,624	3,747,760	0	5,621,640	7,555,560	21,298	0	31,948	2,600,680	0	3,899,440	20.5	0.69
4	Medium Off-Peak	2200	414,238	56,980	142,780	240	10,516	326	811,800	0	1,218,800	7,387,600	3,520	0	5,302	464,200	0	697,400	15.7	0.57
5	Light Off-Peak	2440	64,221	8,052	20,252	34	1,366	44	117,120	0	175,680	4,255,360	708	0	1,049	56,120	0	85,400	21.5	0.49
Total per year >>			3,144,743	426,692	1,067,752	1,825	81,898	2,463	5,748,040	0	8,623,160	21,740,120	31,540	0	47,313	3,879,400	0	5,819,840	19.8	0.67
Total per day >>			8,616	1,169	2,925	5	224	7	15,748	0	23,625	59,562	86	0	130	10,628	0	15,945		
Percentage of "Period 1" to daily total >>			6%	6%	6%	6%	6%	6%	6%	NA	6%	4%	5%	NA	5%	6%	NA	6%		
Percentage of "Period 2" to daily total >>			9%	9%	9%	9%	9%	9%	9%	NA	9%	5%	9%	NA	9%	9%	NA	9%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Figure J1– Case Study 9 (N00239) – 1999 aaSIDRA "Annual Sums"

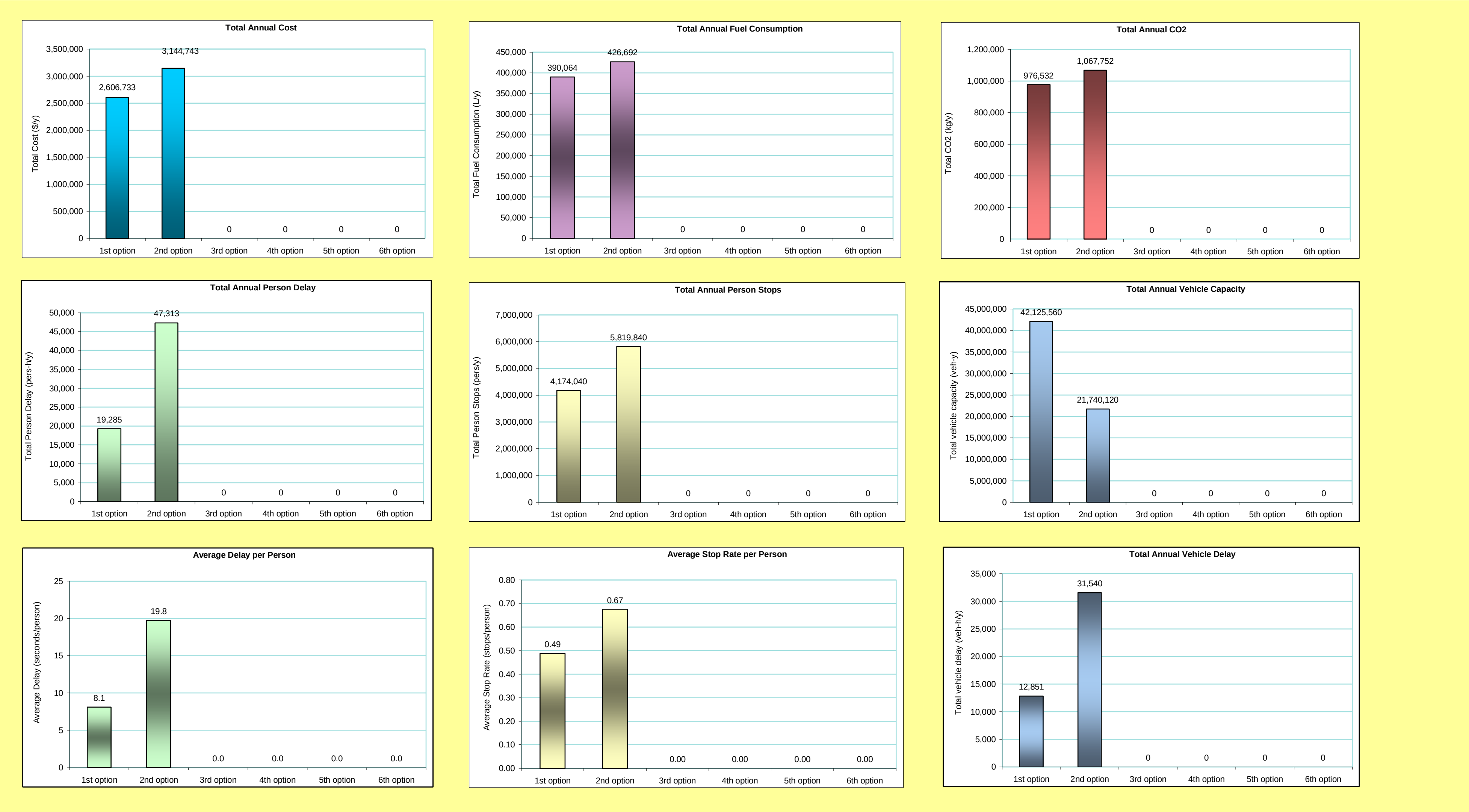

Figure J2– Case Study 9 (N00239) – 1999 aaSIDRA "Annual Sums Comparisons"

Annual sums for aaSIDRA results © **Akcelik & Associates Pty Ltd 2000-2004** **Version 4, September 2004**

Calculation of ANNUAL SUMS

See "Combined Cases" sheet for calculating weighted average of Options A to F as cases (event scenarios)

Design Option / Case: A

Default values set in Defaults sheet

Flow Period Ref. No.	Flow Period Description	Total Hours per year	Total per YEAR																	Average	
			Cost	Fuel	CO2	HC	CO	NOX		Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)		(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	207,922	31,824	79,680	129	6,106	189		456,000	0	684,000	2,134,560	950	0	1,426	217,920	0	326,880	7.5	0.48
2	PM Peak	480	336,221	49,440	123,648	206	9,638	293		703,680	0	1,055,520	1,159,680	2,078	0	3,115	371,520	0	557,280	10.6	0.53
3	Business Hours	3160	1,886,362	282,188	706,260	1,163	54,826	1,675		4,047,960	0	6,073,520	9,679,080	10,175	0	15,263	2,050,840	0	3,077,840	9.0	0.51
4	Medium Off-Peak	2200	381,370	58,080	145,640	233	10,780	341		866,800	0	1,300,200	13,178,000	1,474	0	2,222	378,400	0	565,400	6.2	0.43
5	Light Off-Peak	2440	42,822	6,344	16,104	27	1,171	37		100,040	0	151,280	15,530,600	146	0	244	43,920	0	65,880	5.8	0.44
Total per year >>			2,854,696	427,876	1,071,332	1,757	82,521	2,534		6,174,480	0	9,264,520	41,681,920	14,824	0	22,270	3,062,600	0	4,593,280	8.7	0.50
Total per day >>			7,821	1,172	2,935	5	226	7		16,916	0	25,382	114,197	41	0	61	8,391	0	12,584		
Percentage of "Period 1" to daily total >>			6%	6%	6%	6%	6%	6%		6%	NA	6%	4%	5%	NA	5%	5%	NA	5%		
Percentage of "Period 2" to daily total >>			9%	9%	9%	9%	9%	9%		9%	NA	9%	2%	11%	NA	11%	9%	NA	9%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Design Option / Case: B

Default values set in Defaults sheet

Flow Period Ref. No.	Flow Period Description	Total Hours per year	Total per YEAR																	Average	
			Cost	Fuel	CO2	HC	CO	NOX		Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)		(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	249,067	34,608	86,544	148	6,850	203		460,320	0	690,240	1,260,960	2,386	0	3,581	326,880	0	490,560	18.7	0.71
2	PM Peak	480	401,290	53,856	134,784	233	10,488	312		705,120	0	1,057,920	1,290,720	4,354	0	6,528	512,640	0	768,960	22.2	0.73
3	Business Hours	3160	2,255,545	304,940	763,456	1,311	59,060	1,766		4,057,440	0	6,086,160	7,523,960	23,352	0	35,044	2,844,000	0	4,266,000	20.7	0.70
4	Medium Off-Peak	2200	446,028	61,380	153,780	257	11,330	352		873,400	0	1,311,200	7,436,000	3,806	0	5,720	503,800	0	754,600	15.7	0.58
5	Light Off-Peak	2440	69,955	8,784	21,960	37	1,513	46		124,440	0	187,880	4,150,440	805	0	1,196	61,000	0	92,720	22.9	0.49
Total per year >>			3,421,884	463,568	1,160,524	1,987	89,241	2,680		6,220,720	0	9,333,400	21,662,080	34,703	0	52,069	4,248,320	0	6,372,840	20.1	0.68
Total per day >>			9,375	1,270	3,180	5	244	7		17,043	0	25,571	59,348	95	0	143	11,639	0	17,460		
Percentage of "Period 1" to daily total >>			6%	6%	6%	6%	6%	6%		6%	NA	6%	4%	5%	NA	5%	6%	NA	6%		
Percentage of "Period 2" to daily total >>			9%	9%	9%	9%	9%	9%		9%	NA	9%	5%	10%	NA	10%	9%	NA	9%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Figure J3 – Case Study 9 (N00239) – 2014 aaSIDRA "Annual Sums"

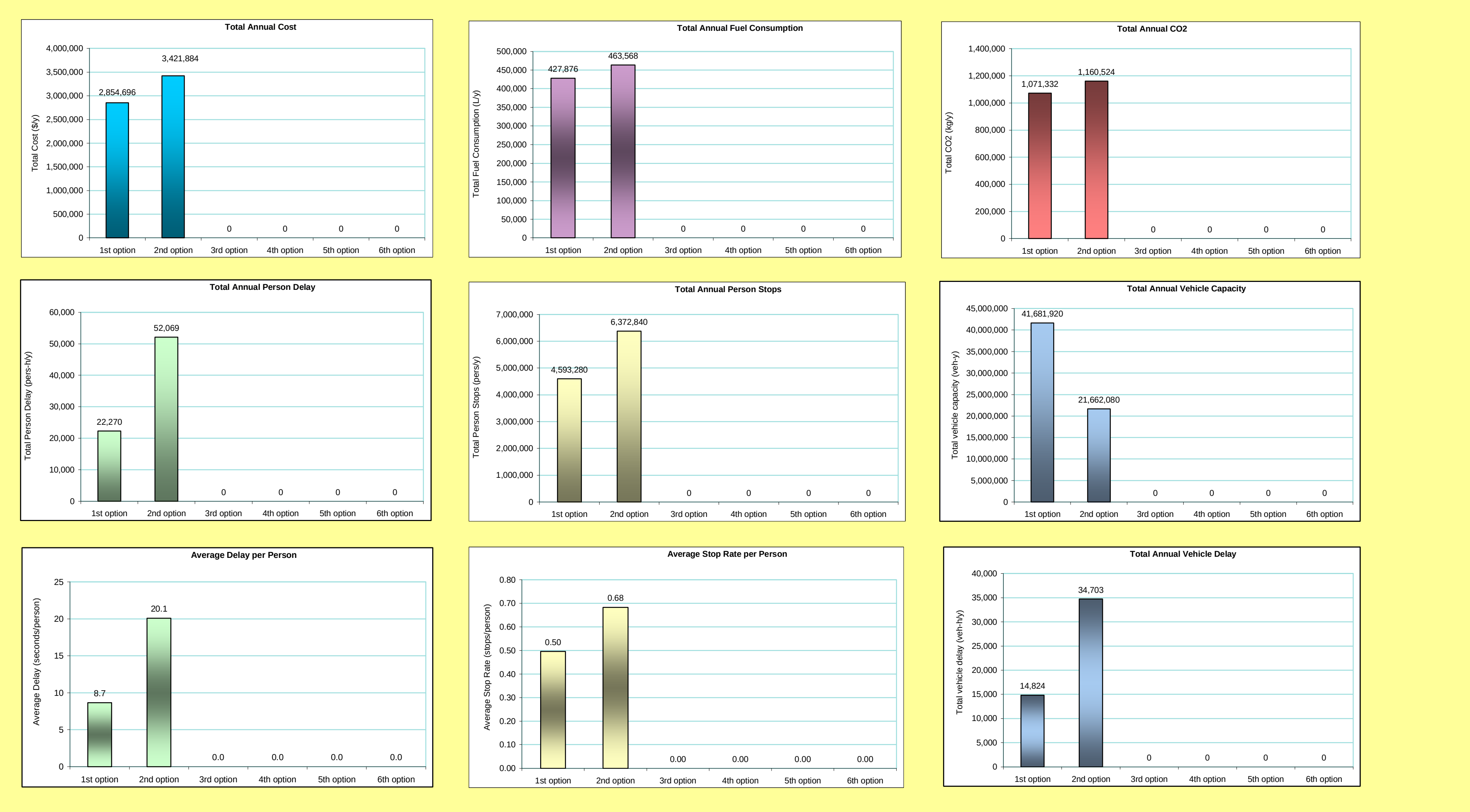

Figure J4 – Case Study 9 (N00239) – 2014 aaSIDRA “Annual Sums Comparisons”

Annual sums for aaSIDRA results © Akcelik & Associates Pty Ltd 2000-2004 **Version 4, September 2004**

Calculation of ANNUAL SUMS

See "Combined Cases" sheet for calculating weighted average of Options A to F as cases (event scenarios)

Design Option / Case: A

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	76,546	11,712	29,328	44	1,949	65	178,080	0	267,360	2,116,320	206	0	312	41,280	0	61,920	4.2	0.23
2	PM Peak	480	116,045	17,952	45,024	70	3,230	104	259,200	0	388,800	1,481,280	398	0	600	72,960	0	109,920	5.6	0.28
3	Business Hours	3160	438,608	67,308	168,428	256	11,344	376	1,017,520	0	1,526,280	14,178,920	1,232	0	1,833	249,640	0	376,040	4.3	0.25
4	Medium Off-Peak	2200	165,132	25,080	63,140	95	4,114	139	389,400	0	585,200	10,722,800	440	0	660	96,800	0	145,200	4.1	0.25
5	Light Off-Peak	2440	65,270	9,760	24,644	37	1,562	54	156,160	0	234,240	10,228,480	171	0	268	46,360	0	68,320	4.1	0.29
Total per year >>			861,600	131,812	330,564	501	22,199	737	2,000,360	0	3,001,880	38,727,800	2,448	0	3,673	507,040	0	761,400	4.4	0.25
Total per day >>			2,361	361	906	1	61	2	5,480	0	8,224	106,104	7	0	10	1,389	0	2,086		
Percentage of "Period 1" to daily total >>			7%	7%	7%	7%	7%	7%	7%	NA	7%	4%	6%	NA	6%	6%	NA	6%		
Percentage of "Period 2" to daily total >>			10%	10%	10%	11%	11%	11%	10%	NA	10%	3%	12%	NA	12%	11%	NA	11%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Design Option / Case: B

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	82,915	13,248	33,216	53	2,659	81	178,080	0	267,360	1,464,000	374	0	562	97,440	0	145,920	7.6	0.55
2	PM Peak	480	121,997	19,488	48,864	78	3,941	120	259,200	0	388,800	1,579,680	571	0	859	145,920	0	218,880	8.0	0.56
3	Business Hours	3160	474,063	75,840	189,916	300	15,200	465	1,017,520	0	1,526,280	10,939,920	2,149	0	3,223	559,320	0	837,400	7.6	0.55
4	Medium Off-Peak	2200	180,202	28,820	72,380	114	5,764	176	389,400	0	585,200	7,772,600	814	0	1,210	213,400	0	321,200	7.4	0.55
5	Light Off-Peak	2440	71,614	11,468	28,548	46	2,269	68	156,160	0	234,240	8,862,080	317	0	488	87,840	0	131,760	7.5	0.56
Total per year >>			930,791	148,864	372,924	592	29,833	909	2,000,360	0	3,001,880	30,618,280	4,226	0	6,342	1,103,920	0	1,655,160	7.6	0.55
Total per day >>			2,550	408	1,022	2	82	2	5,480	0	8,224	83,886	12	0	17	3,024	0	4,535		
Percentage of "Period 1" to daily total >>			7%	7%	7%	7%	7%	7%	7%	NA	7%	4%	7%	NA	7%	7%	NA	7%		
Percentage of "Period 2" to daily total >>			10%	10%	10%	10%	10%	10%	10%	NA	10%	4%	10%	NA	10%	10%	NA	10%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Figure K1– Case Study 10 (N01073) – 2001 aaSIDRA "Annual Sums"

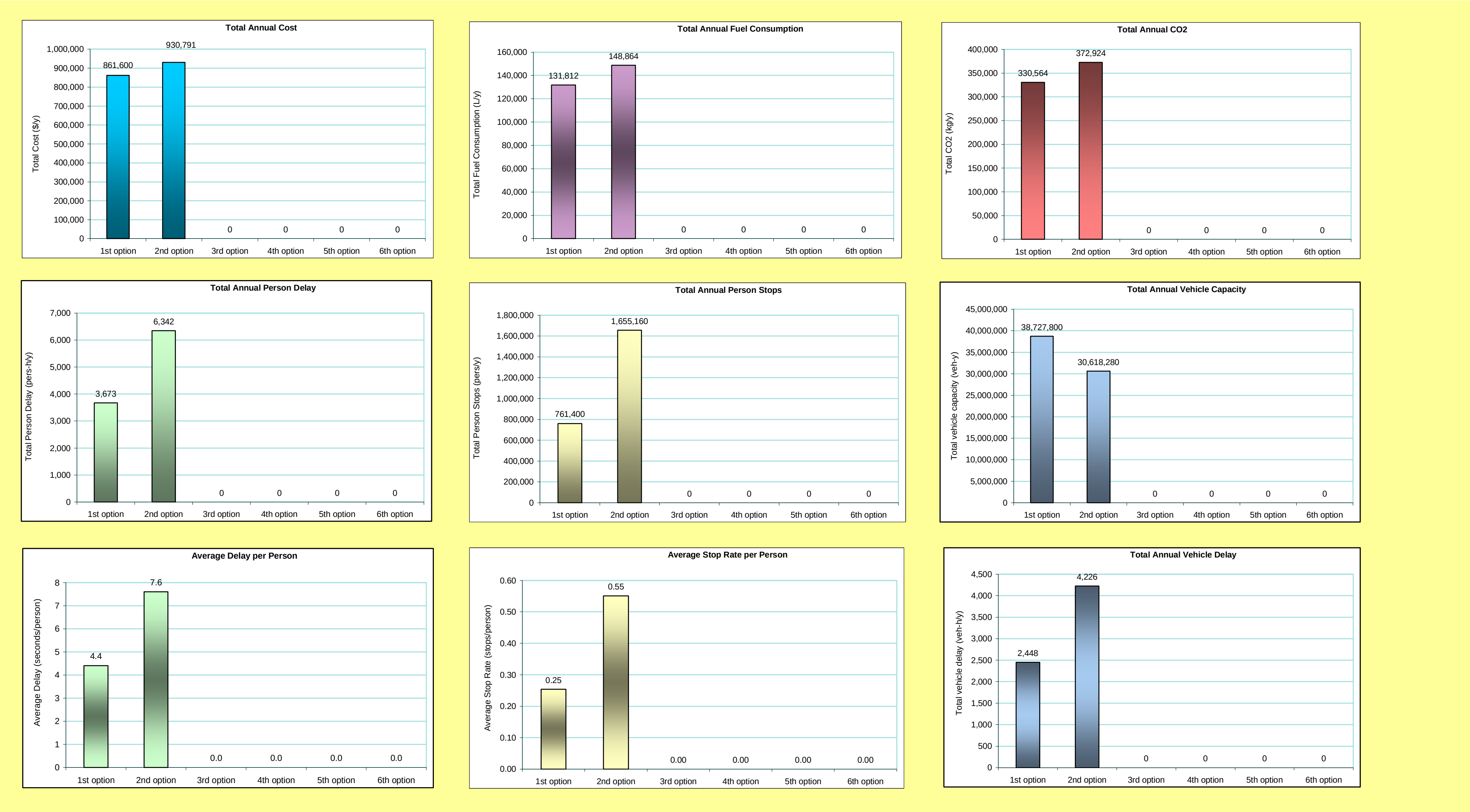

Figure K2– Case Study 10 (N01073) – 2001 aaSIDRA “Annual Sums Comparisons”

Annual sums for aaSIDRA results © Akcelik & Associates Pty Ltd 2000-2004 Version 4, September 2004

Calculation of ANNUAL SUMS

See "Combined Cases" sheet for calculating weighted average of Options A to F as cases (event scenarios)

Design Option / Case: A

Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Average: Person delay	Average: Person stops
Default values set in Defaults sheet			Total per YEAR																	
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	94,435	14,448	36,240	55	2,453	81	217,440	0	326,400	2,101,920	269	0	403	51,840	0	78,240	4.4	0.24
2	PM Peak	480	143,366	22,224	55,680	87	4,080	129	314,880	0	472,320	1,338,240	538	0	806	92,160	0	137,760	6.1	0.29
3	Business Hours	3160	542,951	83,424	209,508	319	14,410	474	1,245,040	0	1,867,560	13,196,160	1,612	0	2,402	312,840	0	470,840	4.6	0.25
4	Medium Off-Peak	2200	198,704	30,360	76,120	114	5,016	169	466,400	0	699,600	10,696,400	528	0	792	112,200	0	169,400	4.1	0.24
5	Light Off-Peak	2440	75,518	11,468	28,548	44	1,806	61	180,560	0	270,840	11,014,160	195	0	317	51,240	0	75,640	4.2	0.28
Total per year >>			1,054,975	161,924	406,096	620	27,764	915	2,424,320	0	3,636,720	38,346,880	3,141	0	4,720	620,280	0	931,880	4.7	0.26
Total per day >>			2,890	444	1,113	2	76	3	6,642	0	9,964	105,060	9	0	13	1,699	0	2,553		
Percentage of "Period 1" to daily total >>			7%	7%	7%	7%	7%	7%	7%	NA	7%	4%	7%	NA	6%	6%	NA	6%		
Percentage of "Period 2" to daily total >>			10%	10%	10%	11%	11%	11%	10%	NA	10%	3%	13%	NA	13%	11%	NA	11%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Design Option / Case: B

Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Average: Person delay	Average: Person stops
Default values set in Defaults sheet			Total per YEAR																	
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	101,549	16,224	40,704	65	3,264	99	217,440	0	326,400	1,442,880	461	0	691	119,520	0	179,520	7.6	0.55
2	PM Peak	480	148,757	23,760	59,568	95	4,814	146	314,880	0	472,320	1,535,040	706	0	1,061	180,000	0	270,240	8.1	0.57
3	Business Hours	3160	581,598	92,904	233,208	370	18,707	569	1,245,040	0	1,867,560	10,946,240	2,654	0	3,982	685,720	0	1,030,160	7.7	0.55
4	Medium Off-Peak	2200	216,128	34,540	86,680	136	6,908	211	466,400	0	699,600	7,785,800	968	0	1,452	255,200	0	385,000	7.5	0.55
5	Light Off-Peak	2440	82,765	13,176	33,184	54	2,611	81	180,560	0	270,840	8,837,680	366	0	561	102,480	0	151,280	7.5	0.56
Total per year >>			1,130,796	180,604	453,344	720	36,304	1,106	2,424,320	0	3,636,720	30,547,640	5,155	0	7,747	1,342,920	0	2,016,200	7.7	0.55
Total per day >>			3,098	495	1,242	2	99	3	6,642	0	9,964	83,692	14	0	21	3,679	0	5,524		
Percentage of "Period 1" to daily total >>			7%	7%	7%	7%	7%	7%	7%	NA	7%	4%	7%	NA	7%	7%	NA	7%		
Percentage of "Period 2" to daily total >>			10%	10%	10%	10%	10%	10%	10%	NA	10%	4%	10%	NA	10%	10%	NA	10%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Figure K3 – Case Study 10 (N01073) – 2016 aaSIDRA "Annual Sums"

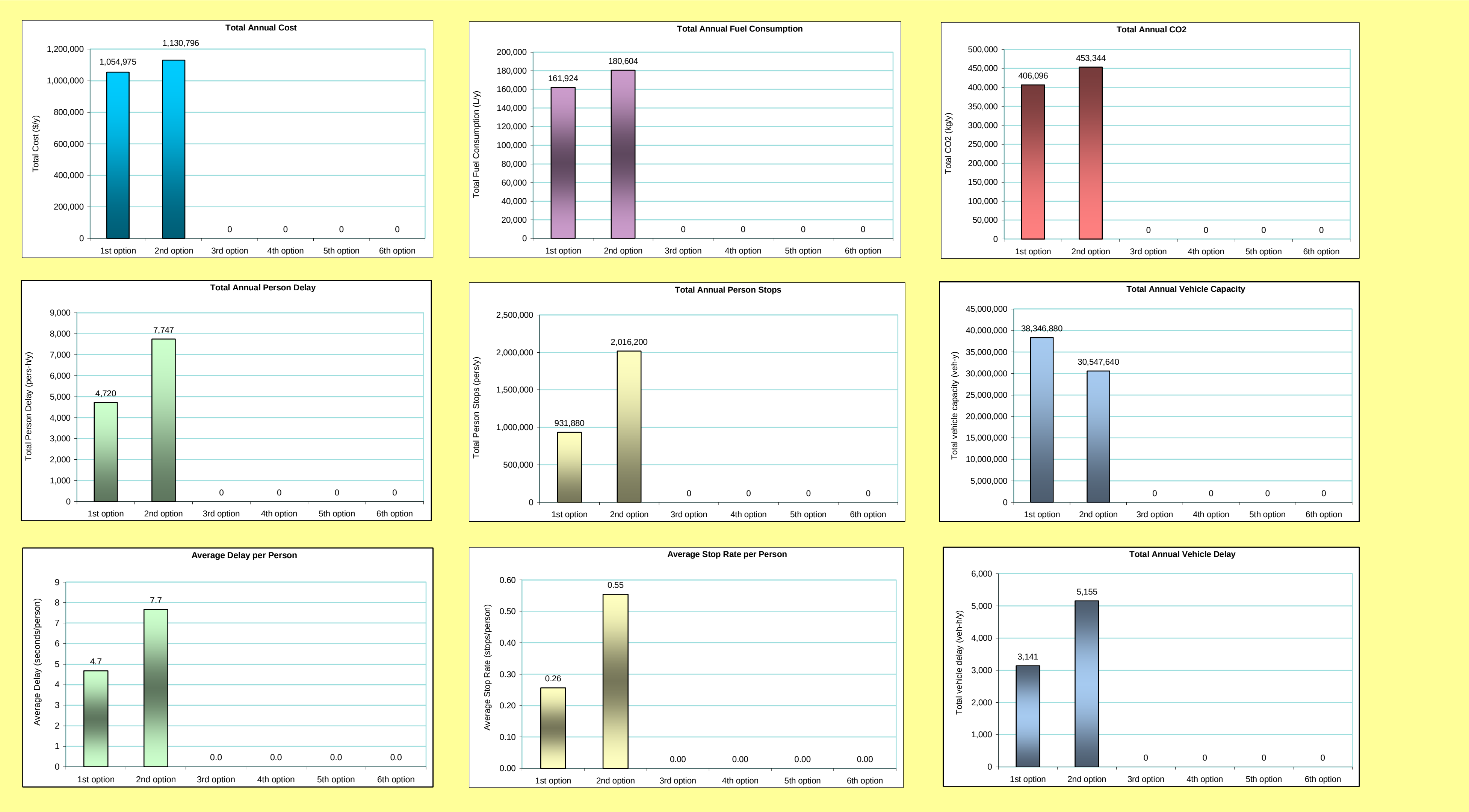

Figure K4 – Case Study 10 (N01073) – 2016 aaSIDRA "Annual Sums Comparisons"

Annual sums for aaSIDRA results © Akcelik & Associates Pty Ltd 2000-2004 Version 4, September 2004

Calculation of ANNUAL SUMS

See "Combined Cases" sheet for calculating weighted average of Options A to F as cases (event scenarios)

Design Option / Case: A

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	633,422	87,888	219,936	370	16,853	510	1,158,720	0	1,738,080	1,670,880	6,154	0	9,230	855,840	0	1,283,520	19.1	0.74
2	PM Peak	480	582,182	83,808	209,712	348	16,133	491	1,140,480	0	1,710,720	1,730,880	4,656	0	6,979	811,680	0	1,217,280	14.7	0.71
3	Business Hours	3160	2,678,163	381,412	954,952	1,567	70,405	2,193	5,375,160	0	8,064,320	13,117,160	20,445	0	30,684	3,355,920	0	5,037,040	13.7	0.62
4	Medium Off-Peak	2200	960,542	138,820	347,380	568	25,564	801	1,984,400	0	2,976,600	8,668,000	6,622	0	9,922	1,166,000	0	1,749,000	12.0	0.59
5	Light Off-Peak	2440	321,177	47,092	117,852	193	8,930	276	663,680	0	995,520	6,417,200	2,147	0	3,221	385,520	0	578,280	11.6	0.58
Total per year >>			5,175,487	739,020	1,849,832	3,046	137,885	4,270	10,322,440	0	15,485,240	31,604,120	40,024	0	60,036	6,574,960	0	9,865,120	14.0	0.64
Total per day >>			14,179	2,025	5,068	8	378	12	28,281	0	42,425	86,587	110	0	164	18,014	0	27,028		
Percentage of "Period 1" to daily total >>			9%	9%	9%	9%	9%	9%	9%	NA	9%	4%	12%	NA	12%	10%	NA	10%		
Percentage of "Period 2" to daily total >>			9%	9%	9%	9%	9%	9%	8%	NA	8%	4%	9%	NA	9%	9%	NA	9%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Design Option / Case: B

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	649,003	88,320	221,088	373	16,723	507	1,158,720	0	1,738,080	1,670,880	6,720	0	10,080	849,600	0	1,274,400	20.9	0.73
2	PM Peak	480	617,909	86,304	216,000	363	16,622	502	1,140,480	0	1,710,720	1,485,600	5,827	0	8,741	863,040	0	1,294,080	18.4	0.76
3	Business Hours	3160	2,826,241	394,052	985,920	1,640	73,502	2,263	5,375,160	0	8,064,320	10,573,360	25,248	0	37,857	3,539,200	0	5,308,800	16.9	0.66
4	Medium Off-Peak	2200	1,011,890	143,440	359,040	594	26,818	827	1,984,400	0	2,976,600	6,322,800	8,250	0	12,386	1,238,600	0	1,856,800	15.0	0.62
5	Light Off-Peak	2440	332,108	47,824	119,804	198	9,077	278	663,680	0	995,520	5,170,360	2,513	0	3,782	392,840	0	590,480	13.7	0.59
Total per year >>			5,437,151	759,940	1,901,852	3,168	142,742	4,377	10,322,440	0	15,485,240	25,223,000	48,559	0	72,846	6,883,280	0	10,324,560	16.9	0.67
Total per day >>			14,896	2,082	5,211	9	391	12	28,281	0	42,425	69,104	133	0	200	18,858	0	28,286		
Percentage of "Period 1" to daily total >>			9%	9%	9%	9%	9%	9%	9%	NA	9%	5%	11%	NA	11%	9%	NA	9%		
Percentage of "Period 2" to daily total >>			9%	9%	9%	9%	9%	9%	8%	NA	8%	4%	9%	NA	9%	10%	NA	10%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Figure L1– Case Study 11 (V00385) – 1998 aaSIDRA "Annual Sums"

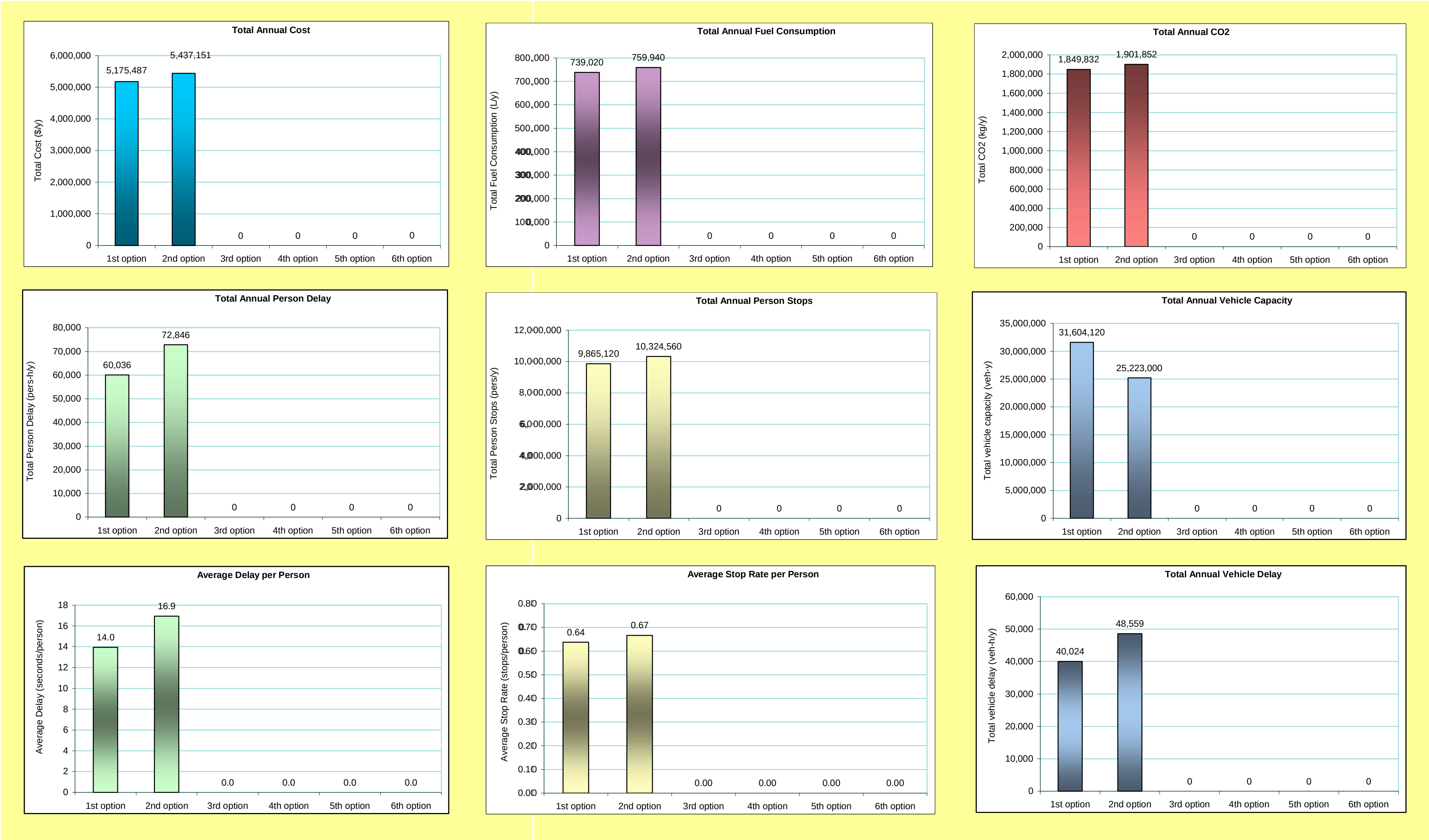

Figure L2– Case Study 11 (V00385) – 1998 aaSIDRA "Annual Sums Comparisons"

Annual sums for aaSIDRA results **© Akcelik & Associates Pty Ltd 2000-2004** **Version 4, September 2004**

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Calculation of ANNUAL SUMS

See "Combined Cases" sheet for calculating weighted average of Options A to F as cases (event scenarios)

Design Option / Case: A

Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay (Average)	Person stops (Average)
Default values set in Defaults sheet			Total per YEAR																Average	
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	722,942	99,456	248,928	422	19,330	578	1,281,600	0	1,922,400	1,673,760	7,474	0	11,208	1,016,640	0	1,524,960	21.0	0.79
2	PM Peak	480	661,003	94,416	236,352	396	18,403	555	1,259,520	0	1,889,280	1,692,000	5,678	0	8,520	960,000	0	1,439,520	16.2	0.76
3	Business Hours	3160	2,973,118	423,756	1,060,496	1,744	78,621	2,443	5,937,640	0	8,904,880	13,085,560	23,005	0	34,476	3,788,840	0	5,681,680	13.9	0.64
4	Medium Off-Peak	2200	1,059,674	153,120	383,240	627	28,270	884	2,184,600	0	3,278,000	8,734,000	7,348	0	11,022	1,300,200	0	1,949,200	12.1	0.59
5	Light Off-Peak	2440	356,704	52,216	131,028	215	9,906	305	736,880	0	1,105,320	6,485,520	2,391	0	3,587	431,880	0	646,600	11.7	0.58
Total per year >>			5,773,441	822,964	2,060,044	3,404	154,530	4,765	11,400,240	0	17,099,880	31,670,840	45,896	0	68,812	7,497,560	0	11,241,960	14.5	0.66
Total per day >>			15,818	2,255	5,644	9	423	13	31,234	0	46,849	86,769	126	0	189	20,541	0	30,800		
Percentage of "Period 1" to daily total >>			10%	9%	9%	9%	10%	9%	9%	NA	9%	4%	12%	NA	12%	10%	NA	10%		
Percentage of "Period 2" to daily total >>			9%	9%	9%	9%	9%	9%	8%	NA	8%	4%	9%	NA	9%	10%	NA	10%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Design Option / Case: B

Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay (Average)	Person stops (Average)
Default values set in Defaults sheet			Total per YEAR																Average	
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	740,203	99,984	250,224	425	19,186	576	1,281,600	0	1,922,400	1,673,760	8,098	0	12,149	1,011,840	0	1,518,240	22.8	0.79
2	PM Peak	480	708,240	97,776	244,752	415	19,080	570	1,259,520	0	1,889,280	1,483,200	7,214	0	10,824	1,035,360	0	1,553,280	20.6	0.82
3	Business Hours	3160	3,138,954	437,660	1,095,256	1,823	82,097	2,519	5,937,640	0	8,904,880	10,601,800	28,377	0	42,534	3,991,080	0	5,988,200	17.2	0.67
4	Medium Off-Peak	2200	1,116,368	158,180	396,220	656	29,678	915	2,184,600	0	3,278,000	6,298,600	9,152	0	13,728	1,379,400	0	2,070,200	15.1	0.63
5	Light Off-Peak	2440	368,757	53,192	133,224	220	10,102	310	736,880	0	1,105,320	5,238,680	2,806	0	4,197	439,200	0	658,800	13.7	0.60
Total per year >>			6,072,523	846,792	2,119,676	3,539	160,142	4,890	11,400,240	0	17,099,880	25,296,040	55,647	0	83,431	7,856,880	0	11,788,720	17.6	0.69
Total per day >>			16,637	2,320	5,807	10	439	13	31,234	0	46,849	69,304	152	0	229	21,526	0	32,298		
Percentage of "Period 1" to daily total >>			9%	9%	9%	9%	9%	9%	9%	NA	9%	5%	11%	NA	11%	10%	NA	10%		
Percentage of "Period 2" to daily total >>			9%	9%	9%	9%	9%	9%	8%	NA	8%	4%	10%	NA	10%	10%	NA	10%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Figure L3 – Case Study 11 (V00385) – 2008 aaSIDRA "Annual Sums"

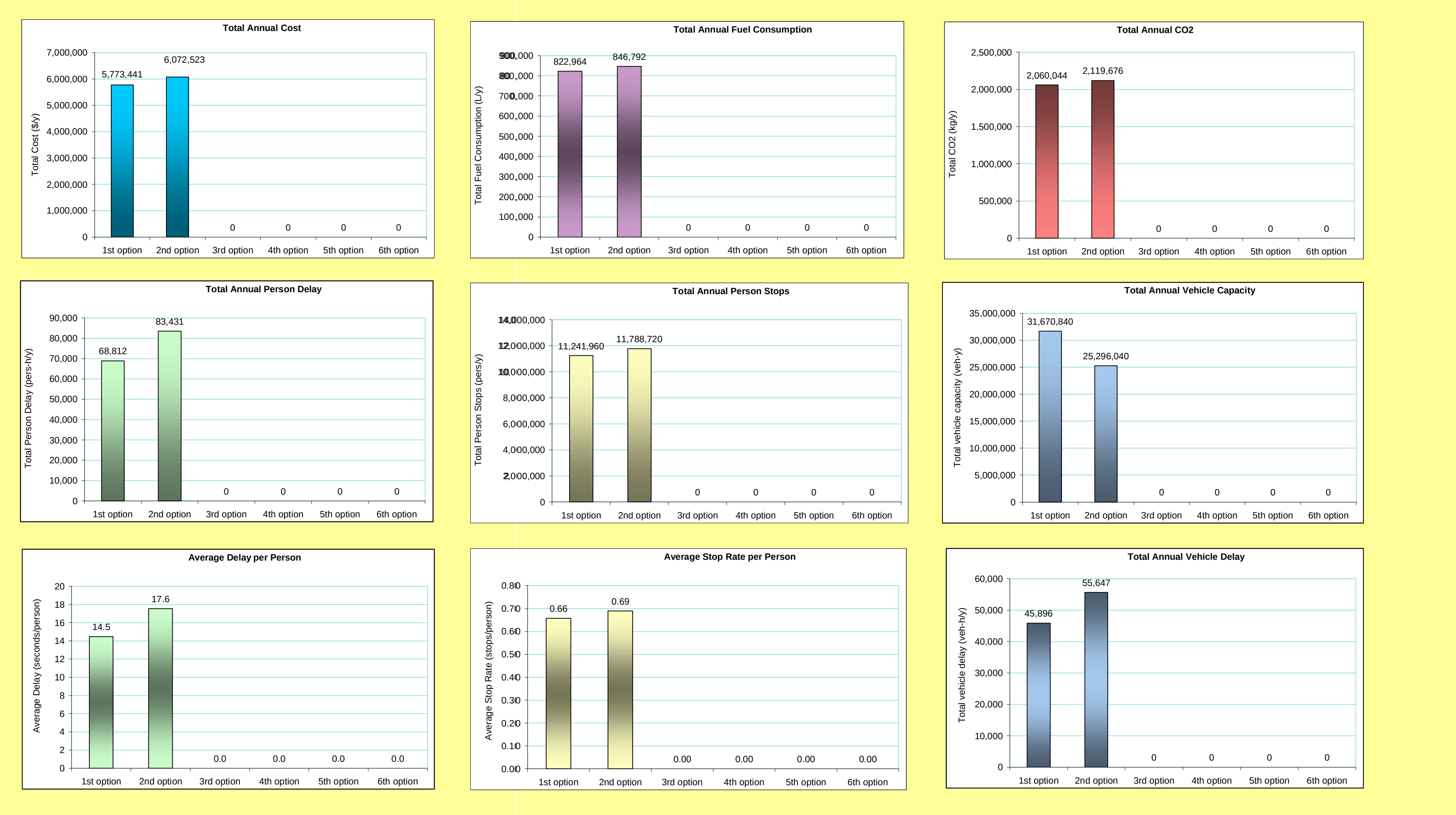

Figure L4 – Case Study 11 (V00385) – 2008 aaSIDRA "Annual Sums Comparisons"

Annual sums for aaSIDRA results © Akcelik & Associates Pty Ltd 2000-2004 **Version 4, September 2004**

Calculation of ANNUAL SUMS

See "Combined Cases" sheet for calculating weighted average of Options A to F as cases (event scenarios)

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Design Option / Case: A

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	683,894	87,984	220,416	320	10,022	409	1,484,160	0	2,226,240	1,920,480	4,766	0	7,147	62,400	0	94,080	11.6	0.04
2	PM Peak	480	699,998	83,376	208,560	306	7,814	377	1,615,680	0	2,423,520	2,056,320	4,498	0	6,744	103,680	0	155,520	10.0	0.06
3	Business Hours	3160	2,889,788	397,528	994,768	1,435	47,874	1,959	7,252,200	0	10,876,720	22,647,720	8,374	0	12,577	369,720	0	556,160	4.2	0.05
4	Medium Off-Peak	2200	1,011,802	141,020	353,100	495	15,730	682	2,679,600	0	4,019,400	16,724,400	1,100	0	1,650	121,000	0	180,400	1.5	0.04
5	Light Off-Peak	2440	329,815	45,384	113,704	156	4,514	212	893,040	0	1,339,560	18,448,840	171	0	268	31,720	0	48,800	0.7	0.04
Total per year >>			5,615,298	755,292	1,890,548	2,712	85,955	3,640	13,924,680	0	20,885,440	61,797,760	18,909	0	28,386	688,520	0	1,034,960	4.9	0.05
Total per day >>			15,384	2,069	5,180	7	235	10	38,150	0	57,220	169,309	52	0	78	1,886	0	2,836		
Percentage of "Period 1" to daily total >>			9%	9%	9%	9%	9%	9%	8%	NA	8%	2%	19%	NA	19%	7%	NA	7%		
Percentage of "Period 2" to daily total >>			9%	8%	8%	9%	7%	8%	9%	NA	9%	3%	18%	NA	18%	11%	NA	11%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Design Option / Case: B

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	780,202	114,192	285,984	463	21,590	662	1,506,240	0	2,259,360	1,910,400	5,981	0	8,971	1,076,640	0	1,614,720	14.3	0.71
2	PM Peak	480	854,309	124,368	311,568	504	23,573	723	1,613,280	0	2,420,160	1,856,160	7,032	0	10,550	1,215,840	0	1,823,520	15.7	0.75
3	Business Hours	3160	3,240,390	479,688	1,201,432	1,830	78,084	2,620	7,286,960	0	10,930,440	16,223,440	14,378	0	21,583	3,457,040	0	5,185,560	7.1	0.47
4	Medium Off-Peak	2200	1,167,826	172,700	432,520	649	27,104	928	2,692,800	0	4,039,200	10,582,000	4,466	0	6,710	1,122,000	0	1,685,200	6.0	0.42
5	Light Off-Peak	2440	396,988	59,292	148,840	224	9,687	325	910,120	0	1,366,400	10,435,880	1,488	0	2,245	380,640	0	570,960	5.9	0.42
Total per year >>			6,439,715	950,240	2,380,344	3,670	160,038	5,257	14,009,400	0	21,015,560	41,007,880	33,345	0	50,059	7,252,160	0	10,879,960	8.6	0.52
Total per day >>			17,643	2,603	6,521	10	438	14	38,382	0	57,577	112,350	91	0	137	19,869	0	29,808		
Percentage of "Period 1" to daily total >>			9%	9%	9%	10%	10%	10%	8%	NA	8%	4%	14%	NA	14%	11%	NA	11%		
Percentage of "Period 2" to daily total >>			10%	10%	10%	10%	11%	10%	9%	NA	9%	3%	16%	NA	16%	13%	NA	13%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Figure M1– Case Study 12 (V03035) – 2003 aaSIDRA "Annual Sums"

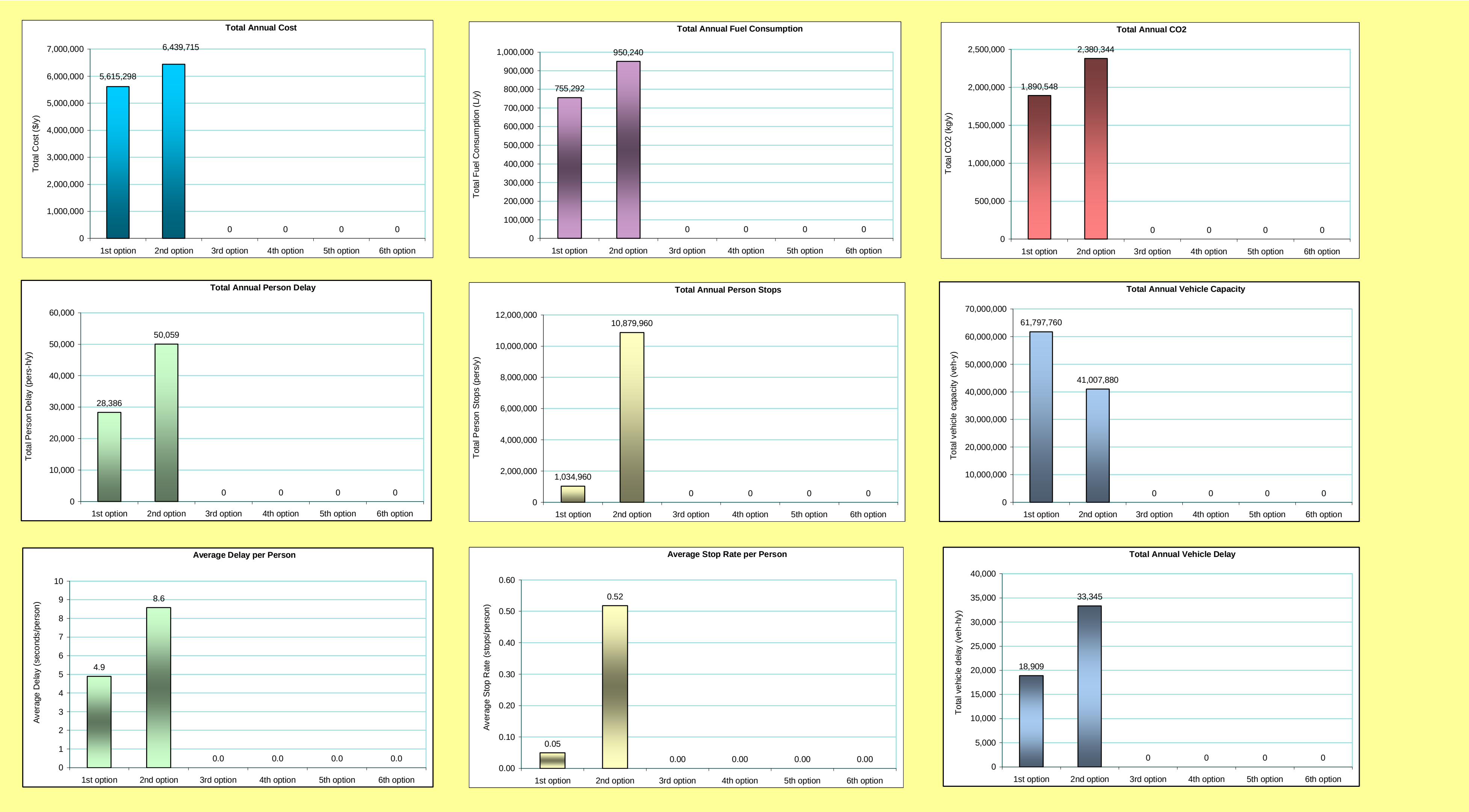

Figure M2– Case Study 12 (V03035) – 2003 aaSIDRA "Annual Sums Comparisons"

Annual sums for aaSIDRA results © Akcelik & Associates Pty Ltd 2000-2004 Version 4, September 2004

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Calculation of ANNUAL SUMS

See "Combined Cases" sheet for calculating weighted average of Options A to F as cases (event scenarios)

Design Option / Case: A

Default values set in Defaults sheet

Flow Period Ref. No.	Flow Period Description	Total Hours per year	Total per YEAR: Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Average: Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	938,179	108,000	270,576	406	11,304	473	1,723,200	0	2,584,800	1,723,200	10,690	0	16,037	78,240	0	117,600	22.3	0.05
2	PM Peak	480	886,378	98,880	247,392	366	8,150	423	1,905,120	0	2,857,920	1,905,120	7,627	0	11,443	166,560	0	250,080	14.4	0.09
3	Business Hours	3160	3,472,208	463,256	1,159,404	1,681	54,004	2,244	8,408,760	0	12,614,720	21,516,440	14,283	0	21,425	436,080	0	654,120	6.1	0.05
4	Medium Off-Peak	2200	1,171,236	162,360	406,560	574	18,216	788	3,102,000	0	4,653,000	16,695,800	1,452	0	2,178	138,600	0	206,800	1.7	0.04
5	Light Off-Peak	2440	377,297	51,240	128,100	176	4,880	237	1,029,680	0	1,544,520	18,529,360	195	0	268	34,160	0	51,240	0.6	0.03
Total per year >>			6,845,298	883,736	2,212,032	3,203	96,555	4,165	16,168,760	0	24,254,960	60,369,920	34,247	0	51,351	853,640	0	1,279,840	7.6	0.05
Total per day >>			18,754	2,421	6,060	9	265	11	44,298	0	66,452	165,397	94	0	141	2,339	0	3,506		
Percentage of "Period 1" to daily total >>			10%	9%	9%	10%	9%	9%	8%	NA	8%	2%	24%	NA	24%	7%	NA	7%		
Percentage of "Period 2" to daily total >>			10%	9%	9%	9%	6%	8%	9%	NA	9%	2%	17%	NA	17%	15%	NA	15%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Design Option / Case: B

Default values set in Defaults sheet

Flow Period Ref. No.	Flow Period Description	Total Hours per year	Total per YEAR: Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Average: Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	975,576	139,680	349,824	577	27,178	816	1,748,160	0	2,622,240	2,003,520	9,038	0	13,560	1,422,720	0	2,133,600	18.6	0.81
2	PM Peak	480	963,470	139,680	349,920	556	25,123	793	1,903,200	0	2,855,040	2,218,560	7,210	0	10,810	1,252,800	0	1,879,680	13.6	0.66
3	Business Hours	3160	4,574,637	703,416	1,762,016	2,936	149,563	4,336	8,462,480	0	12,693,720	9,773,880	35,740	0	53,625	8,617,320	0	12,927,560	15.2	1.02
4	Medium Off-Peak	2200	1,470,172	229,680	575,520	917	44,374	1,362	3,126,200	0	4,690,400	6,809,000	7,326	0	11,000	2,061,400	0	3,093,200	8.4	0.66
5	Light Off-Peak	2440	481,314	74,176	185,684	290	13,542	427	1,056,520	0	1,586,000	7,607,920	2,123	0	3,172	568,520	0	851,560	7.2	0.54
Total per year >>			8,465,170	1,286,632	3,222,964	5,277	259,780	7,734	16,296,560	0	24,447,400	28,412,880	61,436	0	92,167	13,922,760	0	20,885,600	13.6	0.85
Total per day >>			23,192	3,525	8,830	14	712	21	44,648	0	66,979	77,844	168	0	253	38,145	0	57,221		
Percentage of "Period 1" to daily total >>			9%	8%	8%	8%	8%	8%	8%	NA	8%	5%	11%	NA	11%	8%	NA	8%		
Percentage of "Period 2" to daily total >>			9%	8%	8%	8%	7%	8%	9%	NA	9%	6%	9%	NA	9%	7%	NA	7%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Figure M3 – Case Study 12 (V03035) – 2018 aaSIDRA "Annual Sums"

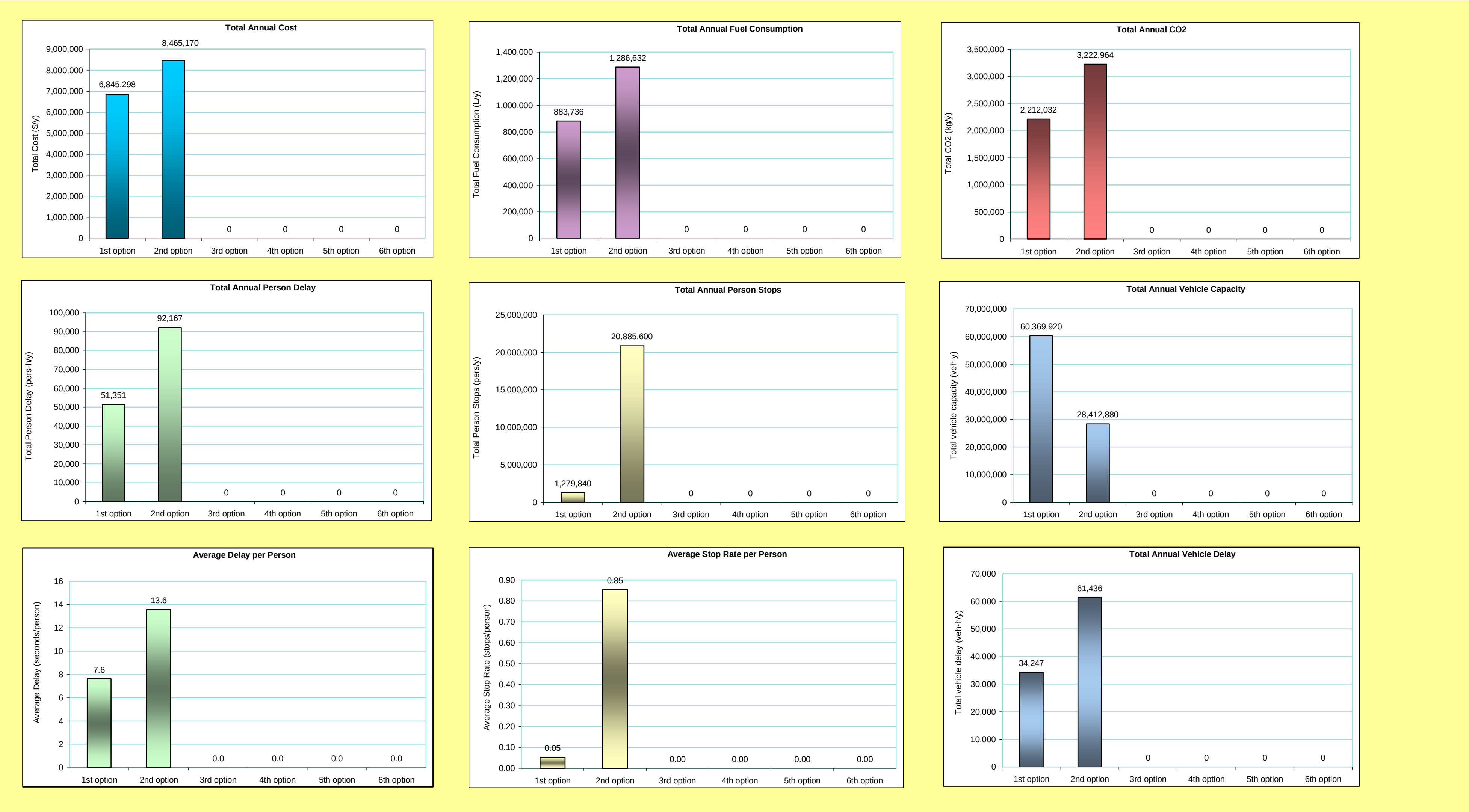

Figure M4 – Case Study 12 (V03035) – 2018 aaSIDRA "Annual Sums Comparisons"

Annual sums for aaSIDRA results © **Akcelik & Associates Pty Ltd 2000-2004** **Version 4, September 2004**

Calculation of ANNUAL SUMS

See "Combined Cases" sheet for calculating weighted average of Options A to F as cases (event scenarios)

Design Option / Case: A

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	363,874	54,144	135,600	215	9,874	314	779,520	0	1,169,280	1,235,040	1,982	0	2,971	503,040	0	754,560	9.1	0.65
2	PM Peak	480	417,106	60,576	151,728	242	10,963	348	862,080	0	1,293,120	1,025,760	2,746	0	4,123	564,960	0	847,200	11.5	0.66
3	Business Hours	3160	1,780,281	267,968	670,868	1,055	48,348	1,548	3,940,520	0	5,909,200	11,979,560	8,216	0	12,292	2,066,640	0	3,099,960	7.5	0.52
4	Medium Off-Peak	2200	644,842	97,680	244,640	383	17,490	563	1,454,200	0	2,182,400	8,470,000	2,640	0	3,960	671,000	0	1,007,600	6.5	0.46
5	Light Off-Peak	2440	222,455	36,844	92,720	137	6,734	217	483,120	0	724,680	9,540,400	830	0	1,244	212,280	0	317,200	6.2	0.44
Total per year >>			3,428,557	517,212	1,295,556	2,032	93,409	2,991	7,519,440	0	11,278,680	32,250,760	16,414	0	24,591	4,017,920	0	6,026,520	7.8	0.53
Total per day >>			9,393	1,417	3,549	6	256	8	20,601	0	30,900	88,358	45	0	67	11,008	0	16,511		
Percentage of "Period 1" to daily total >>			8%	8%	8%	8%	8%	8%	8%	NA	8%	3%	9%	NA	9%	10%	NA	10%		
Percentage of "Period 2" to daily total >>			9%	9%	9%	9%	9%	9%	9%	NA	9%	2%	13%	NA	13%	11%	NA	11%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Design Option / Case: B

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	389,837	60,096	150,432	249	12,422	369	796,800	0	1,195,200	1,107,840	2,318	0	3,475	564,960	0	847,200	10.5	0.71
2	PM Peak	480	428,717	64,224	160,704	271	13,205	391	883,200	0	1,324,800	1,485,120	2,530	0	3,797	608,640	0	912,960	10.3	0.69
3	Business Hours	3160	1,933,509	294,828	737,544	1,226	60,293	1,795	4,035,320	0	6,054,560	8,885,920	10,554	0	15,832	2,556,440	0	3,836,240	9.4	0.63
4	Medium Off-Peak	2200	703,384	107,800	269,720	447	21,890	656	1,487,200	0	2,230,800	6,617,600	3,652	0	5,500	888,800	0	1,333,200	8.9	0.60
5	Light Off-Peak	2440	235,362	36,600	91,744	149	7,418	222	500,200	0	751,520	7,737,240	1,196	0	1,781	300,120	0	448,960	8.5	0.60
Total per year >>			3,690,809	563,548	1,410,144	2,342	115,228	3,432	7,702,720	0	11,556,880	25,833,720	20,250	0	30,385	4,918,960	0	7,378,560	9.5	0.64
Total per day >>			10,112	1,544	3,863	6	316	9	21,103	0	31,663	70,777	55	0	83	13,477	0	20,215		
Percentage of "Period 1" to daily total >>			8%	8%	8%	8%	8%	8%	8%	NA	8%	3%	9%	NA	9%	9%	NA	9%		
Percentage of "Period 2" to daily total >>			9%	9%	9%	9%	9%	9%	9%	NA	9%	4%	9%	NA	10%	9%	NA	9%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Figure N1– Case Study 13 (V01062) – 1998 aaSIDRA "Annual Sums"

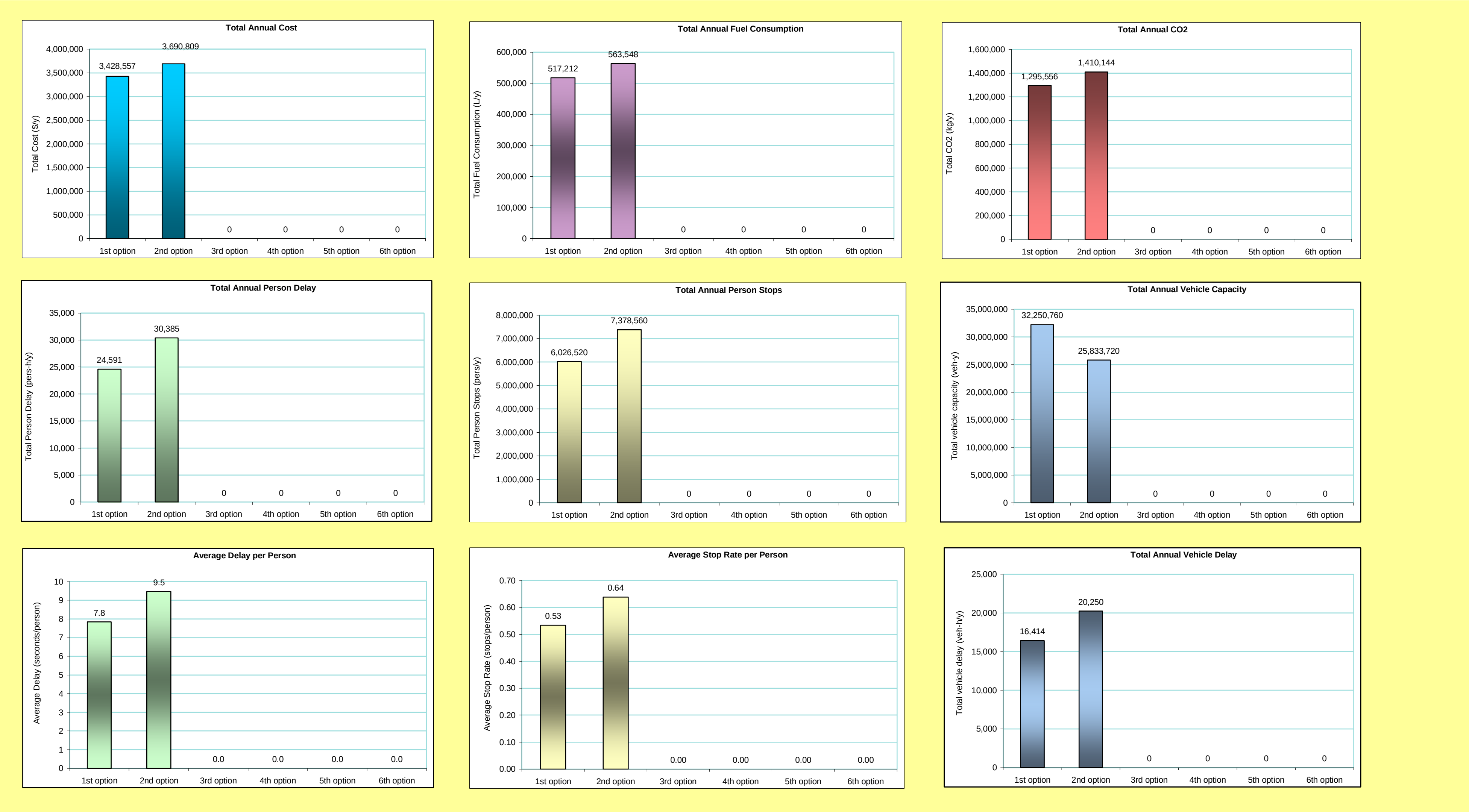

Figure N2– Case Study 13 (V01062) – 1998 aaSIDRA "Annual Sums Comparisons"

Annual sums for aaSIDRA results © Akcelik & Associates Pty Ltd 2000-2004 Version 4, September 2004

Calculation of ANNUAL SUMS

See "Combined Cases" sheet for calculating weighted average of Options A to F as cases (event scenarios)

Design Option / Case: A

Default values set in Defaults sheet

Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay (Average)	Person stops (Average)
			Total per YEAR																Average	
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	409,075	60,432	151,296	241	11,069	350	857,760	0	1,286,400	1,175,040	2,438	0	3,658	603,840	0	905,760	10.2	0.70
2	PM Peak	480	465,442	67,248	168,432	270	12,211	386	948,960	0	1,423,680	1,057,920	3,216	0	4,819	669,600	0	1,004,160	12.2	0.71
3	Business Hours	3160	2,074,192	339,068	851,620	1,270	63,295	2,019	4,335,520	0	6,503,280	10,987,320	10,080	0	15,136	2,452,160	0	3,678,240	8.4	0.57
4	Medium Off-Peak	2200	709,918	108,020	270,160	422	19,360	623	1,595,000	0	2,393,600	8,448,000	2,926	0	4,400	745,800	0	1,117,600	6.6	0.47
5	Light Off-Peak	2440	234,460	35,380	88,328	139	6,246	203	536,800	0	805,200	9,611,160	903	0	1,366	236,680	0	356,240	6.1	0.44
Total per year >>			3,893,087	610,148	1,529,836	2,343	112,181	3,581	8,274,040	0	12,412,160	31,279,440	19,564	0	29,380	4,708,080	0	7,062,000	8.5	0.57
Total per day >>			10,666	1,672	4,191	6	307	10	22,669	0	34,006	85,697	54	0	80	12,899	0	19,348		
Percentage of "Period 1" to daily total >>			8%	8%	8%	8%	8%	7%	8%	NA	8%	3%	9%	NA	9%	10%	NA	10%		
Percentage of "Period 2" to daily total >>			9%	8%	8%	9%	8%	8%	9%	NA	9%	3%	13%	NA	12%	11%	NA	11%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Design Option / Case: B

Default values set in Defaults sheet

Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay (Average)	Person stops (Average)
			Total per YEAR																Average	
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	430,286	66,048	165,360	275	13,728	406	865,920	0	1,298,880	1,099,200	2,707	0	4,061	639,840	0	960,000	11.3	0.74
2	PM Peak	480	475,397	71,040	177,792	300	14,645	432	974,400	0	1,461,600	1,463,040	2,894	0	4,339	696,480	0	1,044,480	10.7	0.71
3	Business Hours	3160	2,143,776	326,428	816,860	1,362	66,897	1,991	4,458,760	0	6,686,560	8,772,160	11,850	0	17,791	2,878,760	0	4,319,720	9.6	0.65
4	Medium Off-Peak	2200	777,744	118,800	297,660	493	24,178	724	1,643,400	0	2,464,000	6,602,200	4,070	0	6,116	987,800	0	1,480,600	8.9	0.60
5	Light Off-Peak	2440	257,810	40,016	100,040	163	8,076	242	549,000	0	824,720	7,698,200	1,318	0	1,952	329,400	0	492,880	8.5	0.60
Total per year >>			4,085,013	622,332	1,557,712	2,593	127,524	3,795	8,491,480	0	12,735,760	25,634,800	22,839	0	34,259	5,532,280	0	8,297,680	9.7	0.65
Total per day >>			11,192	1,705	4,268	7	349	10	23,264	0	34,892	70,232	63	0	94	15,157	0	22,733		
Percentage of "Period 1" to daily total >>			8%	8%	8%	8%	8%	8%	8%	NA	8%	3%	9%	NA	9%	9%	NA	9%		
Percentage of "Period 2" to daily total >>			9%	9%	9%	9%	9%	9%	9%	NA	9%	4%	10%	NA	10%	10%	NA	10%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Figure N3 – Case Study 13 (V01062) – 2018 aaSIDRA "Annual Sums"

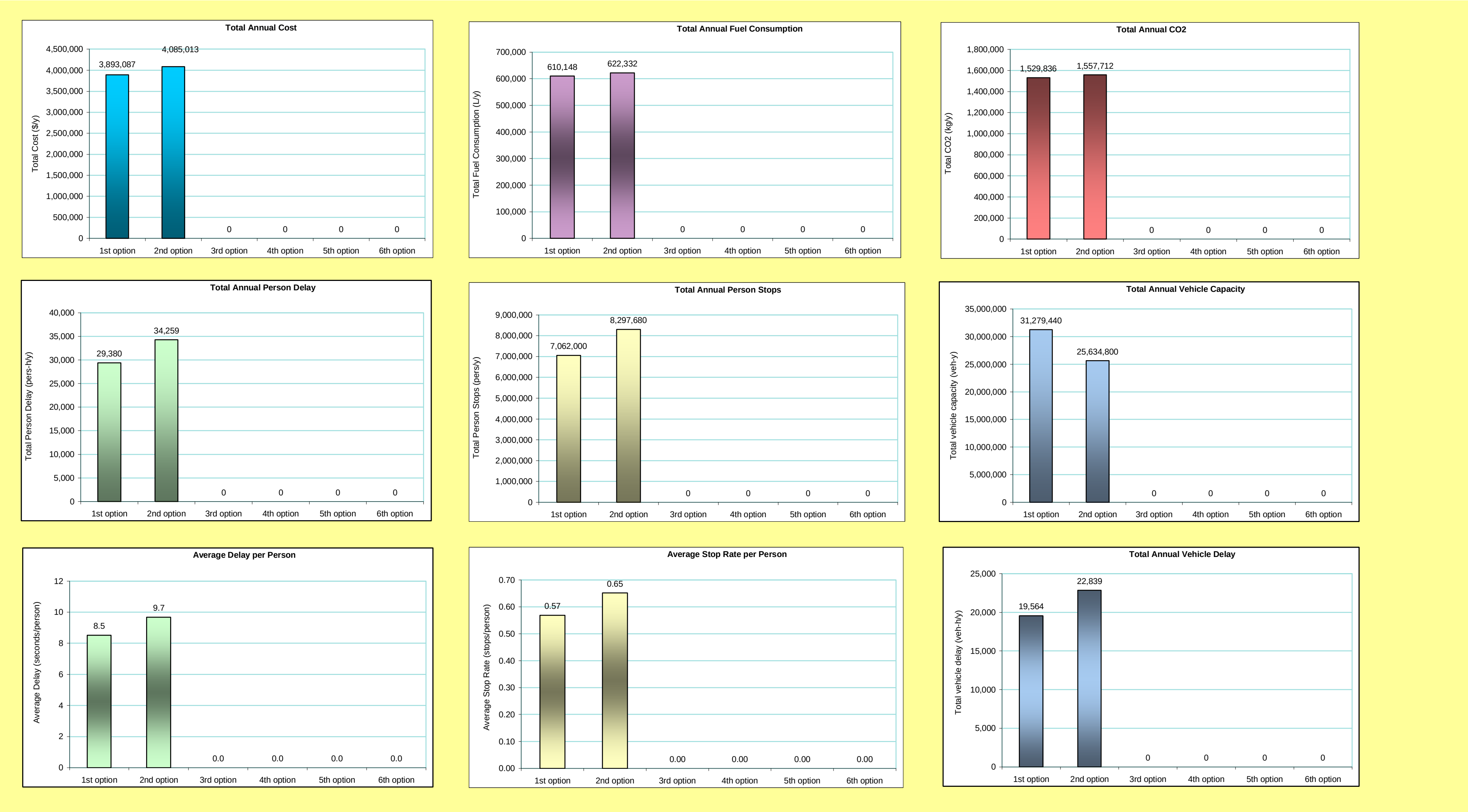

Figure N4 – Case Study 13 (V01062) – 2018 aaSIDRA "Annual Sums Comparisons"

Annual sums for aaSIDRA results © **Akcelik & Associates Pty Ltd 2000-2004** **Version 4, September 2004**

Calculation of ANNUAL SUMS

See "Combined Cases" sheet for calculating weighted average of Options A to F as cases (event scenarios)

Design Option / Case: A

Default values set in Defaults sheet			Total per **YEAR**																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	712,238	100,368	251,424	412	18,950	579	1,263,360	0	1,895,040	2,335,680	7,128	0	10,690	873,120	0	1,309,440	20.3	0.69
2	PM Peak	480	745,632	105,552	264,432	433	20,006	611	1,328,160	0	1,992,000	2,494,560	7,358	0	11,035	929,280	0	1,393,440	19.9	0.70
3	Business Hours	3160	3,184,206	466,416	1,168,568	1,893	88,512	2,718	6,060,880	0	9,091,320	15,651,480	26,291	0	39,405	3,959,480	0	5,937,640	15.6	0.65
4	Medium Off-Peak	2200	1,621,202	240,020	601,040	968	45,474	1,399	3,150,400	0	4,725,600	9,801,000	12,540	0	18,810	1,988,800	0	2,981,000	14.3	0.63
5	Light Off-Peak	2440	509,814	78,080	195,444	310	14,738	459	1,056,520	0	1,586,000	11,895,000	3,074	0	4,636	597,800	0	895,480	10.5	0.56
Total per year >>			6,773,092	990,436	2,480,908	4,016	187,680	5,765	12,859,320	0	19,289,960	42,177,720	56,392	0	84,576	8,348,480	0	12,517,000	15.8	0.65
Total per day >>			18,556	2,714	6,797	11	514	16	35,231	0	52,849	115,555	154	0	232	22,873	0	34,293		
Percentage of "Period 1" to daily total >>			8%	8%	8%	8%	8%	8%	7%	NA	7%	4%	10%	NA	10%	8%	NA	8%		
Percentage of "Period 2" to daily total >>			8%	8%	8%	8%	8%	8%	8%	NA	8%	4%	10%	NA	10%	8%	NA	8%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Design Option / Case: B

Default values set in Defaults sheet			Total per **YEAR**																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	749,808	104,016	260,544	433	19,982	602	1,263,360	0	1,895,040	1,843,680	8,290	0	12,437	939,840	0	1,409,760	23.6	0.74
2	PM Peak	480	772,310	107,856	270,144	446	20,587	624	1,327,680	0	1,991,520	2,382,720	8,213	0	12,322	967,680	0	1,451,520	22.3	0.73
3	Business Hours	3160	3,181,930	466,416	1,168,252	1,890	88,448	2,718	6,064,040	0	9,094,480	15,660,960	26,165	0	39,247	3,953,160	0	5,931,320	15.5	0.65
4	Medium Off-Peak	2200	1,622,940	240,240	602,140	970	45,540	1,401	3,157,000	0	4,734,400	9,820,800	12,518	0	18,766	1,991,000	0	2,985,400	14.3	0.63
5	Light Off-Peak	2440	507,862	77,836	194,712	310	14,689	456	1,054,080	0	1,581,120	11,868,160	3,050	0	4,587	595,360	0	890,600	10.4	0.56
Total per year >>			6,834,850	996,364	2,495,792	4,049	189,247	5,802	12,866,160	0	19,296,560	41,576,320	58,235	0	87,359	8,447,040	0	12,668,600	16.3	0.66
Total per day >>			18,726	2,730	6,838	11	518	16	35,250	0	52,867	113,908	160	0	239	23,143	0	34,708		
Percentage of "Period 1" to daily total >>			8%	8%	8%	8%	8%	8%	7%	NA	7%	3%	11%	NA	11%	8%	NA	8%		
Percentage of "Period 2" to daily total >>			9%	8%	8%	8%	8%	8%	8%	NA	8%	4%	11%	NA	11%	9%	NA	9%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Figure O1– Case Study 14 (N00995) – 2001 aaSIDRA "Annual Sums"

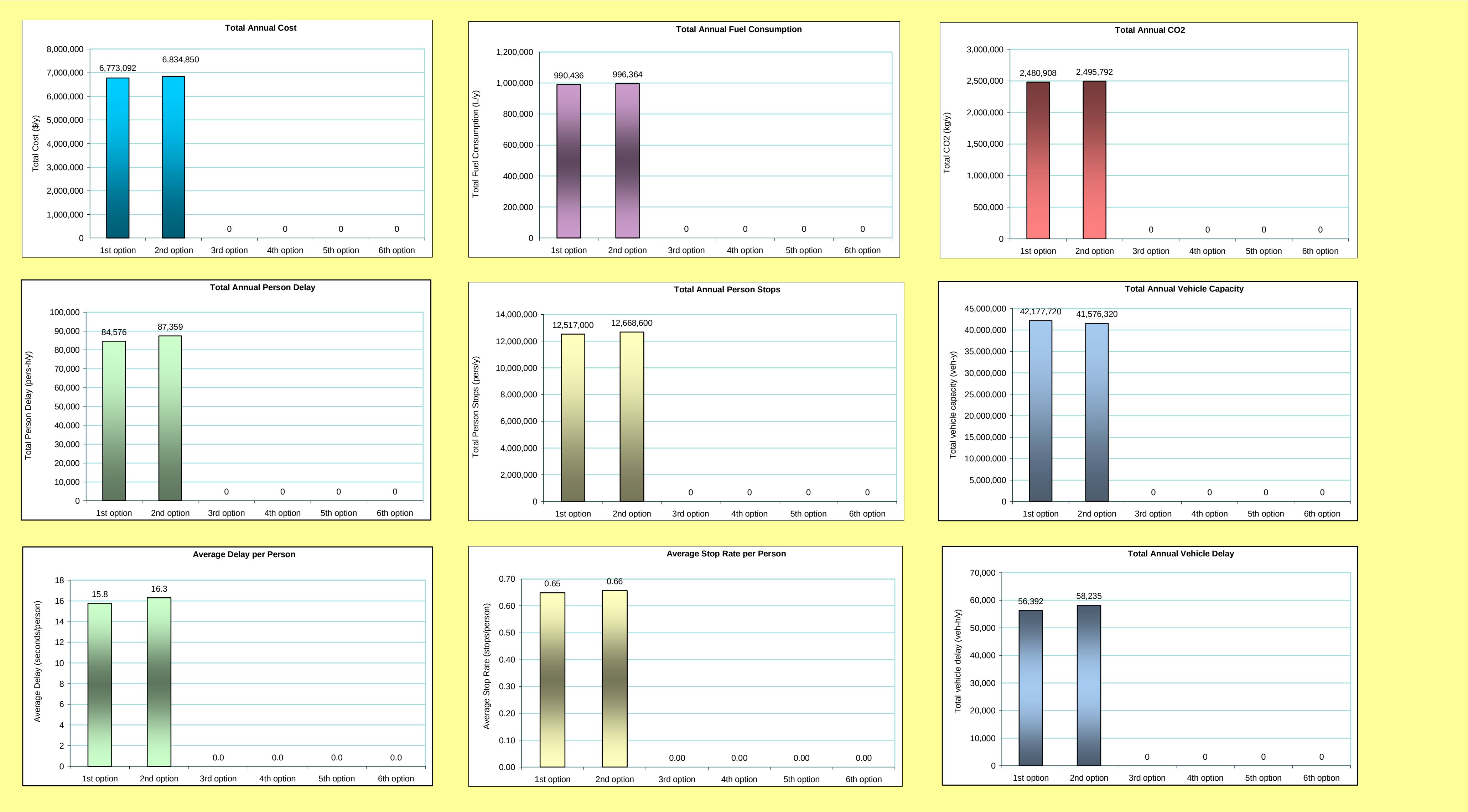

Figure O2– Case Study 14 (N00995) – 2001 aaSIDRA "Annual Sums Comparisons"

Annual sums for aaSIDRA results **© Akcelik & Associates Pty Ltd 2000-2004** **Version 4, September 2004**

Calculation of ANNUAL SUMS

See "Combined Cases" sheet for calculating weighted average of Options A to F as cases (event scenarios)

Design Option / Case: A

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	841,008	118,368	296,496	489	22,646	686	1,466,400	0	2,199,360	2,271,360	8,678	0	13,018	1,063,200	0	1,595,040	21.3	0.73
2	PM Peak	480	890,054	125,472	314,304	520	24,206	731	1,541,280	0	2,311,680	2,404,800	9,264	0	13,901	1,155,840	0	1,733,760	21.6	0.75
3	Business Hours	3160	3,720,774	545,100	1,365,752	2,218	104,154	3,185	7,031,000	0	10,548,080	15,234,360	31,221	0	46,831	4,721,040	0	7,081,560	16.0	0.67
4	Medium Off-Peak	2200	1,897,698	280,940	704,000	1,140	53,746	1,646	3,656,400	0	5,484,600	9,631,600	14,982	0	22,462	2,382,600	0	3,575,000	14.7	0.65
5	Light Off-Peak	2440	592,700	90,768	227,408	361	17,178	532	1,227,320	0	1,839,760	11,909,640	3,587	0	5,392	702,720	0	1,054,080	10.6	0.57
Total per year >>			7,942,234	1,160,648	2,907,960	4,728	221,930	6,780	14,922,400	0	22,383,480	41,451,760	67,732	0	101,604	10,025,400	0	15,039,440	16.3	0.67
Total per day >>			21,760	3,180	7,967	13	608	19	40,883	0	61,325	113,566	186	0	278	27,467	0	41,204		
Percentage of "Period 1" to daily total >>			8%	8%	8%	8%	8%	8%	7%	NA	7%	4%	10%	NA	10%	8%	NA	8%		
Percentage of "Period 2" to daily total >>			9%	8%	8%	8%	8%	8%	8%	NA	8%	4%	10%	NA	10%	9%	NA	9%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Design Option / Case: B

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	894,648	123,216	308,592	516	23,938	716	1,466,400	0	2,199,360	1,846,080	10,354	0	15,528	1,164,480	0	1,746,240	25.4	0.79
2	PM Peak	480	913,805	127,344	319,008	530	24,638	741	1,541,280	0	2,311,680	2,371,680	10,032	0	15,048	1,188,480	0	1,782,720	23.4	0.77
3	Business Hours	3160	3,715,623	544,784	1,364,488	2,215	103,996	3,182	7,031,000	0	10,548,080	15,294,400	31,063	0	46,578	4,711,560	0	7,065,760	15.9	0.67
4	Medium Off-Peak	2200	1,889,162	279,620	700,700	1,131	53,262	1,635	3,654,200	0	5,482,400	9,640,400	14,762	0	22,154	2,354,000	0	3,531,000	14.5	0.64
5	Light Off-Peak	2440	590,724	90,524	226,676	361	17,104	532	1,224,880	0	1,837,320	11,885,240	3,562	0	5,344	697,840	0	1,049,200	10.5	0.57
Total per year >>			8,003,962	1,165,488	2,919,464	4,754	222,938	6,805	14,917,760	0	22,378,840	41,037,800	69,773	0	104,652	10,116,360	0	15,174,920	16.8	0.68
Total per day >>			21,929	3,193	7,999	13	611	19	40,871	0	61,312	112,432	191	0	287	27,716	0	41,575		
Percentage of "Period 1" to daily total >>			8%	8%	8%	8%	8%	8%	7%	NA	7%	3%	11%	NA	11%	9%	NA	9%		
Percentage of "Period 2" to daily total >>			9%	8%	8%	8%	8%	8%	8%	NA	8%	4%	11%	NA	11%	9%	NA	9%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Figure O3 – Case Study 14 (N00995) – 2016 aaSIDRA “Annual Sums”

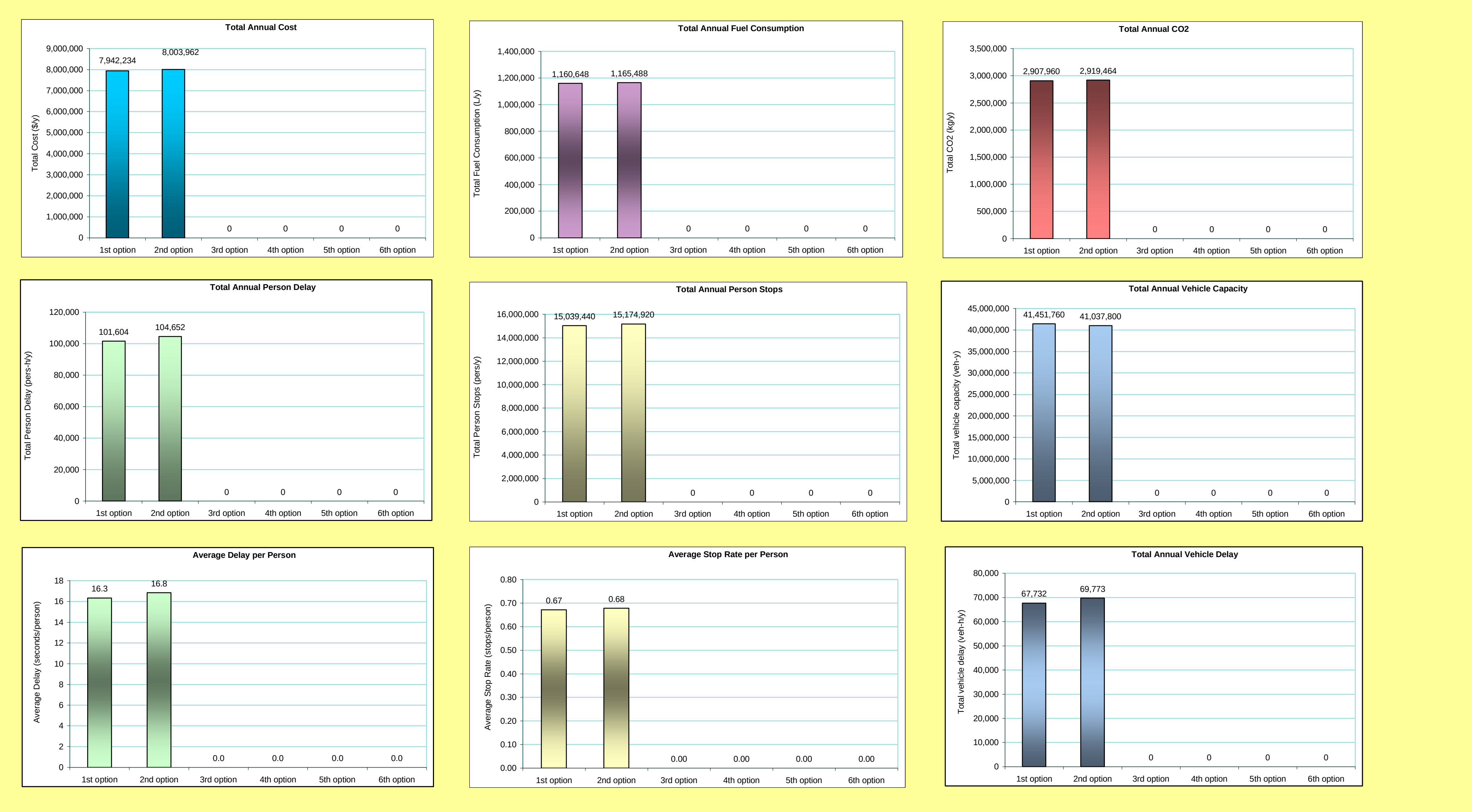

Figure O4 – Case Study 14 (N00995) – 2016 aaSIDRA "Annual Sums Comparisons"

Annual sums for aaSIDRA results © Akcelik & Associates Pty Ltd 2000-2004 Version 4, September 2004

Calculation of ANNUAL SUMS

See "Combined Cases" sheet for calculating weighted average of Options A to F as cases (event scenarios)

Design Option / Case: A

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	322,877	42,576	106,560	146	3,946	191	819,360	0	1,228,800	1,173,120	989	0	1,483	90,240	0	135,360	4.3	0.11
2	PM Peak	480	354,422	45,696	114,384	158	4,238	203	865,440	0	1,297,920	983,520	1,507	0	2,261	101,280	0	151,680	6.3	0.12
3	Business Hours	3160	1,475,341	200,660	502,440	679	18,834	910	3,934,200	0	5,902,880	19,797,400	2,117	0	3,160	395,000	0	590,920	1.9	0.10
4	Medium Off-Peak	2200	537,548	73,700	184,360	249	6,886	334	1,452,000	0	2,178,000	18,095,000	528	0	814	125,400	0	187,000	1.3	0.09
5	Light Off-Peak	2440	183,561	25,376	63,440	85	2,440	115	495,320	0	741,760	20,308,120	171	0	268	43,920	0	65,880	1.3	0.09
Total per year >>			2,873,749	388,008	971,184	1,318	36,344	1,753	7,566,320	0	11,349,360	60,357,160	5,312	0	7,986	755,840	0	1,130,840	2.5	0.10
Total per day >>			7,873	1,063	2,661	4	100	5	20,730	0	31,094	165,362	15	0	22	2,071	0	3,098		
Percentage of "Period 1" to daily total >>			9%	8%	8%	8%	8%	8%	8%	NA	8%	1%	14%	NA	14%	9%	NA	9%		
Percentage of "Period 2" to daily total >>			9%	9%	9%	9%	9%	9%	9%	NA	9%	1%	22%	NA	22%	10%	NA	10%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Design Option / Case: B

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	385,714	51,744	129,552	198	7,354	265	819,360	0	1,228,800	2,738,880	2,712	0	4,070	290,880	0	436,320	11.9	0.36
2	PM Peak	480	408,120	55,296	138,480	212	8,102	287	865,440	0	1,297,920	2,507,040	2,842	0	4,262	329,280	0	493,920	11.8	0.38
3	Business Hours	3160	1,805,877	247,112	619,044	942	35,771	1,280	3,934,200	0	5,902,880	16,643,720	11,313	0	17,001	1,399,880	0	2,098,240	10.4	0.36
4	Medium Off-Peak	2200	670,626	98,120	245,520	385	16,786	548	1,452,000	0	2,178,000	7,066,400	3,806	0	5,698	704,000	0	1,056,000	9.4	0.48
5	Light Off-Peak	2440	233,923	34,648	86,620	139	6,222	198	495,320	0	741,760	5,121,560	1,415	0	2,123	248,880	0	373,320	10.3	0.50
Total per year >>			3,504,259	486,920	1,219,216	1,876	74,235	2,577	7,566,320	0	11,349,360	34,077,600	22,088	0	33,154	2,972,920	0	4,457,800	10.5	0.39
Total per day >>			9,601	1,334	3,340	5	203	7	20,730	0	31,094	93,363	61	0	91	8,145	0	12,213		
Percentage of "Period 1" to daily total >>			8%	8%	8%	8%	8%	8%	8%	NA	8%	6%	9%	NA	9%	7%	NA	7%		
Percentage of "Period 2" to daily total >>			9%	9%	9%	9%	8%	8%	9%	NA	9%	6%	10%	NA	10%	8%	NA	8%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Figure P1– Case Study 15 (N00851) – 2000 aaSIDRA "Annual Sums"

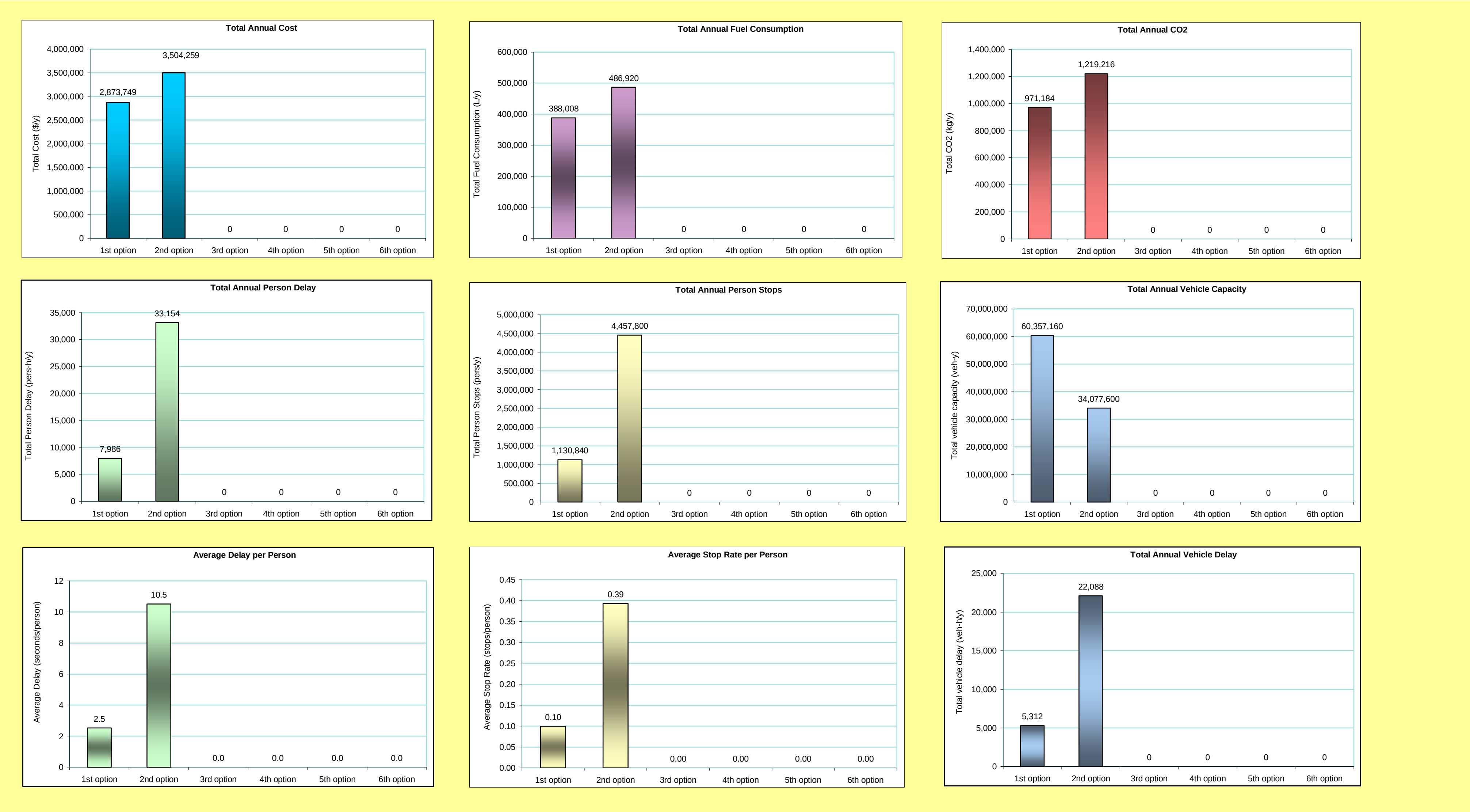

Figure P2– Case Study 15 (N00851) – 2000 aaSIDRA "Annual Sums Comparisons"

Annual sums for aaSIDRA results © **Akcelik & Associates Pty Ltd 2000-2004** **Version 4, September 2004**

Calculation of ANNUAL SUMS

See "Combined Cases" sheet for calculating weighted average of Options A to F as cases (event scenarios)

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aaSIDRA

Design Option / Case: A

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	410,669	54,912	137,472	187	5,131	247	1,065,120	0	1,597,440	1,887,360	965	0	1,445	123,360	0	184,800	3.3	0.12
2	PM Peak	480	442,195	58,464	146,448	201	5,491	263	1,124,160	0	1,686,240	1,577,760	1,315	0	1,973	136,320	0	204,000	4.2	0.12
3	Business Hours	3160	1,914,676	261,016	653,488	882	24,553	1,185	5,116,040	0	7,672,480	26,240,640	2,591	0	3,887	546,680	0	821,600	1.8	0.11
4	Medium Off-Peak	2200	699,402	95,920	240,240	323	8,998	436	1,889,800	0	2,833,600	18,229,200	682	0	1,034	169,400	0	253,000	1.3	0.09
5	Light Off-Peak	2440	239,388	32,940	82,716	112	3,172	151	646,600	0	971,120	20,259,320	220	0	342	56,120	0	82,960	1.3	0.09
Total per year >>			3,706,330	503,252	1,260,364	1,705	47,346	2,282	9,841,720	0	14,760,880	68,194,280	5,773	0	8,680	1,031,880	0	1,546,360	2.1	0.10
Total per day >>			10,154	1,379	3,453	5	130	6	26,964	0	40,441	186,834	16	0	24	2,827	0	4,237		
Percentage of "Period 1" to daily total >>			8%	8%	8%	8%	8%	8%	8%	NA	8%	2%	13%	NA	13%	9%	NA	9%		
Percentage of "Period 2" to daily total >>			9%	9%	9%	9%	9%	9%	9%	NA	9%	2%	17%	NA	17%	10%	NA	10%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Design Option / Case: B

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	507,173	68,208	170,832	262	9,936	353	1,065,120	0	1,597,440	2,745,600	3,677	0	5,515	408,000	0	612,480	12.4	0.38
2	PM Peak	480	537,264	73,056	182,880	283	11,002	383	1,124,160	0	1,686,240	2,505,600	3,874	0	5,813	465,120	0	697,920	12.4	0.41
3	Business Hours	3160	2,367,914	324,848	813,068	1,242	47,811	1,694	5,116,040	0	7,672,480	16,631,080	15,231	0	22,847	1,927,600	0	2,891,400	10.7	0.38
4	Medium Off-Peak	2200	877,404	128,480	321,860	506	22,220	722	1,889,800	0	2,833,600	7,101,600	5,060	0	7,590	952,600	0	1,427,800	9.6	0.50
5	Light Off-Peak	2440	305,756	45,384	113,460	181	8,174	259	646,600	0	971,120	5,097,160	1,854	0	2,757	331,840	0	500,200	10.2	0.52
Total per year >>			4,595,512	639,976	1,602,100	2,473	99,142	3,410	9,841,720	0	14,760,880	34,081,040	29,696	0	44,522	4,085,160	0	6,129,800	10.9	0.42
Total per day >>			12,590	1,753	4,389	7	272	9	26,964	0	40,441	93,373	81	0	122	11,192	0	16,794		
Percentage of "Period 1" to daily total >>			8%	8%	8%	8%	8%	8%	8%	NA	8%	6%	9%	NA	9%	8%	NA	8%		
Percentage of "Period 2" to daily total >>			9%	9%	9%	9%	8%	9%	9%	NA	9%	6%	10%	NA	10%	9%	NA	9%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Figure P3 – Case Study 15 (N00851) – 2015 aaSIDRA "Annual Sums"

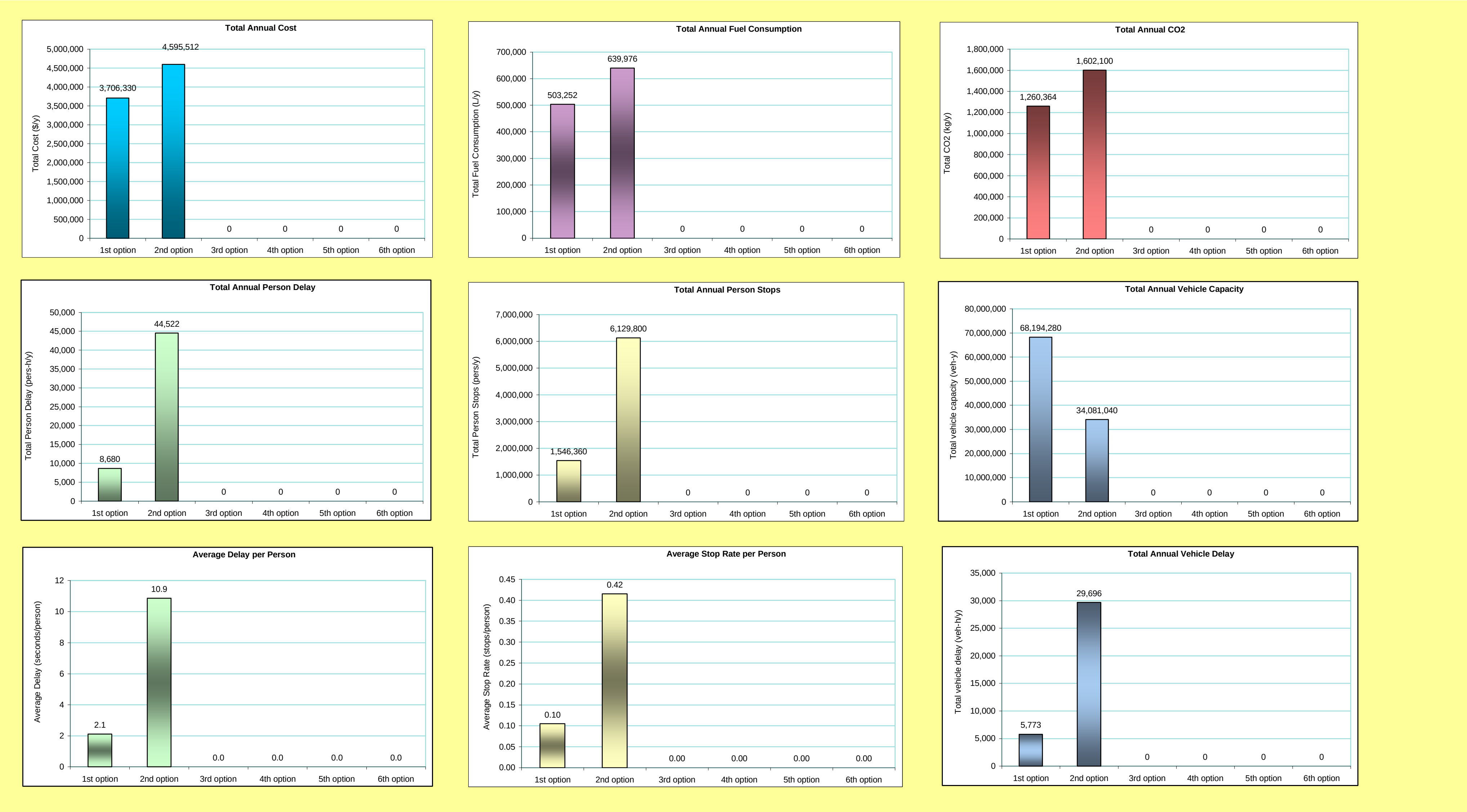

Figure P4 – Case Study 15 (N00851) – 2015 aaSIDRA "Annual Sums Comparisons"

Annual sums for aaSIDRA results © Akcelik & Associates Pty Ltd 2000-2004 Version 4, September 2004

Calculation of ANNUAL SUMS

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See "Combined Cases" sheet for calculating weighted average of Options A to F as cases (event scenarios)

Design Option / Case: A

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	90,446	13,680	34,272	56	2,592	80	199,200	0	298,560	829,920	446	0	672	107,520	0	161,280	8.1	0.54
2	PM Peak	480	90,187	13,680	34,224	56	2,587	80	199,200	0	298,560	1,261,440	432	0	643	101,280	0	152,160	7.8	0.51
3	Business Hours	3160	421,670	63,832	160,212	259	12,040	376	938,520	0	1,409,360	7,631,400	1,959	0	2,939	486,640	0	729,960	7.5	0.52
4	Medium Off-Peak	2200	221,320	33,440	84,040	136	6,292	196	495,000	0	743,600	5,610,000	1,012	0	1,496	257,400	0	387,200	7.2	0.52
5	Light Off-Peak	2440	83,960	12,688	31,720	51	2,342	73	190,320	0	285,480	7,041,840	366	0	561	104,920	0	158,600	7.1	0.56
Total per year >>			907,584	137,320	344,468	558	25,853	805	2,022,240	0	3,035,560	22,374,600	4,216	0	6,311	1,057,760	0	1,589,200	7.5	0.52
Total per day >>			2,487	376	944	2	71	2	5,540	0	8,317	61,300	12	0	17	2,898	0	4,354		
Percentage of "Period 1" to daily total >>			8%	8%	8%	8%	8%	8%	7%	NA	7%	3%	8%	NA	8%	8%	NA	8%		
Percentage of "Period 2" to daily total >>			8%	8%	8%	8%	8%	8%	7%	NA	7%	4%	8%	NA	8%	7%	NA	7%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Design Option / Case: B

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	92,722	14,256	35,664	58	2,851	86	199,200	0	298,560	1,546,560	456	0	682	114,240	0	171,360	8.2	0.57
2	PM Peak	480	91,978	14,160	35,472	58	2,827	86	199,200	0	298,560	1,499,040	432	0	653	110,880	0	166,080	7.9	0.56
3	Business Hours	3160	432,288	66,360	166,532	272	13,240	401	938,520	0	1,409,360	12,134,400	2,054	0	3,065	521,400	0	780,520	7.8	0.55
4	Medium Off-Peak	2200	227,062	34,980	87,340	143	6,930	211	495,000	0	743,600	8,615,200	1,056	0	1,584	275,000	0	411,400	7.7	0.55
5	Light Off-Peak	2440	86,547	13,176	33,428	54	2,635	81	190,320	0	285,480	9,281,760	390	0	610	107,360	0	161,040	7.7	0.56
Total per year >>			930,596	142,932	358,436	584	28,484	865	2,022,240	0	3,035,560	33,076,960	4,388	0	6,594	1,128,880	0	1,690,400	7.8	0.56
Total per day >>			2,550	392	982	2	78	2	5,540	0	8,317	90,622	12	0	18	3,093	0	4,631		
Percentage of "Period 1" to daily total >>			8%	8%	8%	8%	8%	8%	7%	NA	7%	4%	8%	NA	8%	8%	NA	8%		
Percentage of "Period 2" to daily total >>			8%	8%	8%	7%	8%	8%	7%	NA	7%	3%	7%	NA	8%	7%	NA	7%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Figure Q1– Case Study 16 (N00114) – 1998 aaSIDRA "Annual Sums"

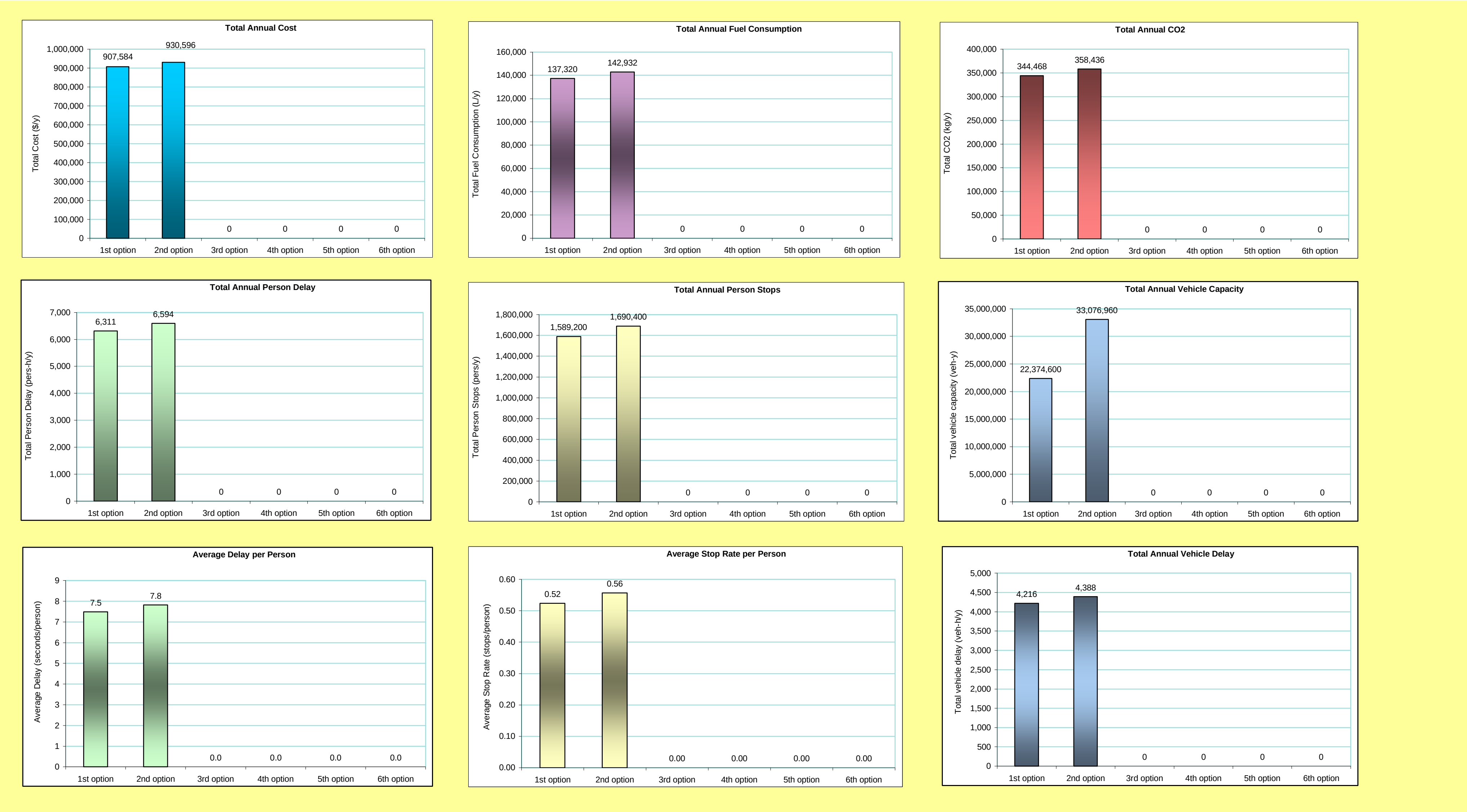

Figure Q2– Case Study 16 (N00114) – 1998 aaSIDRA “Annual Sums Comparisons”

JPT

Annual sums for aaSIDRA results © Akcelik & Associates Pty Ltd 2000-2004 Version 4, September 2004

Calculation of ANNUAL SUMS

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aaSIDRA

See "Combined Cases" sheet for calculating weighted average of Options A to F as cases (event scenarios)

Design Option / Case: A

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	93,173	14,112	35,328	57	2,674	83	204,960	0	307,680	819,840	466	0	696	110,880	0	166,560	8.1	0.54
2	PM Peak	480	93,350	14,160	35,424	58	2,678	83	205,920	0	309,120	1,259,040	446	0	672	105,120	0	157,440	7.8	0.51
3	Business Hours	3160	430,455	65,412	163,372	265	12,292	382	957,480	0	1,434,640	7,596,640	1,991	0	3,002	496,120	0	745,760	7.5	0.52
4	Medium Off-Peak	2200	227,370	34,540	86,240	139	6,468	202	508,200	0	761,200	5,590,200	1,034	0	1,540	266,200	0	398,200	7.3	0.52
5	Light Off-Peak	2440	88,157	13,176	33,428	54	2,440	78	200,080	0	300,120	7,102,840	390	0	586	109,800	0	163,480	7.0	0.54
Total per year >>			932,506	141,400	353,792	572	26,552	829	2,076,640	0	3,112,760	22,368,560	4,327	0	6,496	1,088,120	0	1,631,440	7.5	0.52
Total per day >>			2,555	387	969	2	73	2	5,689	0	8,528	61,284	12	0	18	2,981	0	4,470		
Percentage of "Period 1" to daily total >>			8%	8%	8%	8%	8%	8%	8%	NA	8%	3%	8%	NA	8%	8%	NA	8%		
Percentage of "Period 2" to daily total >>			8%	8%	8%	8%	8%	8%	8%	NA	8%	4%	8%	NA	8%	7%	NA	7%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Design Option / Case: B

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	95,458	14,640	36,720	60	2,933	89	204,960	0	307,680	1,536,480	470	0	706	117,600	0	176,640	8.3	0.57
2	PM Peak	480	95,122	14,640	36,672	60	2,928	89	205,920	0	309,120	1,491,840	451	0	672	114,720	0	171,840	7.8	0.56
3	Business Hours	3160	441,199	67,940	170,008	278	13,525	411	957,480	0	1,434,640	12,105,960	2,086	0	3,128	530,880	0	796,320	7.9	0.56
4	Medium Off-Peak	2200	233,200	35,860	89,760	145	7,128	218	508,200	0	761,200	8,606,400	1,100	0	1,628	281,600	0	422,400	7.7	0.55
5	Light Off-Peak	2440	90,988	13,908	35,136	56	2,757	85	200,080	0	300,120	9,147,560	415	0	634	112,240	0	168,360	7.6	0.56
Total per year >>			955,966	146,988	368,296	599	29,271	892	2,076,640	0	3,112,760	32,888,240	4,522	0	6,768	1,157,040	0	1,735,560	7.8	0.56
Total per day >>			2,619	403	1,009	2	80	2	5,689	0	8,528	90,105	12	0	19	3,170	0	4,755		
Percentage of "Period 1" to daily total >>			8%	8%	8%	8%	8%	8%	8%	NA	8%	4%	8%	NA	8%	8%	NA	8%		
Percentage of "Period 2" to daily total >>			8%	8%	8%	8%	8%	8%	8%	NA	8%	3%	8%	NA	8%	8%	NA	8%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Figure Q3 – Case Study 16 (N00114) – 2013 aaSIDRA "Annual Sums"

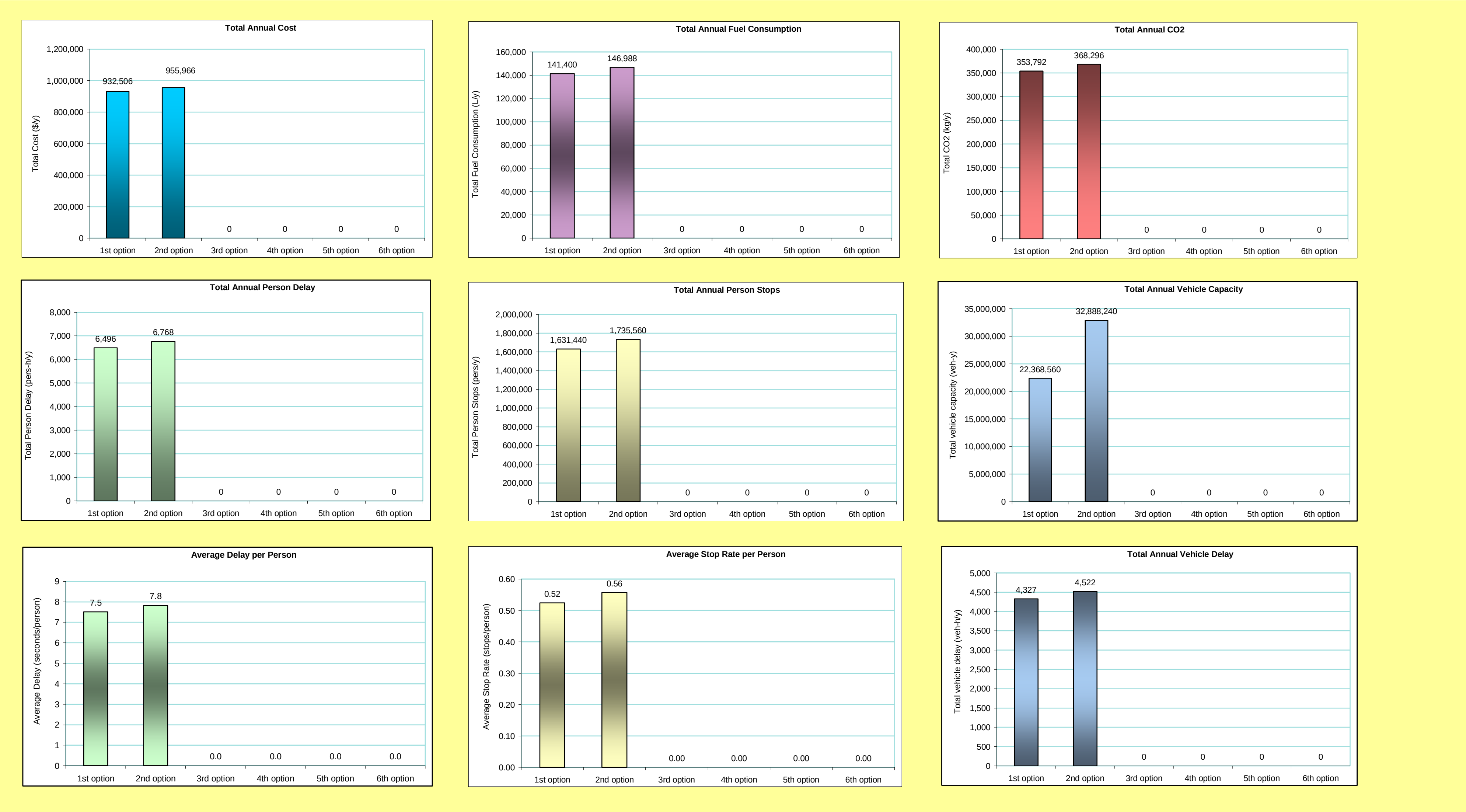

Figure Q4 – Case Study 16 (N00114) – 2013 aaSIDRA “Annual Sums Comparisons”

Annual sums for aaSIDRA results © Akcelik & Associates Pty Ltd 2000-2004 Version 4, September 2004

Calculation of ANNUAL SUMS

See "Combined Cases" sheet for calculating weighted average of Options A to F as cases (event scenarios)

Design Option / Case: A

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	733,368	86,640	216,960	351	12,581	432	1,206,240	0	1,809,600	1,251,360	9,725	0	14,587	773,760	0	1,160,640	29.0	0.64
2	PM Peak	480	759,312	88,224	220,848	357	12,485	433	1,227,840	0	1,841,760	1,227,840	10,402	0	15,605	904,800	0	1,357,440	30.5	0.74
3	Business Hours	3160	2,503,763	354,552	887,644	1,343	53,088	1,877	5,691,160	0	8,538,320	15,070,040	13,240	0	19,845	2,505,880	0	3,757,240	8.4	0.44
4	Medium Off-Peak	2200	1,257,982	181,500	454,520	682	27,258	966	2,952,400	0	4,428,600	15,265,800	5,368	0	8,074	1,214,400	0	1,821,600	6.6	0.41
5	Light Off-Peak	2440	413,678	60,512	151,524	227	9,126	325	993,080	0	1,488,400	29,409,320	1,415	0	2,123	368,440	0	551,440	5.1	0.37
Total per year >>			5,668,102	771,428	1,931,496	2,960	114,537	4,032	12,070,720	0	18,106,680	62,224,360	40,150	0	60,234	5,767,280	0	8,648,360	12.0	0.48
Total per day >>			15,529	2,114	5,292	8	314	11	33,070	0	49,607	170,478	110	0	165	15,801	0	23,694		
Percentage of "Period 1" to daily total >>			10%	9%	9%	9%	8%	8%	8%	NA	8%	2%	18%	NA	18%	10%	NA	10%		
Percentage of "Period 2" to daily total >>			10%	9%	9%	9%	8%	8%	8%	NA	8%	2%	20%	NA	20%	12%	NA	12%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Design Option / Case: B

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	756,115	98,880	247,584	419	18,490	560	1,206,240	0	1,809,600	1,937,760	9,533	0	14,294	902,400	0	1,353,600	28.4	0.75
2	PM Peak	480	802,637	101,952	255,360	434	18,744	569	1,227,840	0	1,841,760	1,757,760	10,891	0	16,334	919,200	0	1,378,560	31.9	0.75
3	Business Hours	3160	3,332,852	451,248	1,130,016	1,890	84,783	2,579	5,691,160	0	8,538,320	10,418,520	37,067	0	55,584	3,972,120	0	5,956,600	23.4	0.70
4	Medium Off-Peak	2200	1,483,636	217,580	544,720	884	41,008	1,267	2,952,400	0	4,428,600	10,590,800	10,978	0	16,478	1,861,200	0	2,791,800	13.4	0.63
5	Light Off-Peak	2440	484,194	71,980	180,316	290	13,542	420	993,080	0	1,488,400	10,972,680	3,221	0	4,807	570,960	0	854,000	11.6	0.57
Total per year >>			6,859,434	941,640	2,357,996	3,918	176,566	5,394	12,070,720	0	18,106,680	35,677,520	71,690	0	107,498	8,225,880	0	12,334,560	21.4	0.68
Total per day >>			18,793	2,580	6,460	11	484	15	33,070	0	49,607	97,747	196	0	295	22,537	0	33,793		
Percentage of "Period 1" to daily total >>			8%	8%	8%	8%	8%	8%	8%	NA	8%	4%	10%	NA	10%	8%	NA	8%		
Percentage of "Period 2" to daily total >>			9%	8%	8%	8%	8%	8%	8%	NA	8%	4%	12%	NA	12%	8%	NA	8%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Figure R1– Case Study 17 (N00228) – 2001 aaSIDRA "Annual Sums"

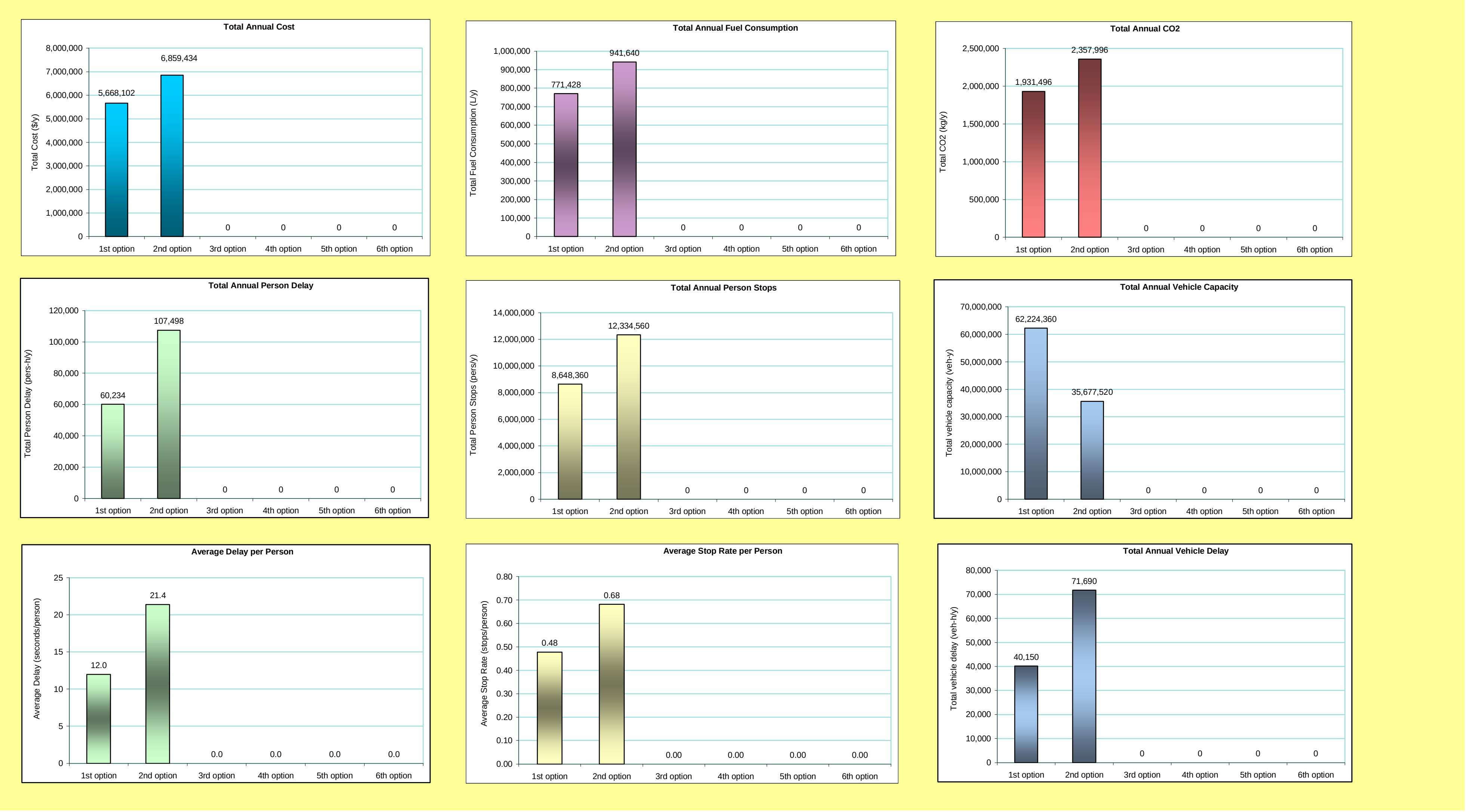

Figure R2– Case Study 17 (N00228) – 2001 aaSIDRA “Annual Sums Comparisons”

Annual sums for aaSIDRA results © Akcelik & Associates Pty Ltd 2000-2004 Version 4, September 2004

Calculation of ANNUAL SUMS

See "Combined Cases" sheet for calculating weighted average of Options A to F as cases (event scenarios)

Design Option / Case: A

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	836,213	92,784	232,320	380	12,667	444	1,258,560	0	1,887,840	1,258,560	12,710	0	19,066	775,680	0	1,163,520	36.4	0.62
2	PM Peak	480	730,258	85,296	213,600	342	11,726	415	1,219,680	0	1,829,760	1,219,680	9,590	0	14,381	787,680	0	1,181,760	28.3	0.65
3	Business Hours	3160	2,849,562	397,212	994,452	1,514	59,250	2,092	6,313,680	0	9,470,520	12,627,360	17,222	0	25,817	2,907,200	0	4,363,960	9.8	0.46
4	Medium Off-Peak	2200	1,406,328	202,180	506,220	761	30,316	1,074	3,278,000	0	4,917,000	13,633,400	6,336	0	9,504	1,364,000	0	2,046,000	7.0	0.42
5	Light Off-Peak	2440	458,549	67,100	168,116	251	10,102	359	1,100,440	0	1,649,440	29,633,800	1,586	0	2,367	407,480	0	610,000	5.2	0.37
Total per year >>			6,280,909	844,572	2,114,708	3,248	124,061	4,383	13,170,360	0	19,754,560	58,372,800	47,445	0	71,134	6,242,040	0	9,365,240	13.0	0.47
Total per day >>			17,208	2,314	5,794	9	340	12	36,083	0	54,122	159,925	130	0	195	17,101	0	25,658		
Percentage of "Period 1" to daily total >>			10%	8%	8%	9%	8%	8%	7%	NA	7%	2%	20%	NA	20%	9%	NA	9%		
Percentage of "Period 2" to daily total >>			9%	8%	8%	8%	7%	7%	7%	NA	7%	2%	15%	NA	15%	10%	NA	10%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Design Option / Case: B

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	850,795	110,928	277,776	472	20,918	629	1,336,320	0	2,004,480	1,904,160	10,954	0	16,430	1,040,640	0	1,560,480	29.5	0.78
2	PM Peak	480	914,813	115,392	288,864	495	21,403	645	1,362,720	0	2,043,840	1,758,240	12,840	0	19,258	1,075,200	0	1,612,800	33.9	0.79
3	Business Hours	3160	3,699,380	501,492	1,255,784	2,101	94,421	2,869	6,313,680	0	9,470,520	10,911,480	41,112	0	61,683	4,461,920	0	6,692,880	23.4	0.71
4	Medium Off-Peak	2200	1,662,342	243,540	610,060	994	46,288	1,423	3,278,000	0	4,917,000	10,557,800	12,606	0	18,920	2,123,000	0	3,183,400	13.9	0.65
5	Light Off-Peak	2440	536,751	79,788	199,836	322	15,006	466	1,100,440	0	1,649,440	11,053,200	3,562	0	5,344	636,840	0	954,040	11.7	0.58
Total per year >>			7,664,082	1,051,140	2,632,320	4,385	198,036	6,033	13,391,160	0	20,085,280	36,184,880	81,074	0	121,635	9,337,600	0	14,003,600	21.8	0.70
Total per day >>			20,997	2,880	7,212	12	543	17	36,688	0	55,028	99,137	222	0	333	25,582	0	38,366		
Percentage of "Period 1" to daily total >>			8%	8%	8%	8%	8%	8%	8%	NA	8%	4%	10%	NA	10%	8%	NA	8%		
Percentage of "Period 2" to daily total >>			9%	8%	8%	9%	8%	8%	8%	NA	8%	4%	12%	NA	12%	9%	NA	9%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Figure R3 – Case Study 17 (N00228) – 2016 aaSIDRA "Annual Sums"

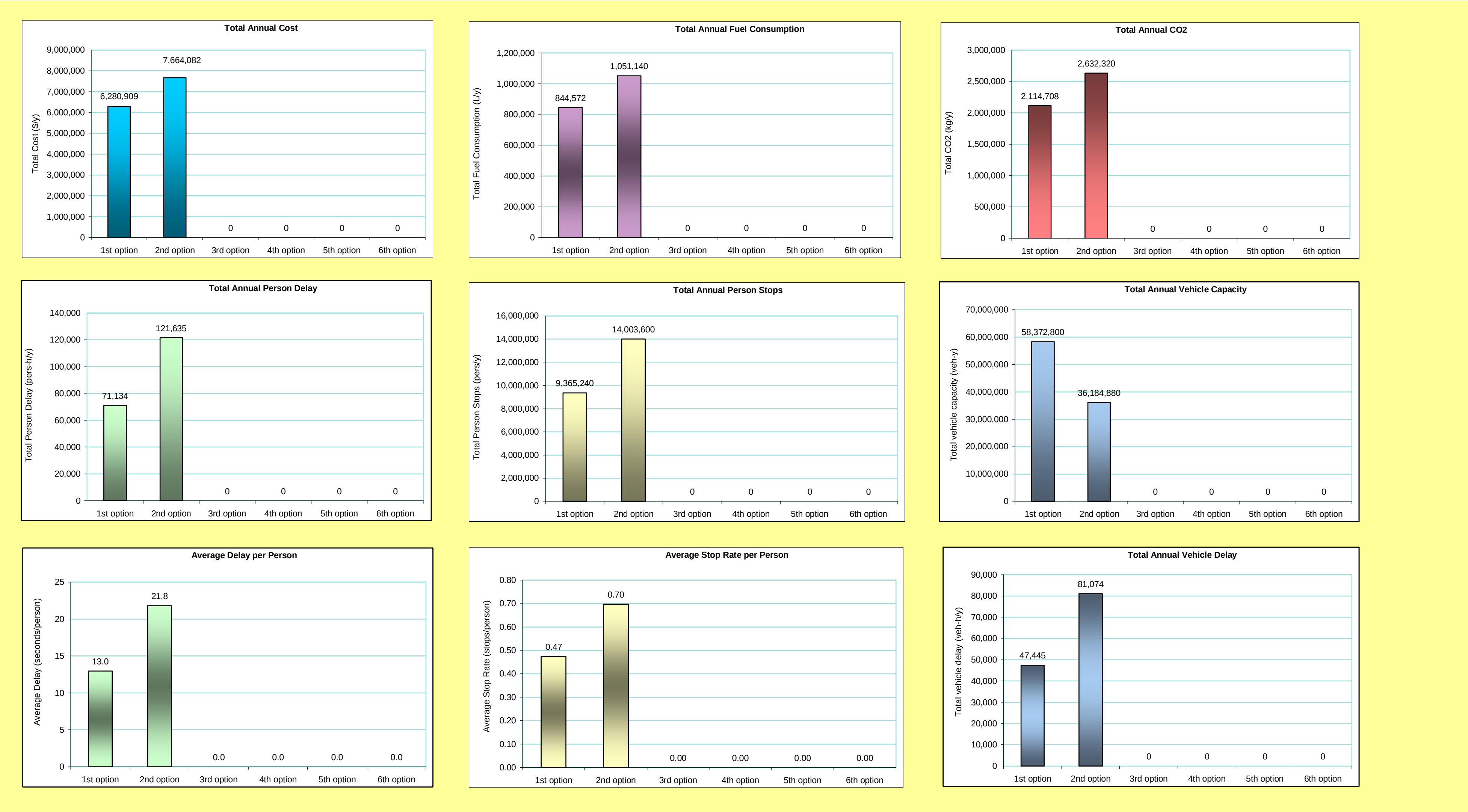

Figure R4 – Case Study 17 (N00228) – 2016 aaSIDRA "Annual Sums Comparisons"

Annual sums for aaSIDRA results © **Akcelik & Associates Pty Ltd 2000-2004** **Version 4, September 2004**

Calculation of ANNUAL SUMS

See "Combined Cases" sheet for calculating weighted average of Options A to F as cases (event scenarios)

Design Option / Case: A

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	783,432	108,384	271,680	390	14,290	534	1,668,480	0	2,502,720	1,807,680	5,141	0	7,709	620,160	0	929,760	11.1	0.37
2	PM Peak	480	616,594	88,464	221,808	307	11,011	430	1,442,880	0	2,164,320	2,199,840	2,486	0	3,730	422,400	0	633,600	6.2	0.29
3	Business Hours	3160	3,017,294	445,244	1,115,796	1,542	57,259	2,203	7,280,640	0	10,920,960	30,475,040	9,069	0	13,588	2,047,680	0	3,071,520	4.5	0.28
4	Medium Off-Peak	2200	1,542,178	229,240	574,640	790	29,348	1,135	3,779,600	0	5,669,400	24,690,600	3,916	0	5,852	968,000	0	1,452,000	3.7	0.26
5	Light Off-Peak	2440	512,766	76,616	192,272	264	9,736	378	1,276,120	0	1,912,960	27,528,080	1,025	0	1,537	256,200	0	385,520	2.9	0.20
Total per year >>			6,472,264	947,948	2,376,196	3,292	121,644	4,680	15,447,720	0	23,170,360	86,701,240	21,637	0	32,416	4,314,440	0	6,472,400	5.0	0.28
Total per day >>			17,732	2,597	6,510	9	333	13	42,323	0	63,480	237,538	59	0	89	11,820	0	17,733		
Percentage of "Period 1" to daily total >>			9%	9%	9%	9%	9%	9%	8%	NA	8%	2%	18%	NA	18%	11%	NA	11%		
Percentage of "Period 2" to daily total >>			7%	7%	7%	7%	7%	7%	7%	NA	7%	2%	9%	NA	9%	7%	NA	7%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Design Option / Case: B

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	903,643	128,352	321,840	511	23,362	729	1,575,360	0	2,363,040	2,386,080	9,173	0	13,757	1,032,480	0	1,548,960	21.0	0.66
2	PM Peak	480	727,238	105,840	265,392	417	19,157	602	1,334,880	0	2,002,560	2,563,680	6,499	0	9,744	834,240	0	1,251,360	17.5	0.62
3	Business Hours	3160	3,364,452	494,540	1,239,668	1,874	81,939	2,708	6,809,800	0	10,213,120	22,116,840	23,352	0	35,044	3,286,400	0	4,926,440	12.4	0.48
4	Medium Off-Peak	2200	1,681,592	259,600	650,760	988	45,628	1,474	3,535,400	0	5,302,000	12,577,400	9,350	0	14,036	1,839,200	0	2,758,800	9.5	0.52
5	Light Off-Peak	2440	559,907	87,352	219,112	332	15,494	500	1,190,720	0	1,786,080	12,392,760	2,904	0	4,343	585,600	0	878,400	8.8	0.49
Total per year >>			7,236,832	1,075,684	2,696,772	4,121	185,579	6,013	14,446,160	0	21,666,800	52,036,760	51,278	0	76,924	7,577,920	0	11,363,960	12.8	0.52
Total per day >>			19,827	2,947	7,388	11	508	16	39,579	0	59,361	142,566	140	0	211	20,761	0	31,134		
Percentage of "Period 1" to daily total >>			9%	9%	9%	9%	10%	9%	8%	NA	8%	3%	14%	NA	14%	10%	NA	10%		
Percentage of "Period 2" to daily total >>			8%	7%	7%	8%	8%	8%	7%	NA	7%	4%	10%	NA	10%	8%	NA	8%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Figure S1 – Case Study 18 (N00846) – 1999 aaSIDRA "Annual Sums"

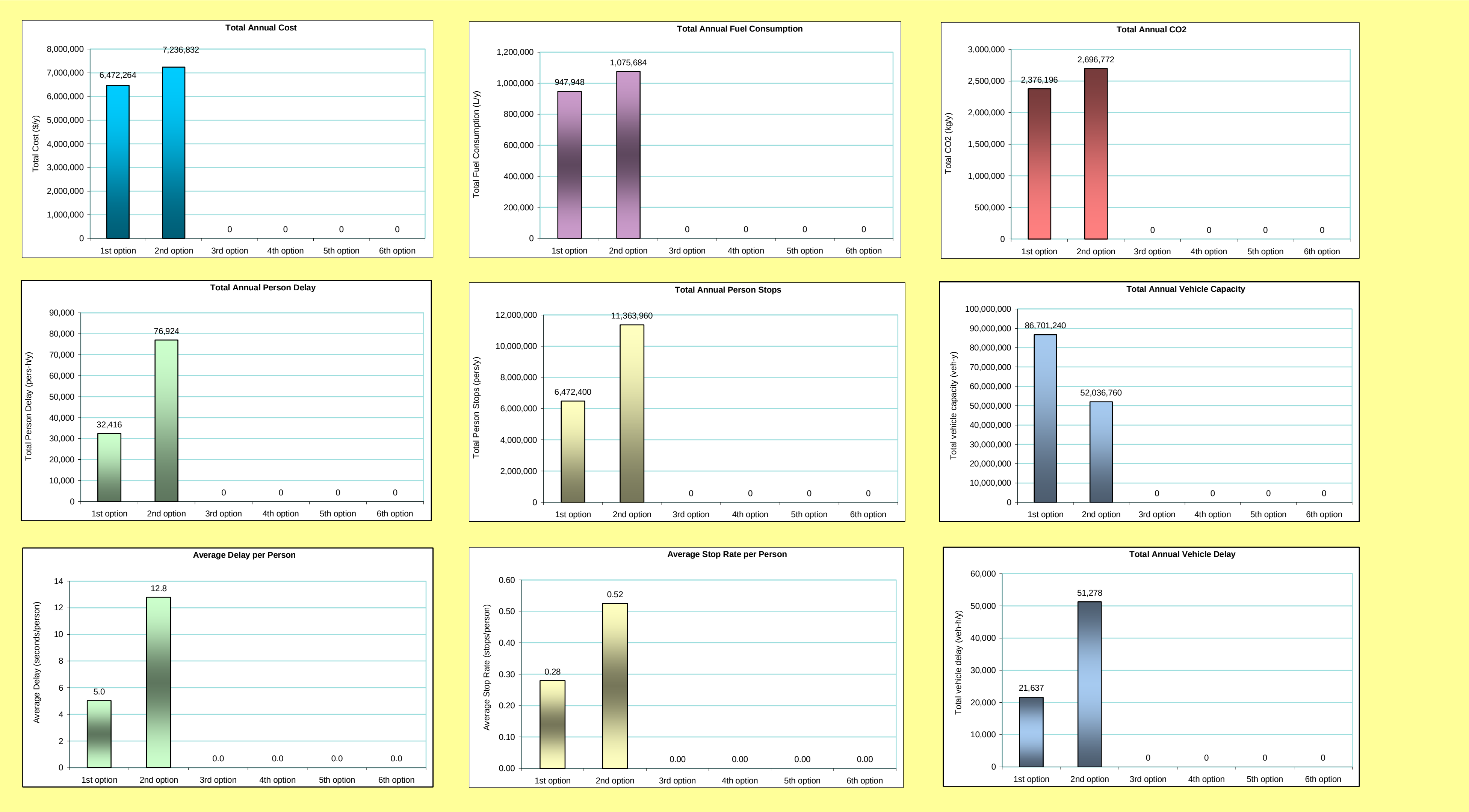

Figure S2 – Case Study 18 (N00846) – 1999 aaSIDRA "Annual Sums Comparisons"

Annual sums for aaSIDRA results © Akcelik & Associates Pty Ltd 2000-2004 Version 4, September 2004

Calculation of ANNUAL SUMS

See "Combined Cases" sheet for calculating weighted average of Options A to F as cases (event scenarios)

Design Option / Case: A

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	3,515,626	270,000	676,896	1,237	25,958	940	2,214,720	0	3,322,080	1,038,240	92,942	0	139,411	2,105,760	0	3,158,880	151.1	0.95
2	PM Peak	480	1,465,718	151,248	379,200	601	16,944	642	1,911,360	0	2,867,040	1,189,440	25,742	0	38,616	1,070,880	0	1,606,080	48.5	0.56
3	Business Hours	3160	4,186,652	601,980	1,509,532	2,114	77,926	2,970	9,641,160	0	14,460,160	15,405,000	18,423	0	27,618	3,074,680	0	4,610,440	6.9	0.32
4	Medium Off-Peak	2200	2,084,390	307,560	770,880	1,067	39,732	1,525	5,018,200	0	7,528,400	18,697,800	6,402	0	9,592	1,434,400	0	2,151,600	4.6	0.29
5	Light Off-Peak	2440	677,905	101,504	254,248	349	12,956	503	1,683,600	0	2,525,400	27,542,720	1,391	0	2,098	351,360	0	524,600	3.0	0.21
Total per year >>			11,930,292	1,432,292	3,590,756	5,368	173,516	6,580	20,469,040	0	30,703,080	63,873,200	144,900	0	217,336	8,037,080	0	12,051,600	25.5	0.39
Total per day >>			32,686	3,924	9,838	15	475	18	56,080	0	84,118	174,995	397	0	595	22,019	0	33,018		
Percentage of "Period 1" to daily total >>			22%	14%	14%	18%	11%	11%	8%	NA	8%	1%	49%	NA	49%	20%	NA	20%		
Percentage of "Period 2" to daily total >>			9%	8%	8%	9%	7%	7%	7%	NA	7%	1%	14%	NA	14%	10%	NA	10%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Design Option / Case: B

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	1,321,786	183,312	459,504	749	34,886	1,058	2,089,920	0	3,134,880	2,394,720	15,850	0	23,774	1,650,720	0	2,475,840	27.3	0.79
2	PM Peak	480	997,440	144,576	362,400	579	27,149	836	1,747,680	0	2,621,760	2,508,960	9,792	0	14,688	1,235,520	0	1,852,800	20.2	0.71
3	Business Hours	3160	4,564,367	668,972	1,676,696	2,566	114,076	3,710	8,964,920	0	13,448,960	18,542,880	34,570	0	51,887	4,758,960	0	7,138,440	13.9	0.53
4	Medium Off-Peak	2200	2,290,728	354,860	889,680	1,371	64,988	2,053	4,668,400	0	7,002,600	11,935,000	14,124	0	21,164	2,734,600	0	4,100,800	10.9	0.59
5	Light Off-Peak	2440	740,174	115,412	289,140	439	20,545	659	1,564,040	0	2,347,280	12,295,160	3,953	0	5,929	790,560	0	1,185,840	9.1	0.51
Total per year >>			9,914,495	1,467,132	3,677,420	5,704	261,644	8,315	19,034,960	0	28,555,480	47,676,720	78,289	0	117,443	11,170,360	0	16,753,720	14.8	0.59
Total per day >>			27,163	4,020	10,075	16	717	23	52,151	0	78,234	130,621	214	0	322	30,604	0	45,901		
Percentage of "Period 1" to daily total >>			10%	10%	10%	10%	10%	10%	8%	NA	8%	4%	15%	NA	15%	11%	NA	11%		
Percentage of "Period 2" to daily total >>			8%	7%	7%	8%	8%	8%	7%	NA	7%	4%	10%	NA	10%	8%	NA	8%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Figure S3 – Case Study 18 (N00846) – 2014 aaSIDRA "Annual Sums"

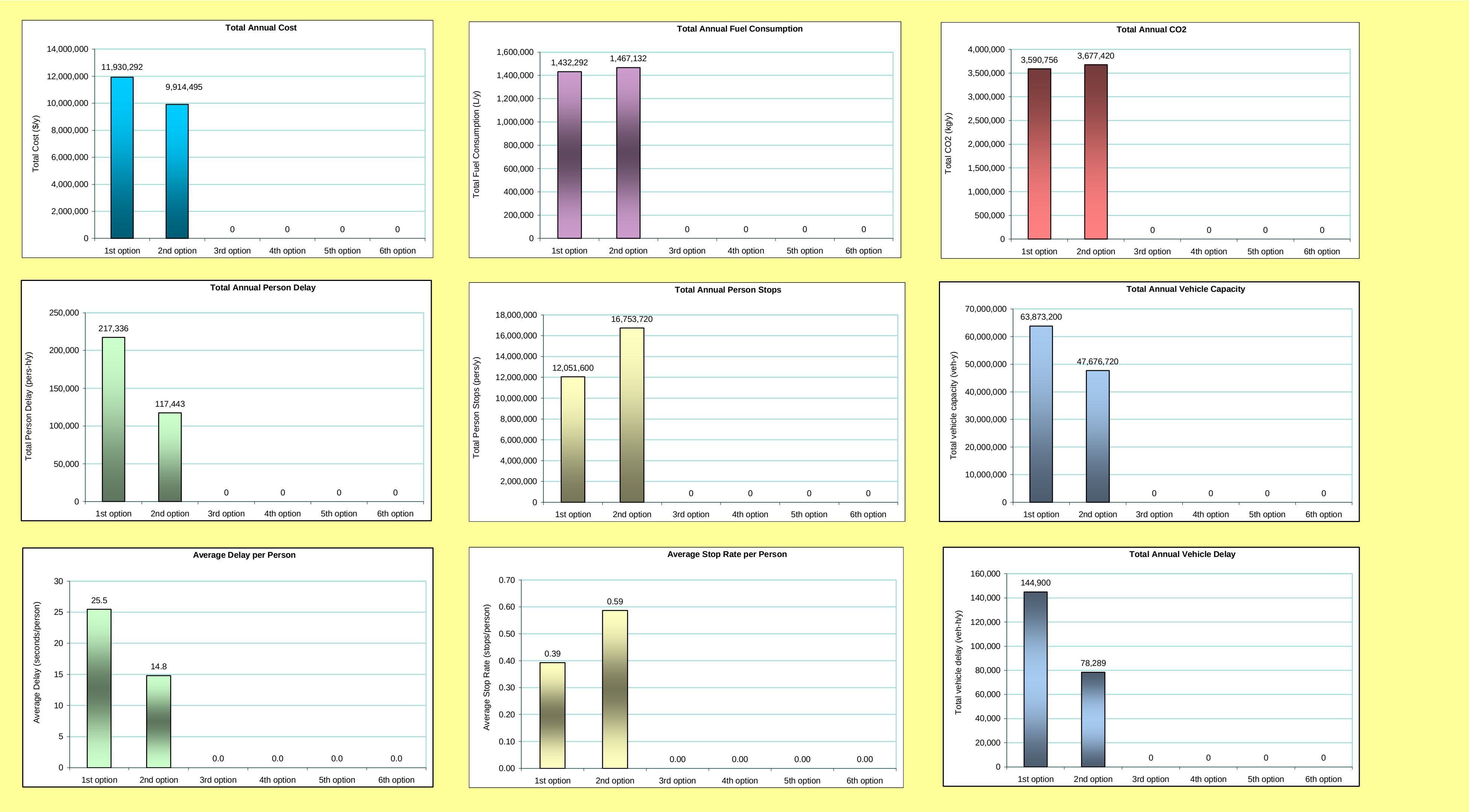

Figure S4 – Case Study 18 (N00846) – 2014 aaSIDRA "Annual Sums Comparisons"

APPENDIX T – BITRE Cost Assumptions

(BITRE text)

The BITRE requested changes to the default values aaSIDRA uses to estimate costs of vehicle operation and time. The changed values are derived from Austroads (2006) and apply as at June 2005. Hence, they are consistent with the cost–benefit analysis results in the main report.

Since aaSIDRA does not distinguish between petrol and diesel, the pump price of fuel (P_p in Table 4.1) is an average of petrol and diesel prices, weighted by usage, and averaged for all capital cities. The 'fuel resource cost factor' (f_f) is the ratio of the resource cost to the pump price. The resource cost is the pump price minus the fuel excise and goods and services tax. From the weighted average pump prices and resource costs of fuel in Austroads (2006), the ratio was found to be 0.58.

To estimate total vehicle operating costs, aaSIDRA multiplies estimated fuel consumed by a 'vehicle operating cost factor' (k_o) expressed in dollars per litre of fuel consumed, $k_o = f_c \times f_f \times P_p$ where f_c is the 'running cost / fuel cost ratio'. The urban vehicle operating cost and fuel consumption models in Austroads (2006, pp.20-1) were used to derive estimates of typical vehicle operating costs and fuel consumptions for cars, light commercial vehicles and heavy commercial vehicles at speeds over a relevant range. Even though aaSIDRA distinguishes between light and heavy vehicles for calculating PCUs, for the purposes of estimating operating costs, it only recognises one generic vehicle type. At a speed of 50 km/h the running cost / fuel cost ratios implied by the Austroads (2006) models were 2.2 for cars, 2.9 for light commercial vehicles and 4.6 for heavy commercial vehicles. In view of these ratios, it was decided to retain the aaSIDRA default 'running cost / fuel cost ratio' of 3.0 for Australia because it represents a reasonable weighted average value for the three vehicle types at a typical urban speed. The implied vehicle operating cost factor, is $k_o = f_c \times f_f \times P_p = \$1.12 \times 0.58 \times 3.0 = \$1.9488$ per litre of fuel.

Average hourly earnings (W in Table 4.1) is the basis for estimating the value of time. The 'time cost per vehicle' in aaSIDRA (k_t) is calculated as $k_t = f_o \times f_p \times W$, where f_o is average occupancy in persons per vehicle and f_p is the 'time value factor', a proportion that converts average hourly earnings (W) into the 'time cost per person'. The proportion f_p is less than one because, while work time is valued at average earnings, non-work time is valued at some fraction of average earnings (just over 30 per cent in Austroads 2006, p. 15). Also, the drivers of commercial vehicles earn less than the average per hour ($21 to $24 depending on truck size and type).

The assumed amount for average income per hour of $34.35 is the value of business time per person hour for car travel in Austroads (2006 p. 15). Since aaSIDRA has only one generic vehicle type for costing purposes, the proportion f_p and the average occupancy per vehicle f_o need to be weighted averages. Weights for cars, light commercial vehicles and heavy commercial vehicles were developed from statistics of total vehicle kilometres travelled in Austroads (2005), with the ratio of business cars to private cars assumed to be 22:78 based on the Australian Bureau of Statistics Survey of Motor Vehicle Usage. Applying these weights to Austroads (2006 p. 15) values of time, the weighted average time cost per person is about 0.5 and vehicle occupancy rate approximately 1.5, which is the existing aaSIDRA default value for Australia. The assumed time cost per vehicle is then $k_t = f_o \times f_p \times W = 1.5 \times 0.5 \times \$34.35 = \$25.76 / hour$.

References

Austroads 2005, *Roadfacts 2005: An Overview of the Australian and New Zealand Road Systems*, Austroads, Sydney. Available at http://www.austroads.com.au.

Austroads 2006, *Update of RUC Unit Values to June 2005*, Austroads Technical Report AP-T70/06, Austroads, Sydney. Available at http://www.austroads.com.au.

APPENDIX U – Additional Analysis

S00028 – Adelaide Rd / Wellington Rd / Alexandrina Rd / Flaxley Rd (Roundabout Installation) – Case Study No.1

JPT originally modelled the "before" ("give way" crossroad) and "after" (roundabout) layouts at this intersection for the years 1996 and 2016. As noted in Section 5.1.4, the Black Spot treatment is predicted to result in higher operating costs immediately following implementation, however by 2016 it is expected that this situation would be reversed. In order to show more detail of the relationship between traffic volumes and operating costs, BITRE requested that the layouts be further analysed for the years 1986, 1991, 2001, 2006 and 2011.

"Annual Sums" Results

Table U.1 below lists some of the annual totals from the analysis (including the results tabled earlier for 1996 and 2016).

Year / Layout	Cost ($/yr)	Fuel (l/yr)	CO_2 emissions (kg/yr)	Total Vehicle Delay (veh-hr/yr)
1986 "Before"	2,116,938	318,868	798,784	7,148
1986 "After"	2,326,792	366,324	917,972	10,952
1991 "Before"	2,422,601	364,528	912,372	8,584
1991 "After"	2,652,744	417,860	1,046,396	12,577
1996 "Before"	2,767,697	415,792	1,042,020	10,456
1996 "After"	3,010,860	474,520	1,189,312	14,390
2001 "Before"	3,183,600	475,340	1,190,656	13,188
2001 "After"	3,430,709	540,852	1,354,896	16,575
2006 "Before"	3,674,748	543,276	1,361,200	17,214
2006 "After"	3,898,414	614,568	1,539,296	19,091
2011 "Before"	4,232,846	613,120	1,535,868	24,213
2011 "After"	4,343,764	684,460	1,714,804	21,528
2016 "Before"	5,336,958	715,380	1,792,040	49,271
2016 "After"	4,810,702	757,628	1,898,416	24,239

Table U.1 – S00028 – Selected "Annual Sums" Results from Additional aaSIDRA Analysis

Detailed summaries of all the "Annual Sums" figures are given in Figures U1 through U14 on the following pages.

Annual sums for aaSIDRA results © **Akcelik & Associates Pty Ltd 2000-2004** **Version 4, September 2004**

Calculation of ANNUAL SUMS

See "Combined Cases" sheet for calculating weighted average of Options A to F as cases (event scenarios)

Design Option / Case: A

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	223,051	34,176	85,632	129	5,702	192	508,800	0	763,200	2,002,560	830	0	1,243	185,760	0	278,880	5.9	0.37
2	PM Peak	480	258,638	38,208	95,616	147	6,283	213	594,720	0	891,840	2,442,720	1,051	0	1,579	218,400	0	327,840	6.4	0.37
3	Business Hours	3160	1,097,974	165,268	414,276	626	26,986	920	2,572,240	0	3,858,360	20,464,160	3,666	0	5,530	869,000	0	1,301,920	5.2	0.34
4	Medium Off-Peak	2200	402,050	60,720	152,020	229	9,768	337	954,800	0	1,432,200	15,903,800	1,210	0	1,804	299,200	0	446,600	4.5	0.31
5	Light Off-Peak	2440	135,225	20,496	51,240	76	3,245	112	324,520	0	488,000	16,875,040	390	0	586	100,040	0	151,280	4.3	0.31
Total per year >>			2,116,938	318,868	798,784	1,206	51,985	1,773	4,955,080	0	7,433,600	57,688,280	7,148	0	10,742	1,672,400	0	2,506,520	5.2	0.34
Total per day >>			5,800	874	2,188	3	142	5	13,576	0	20,366	158,050	20	0	29	4,582	0	6,867		
Percentage of "Period 1" to daily total >>			8%	8%	8%	8%	8%	8%	8%	NA	8%	3%	9%	NA	9%	8%	NA	8%		
Percentage of "Period 2" to daily total >>			9%	9%	9%	9%	9%	9%	9%	NA	9%	3%	11%	NA	11%	10%	NA	10%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Design Option / Case: B

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	241,824	38,784	97,248	153	7,752	238	508,800	0	763,200	2,783,520	1,133	0	1,699	294,720	0	442,560	8.0	0.58
2	PM Peak	480	281,261	43,680	109,344	176	8,702	265	594,720	0	891,840	2,870,400	1,402	0	2,102	358,560	0	538,080	8.5	0.60
3	Business Hours	3160	1,208,795	190,232	476,528	758	37,762	1,157	2,572,240	0	3,858,360	21,288,920	5,688	0	8,532	1,463,080	0	2,193,040	8.0	0.57
4	Medium Off-Peak	2200	444,950	69,960	175,560	279	13,816	425	954,800	0	1,432,200	15,030,400	2,046	0	3,058	528,000	0	789,800	7.7	0.55
5	Light Off-Peak	2440	149,962	23,668	59,292	93	4,636	144	324,520	0	488,000	17,162,960	683	0	1,025	180,560	0	268,400	7.6	0.55
Total per year >>			2,326,792	366,324	917,972	1,460	72,668	2,228	4,955,080	0	7,433,600	59,136,200	10,952	0	16,416	2,824,920	0	4,231,880	8.0	0.57
Total per day >>			6,375	1,004	2,515	4	199	6	13,576	0	20,366	162,017	30	0	45	7,740	0	11,594		
Percentage of "Period 1" to daily total >>			8%	8%	8%	8%	8%	8%	8%	NA	8%	4%	8%	NA	8%	8%	NA	8%		
Percentage of "Period 2" to daily total >>			9%	9%	9%	9%	9%	9%	9%	NA	9%	4%	10%	NA	10%	10%	NA	10%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Figure U1 – Case Study 1 (S00028) – 1986 aaSIDRA "Annual Sums"

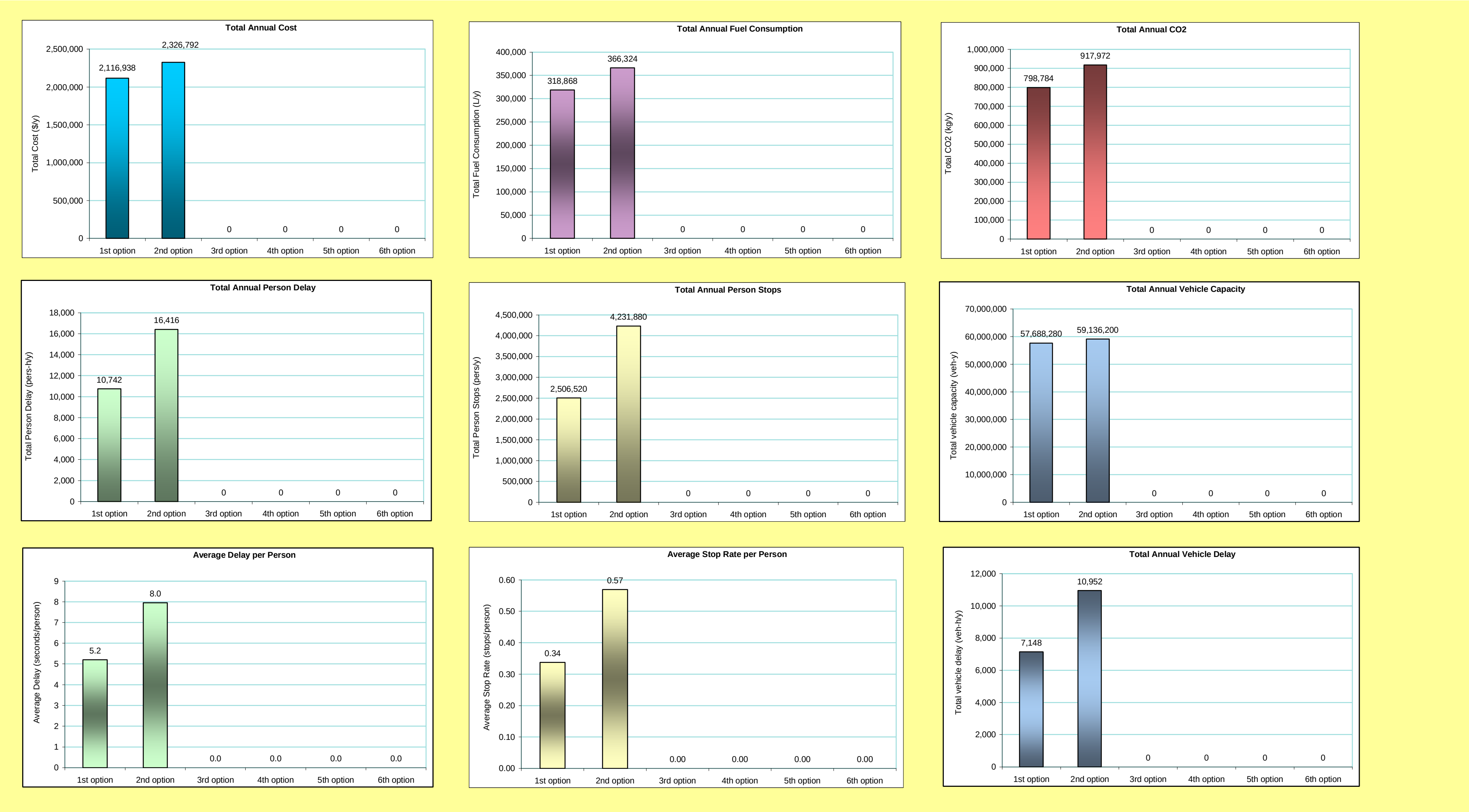

Figure U2 – Case Study 1 (S00028) – 1986 aaSIDRA "Annual Sums Comparisons"

Annual sums for aaSIDRA results © Akcelik & Associates Pty Ltd 2000-2004 Version 4, September 2004

Calculation of ANNUAL SUMS

See "Combined Cases" sheet for calculating weighted average of Options A to F as cases (event scenarios)

Design Option / Case: A

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	266,664	40,608	101,808	154	6,806	228	600,000	0	900,000	1,848,000	1,090	0	1,637	232,800	0	349,440	6.5	0.39
2	PM Peak	480	290,645	42,720	106,944	165	7,046	238	660,960	0	991,680	2,388,000	1,277	0	1,915	250,080	0	375,360	7.0	0.38
3	Business Hours	3160	1,259,671	189,600	474,632	717	31,031	1,055	2,935,640	0	4,405,040	19,595,160	4,392	0	6,604	1,020,680	0	1,532,600	5.4	0.35
4	Medium Off-Peak	2200	452,804	68,420	171,160	257	11,022	378	1,073,600	0	1,610,400	15,798,200	1,386	0	2,068	338,800	0	506,000	4.6	0.31
5	Light Off-Peak	2440	152,817	23,180	57,828	85	3,684	127	366,000	0	549,000	17,080,000	439	0	659	114,680	0	170,800	4.3	0.31
Total per year >>			2,422,601	364,528	912,372	1,378	59,590	2,026	5,636,200	0	8,456,120	56,709,360	8,584	0	12,883	1,957,040	0	2,934,200	5.5	0.35
Total per day >>			6,637	999	2,500	4	163	6	15,442	0	23,167	155,368	24	0	35	5,362	0	8,039		
Percentage of "Period 1" to daily total >>			8%	8%	8%	8%	9%	9%	8%	NA	8%	2%	10%	NA	10%	9%	NA	9%		
Percentage of "Period 2" to daily total >>			9%	9%	9%	9%	9%	9%	9%	NA	9%	3%	11%	NA	11%	10%	NA	10%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Design Option / Case: B

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	286,234	45,936	115,056	181	9,197	281	600,000	0	900,000	2,684,640	1,358	0	2,035	356,160	0	534,240	8.1	0.59
2	PM Peak	480	313,402	48,624	121,824	196	9,715	296	660,960	0	991,680	2,856,480	1,579	0	2,366	405,120	0	607,680	8.6	0.61
3	Business Hours	3160	1,382,911	217,724	545,100	869	43,260	1,324	2,935,640	0	4,405,040	21,206,760	6,573	0	9,859	1,690,600	0	2,534,320	8.1	0.58
4	Medium Off-Peak	2200	500,984	78,980	197,560	315	15,576	480	1,073,600	0	1,610,400	14,968,800	2,310	0	3,454	594,000	0	891,000	7.7	0.55
5	Light Off-Peak	2440	169,214	26,596	66,856	105	5,222	161	366,000	0	549,000	17,311,800	756	0	1,147	202,520	0	302,560	7.5	0.55
Total per year >>			2,652,744	417,860	1,046,396	1,666	82,970	2,542	5,636,200	0	8,456,120	59,028,480	12,577	0	18,862	3,248,400	0	4,869,800	8.0	0.58
Total per day >>			7,268	1,145	2,867	5	227	7	15,442	0	23,167	161,722	34	0	52	8,900	0	13,342		
Percentage of "Period 1" to daily total >>			8%	8%	8%	8%	8%	8%	8%	NA	8%	3%	8%	NA	8%	8%	NA	8%		
Percentage of "Period 2" to daily total >>			9%	9%	9%	9%	9%	9%	9%	NA	9%	4%	10%	NA	10%	9%	NA	9%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Figure U3 – Case Study 1 (S00028) – 1991 aaSIDRA "Annual Sums"

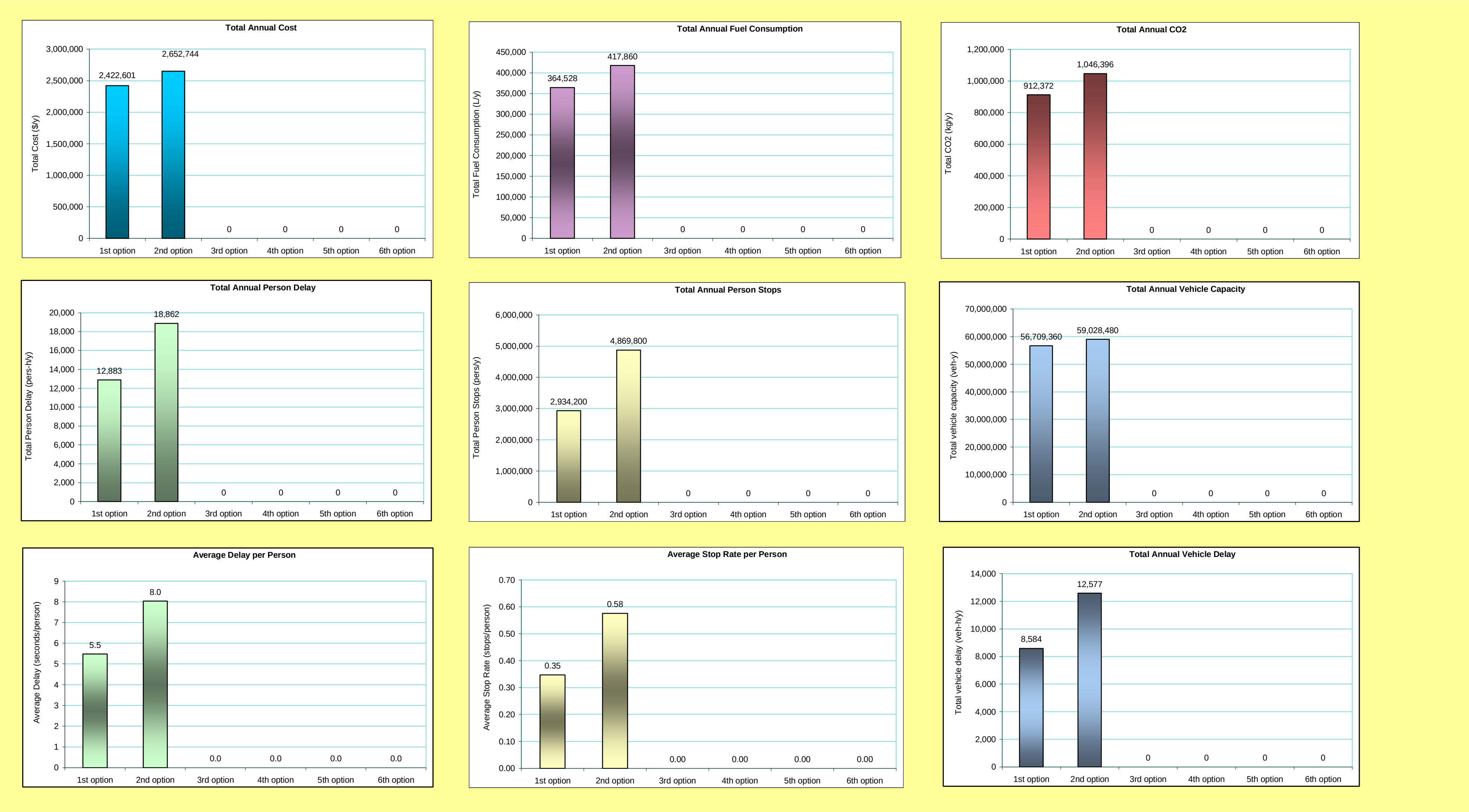

Figure U4 – Case Study 1 (S00028) – 1991 aaSIDRA "Annual Sums Comparisons"

JPT

Annual sums for aaSIDRA results © Akcelik & Associates Pty Ltd 2000-2004 Version 4, September 2004

Calculation of ANNUAL SUMS

See "Combined Cases" sheet for calculating weighted average of Options A to F as cases (event scenarios)

akcelik & associates aaTraffic aaSIDRA

Design Option / Case: A

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	313,958	47,376	118,704	180	7,973	265	692,640	0	1,038,720	1,706,400	1,464	0	2,194	285,600	0	428,640	7.6	0.41
2	PM Peak	480	324,192	47,232	118,224	183	7,800	263	725,280	0	1,087,680	1,770,720	1,574	0	2,366	283,680	0	425,760	7.8	0.39
3	Business Hours	3160	1,433,376	215,828	540,676	818	35,613	1,204	3,311,680	0	4,967,520	18,517,600	5,277	0	7,900	1,181,840	0	1,772,760	5.7	0.36
4	Medium Off-Peak	2200	520,344	78,760	197,560	297	12,870	438	1,225,400	0	1,839,200	15,521,000	1,628	0	2,442	393,800	0	589,600	4.8	0.32
5	Light Off-Peak	2440	175,826	26,596	66,856	100	4,270	146	419,680	0	629,520	17,507,000	512	0	756	129,320	0	192,760	4.3	0.31
Total per year >>			2,767,697	415,792	1,042,020	1,578	68,526	2,317	6,374,680	0	9,562,640	55,022,720	10,456	0	15,658	2,274,240	0	3,409,520	5.9	0.36
Total per day >>			7,583	1,139	2,855	4	188	6	17,465	0	26,199	150,747	29	0	43	6,231	0	9,341		
Percentage of "Period 1" to daily total >>			9%	9%	9%	9%	9%	9%	8%	NA	8%	2%	11%	NA	11%	10%	NA	10%		
Percentage of "Period 2" to daily total >>			9%	9%	9%	9%	9%	9%	9%	NA	9%	2%	11%	NA	11%	9%	NA	9%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Design Option / Case: B

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	331,704	53,136	133,152	210	10,675	326	692,640	0	1,038,720	2,593,440	1,603	0	2,400	422,400	0	633,600	8.3	0.61
2	PM Peak	480	344,630	53,424	133,824	216	10,690	325	725,280	0	1,087,680	2,847,840	1,757	0	2,635	451,680	0	677,760	8.7	0.62
3	Business Hours	3160	1,566,317	246,796	618,412	986	49,201	1,504	3,311,680	0	4,967,520	21,105,640	7,489	0	11,250	1,930,760	0	2,897,720	8.2	0.58
4	Medium Off-Peak	2200	573,716	90,420	226,820	359	17,908	550	1,225,400	0	1,839,200	14,979,800	2,662	0	3,982	682,000	0	1,020,800	7.8	0.56
5	Light Off-Peak	2440	194,492	30,744	77,104	122	6,027	185	419,680	0	629,520	17,382,560	878	0	1,318	231,800	0	346,480	7.5	0.55
Total per year >>			3,010,860	474,520	1,189,312	1,893	94,501	2,891	6,374,680	0	9,562,640	58,909,280	14,390	0	21,584	3,718,640	0	5,576,360	8.1	0.58
Total per day >>			8,249	1,300	3,258	5	259	8	17,465	0	26,199	161,395	39	0	59	10,188	0	15,278		
Percentage of "Period 1" to daily total >>			8%	9%	9%	8%	9%	9%	8%	NA	8%	3%	8%	NA	8%	9%	NA	9%		
Percentage of "Period 2" to daily total >>			9%	9%	9%	9%	9%	9%	9%	NA	9%	4%	9%	NA	9%	9%	NA	9%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Figure U5 – Case Study 1 (S00028) – 1996 aaSIDRA "Annual Sums"

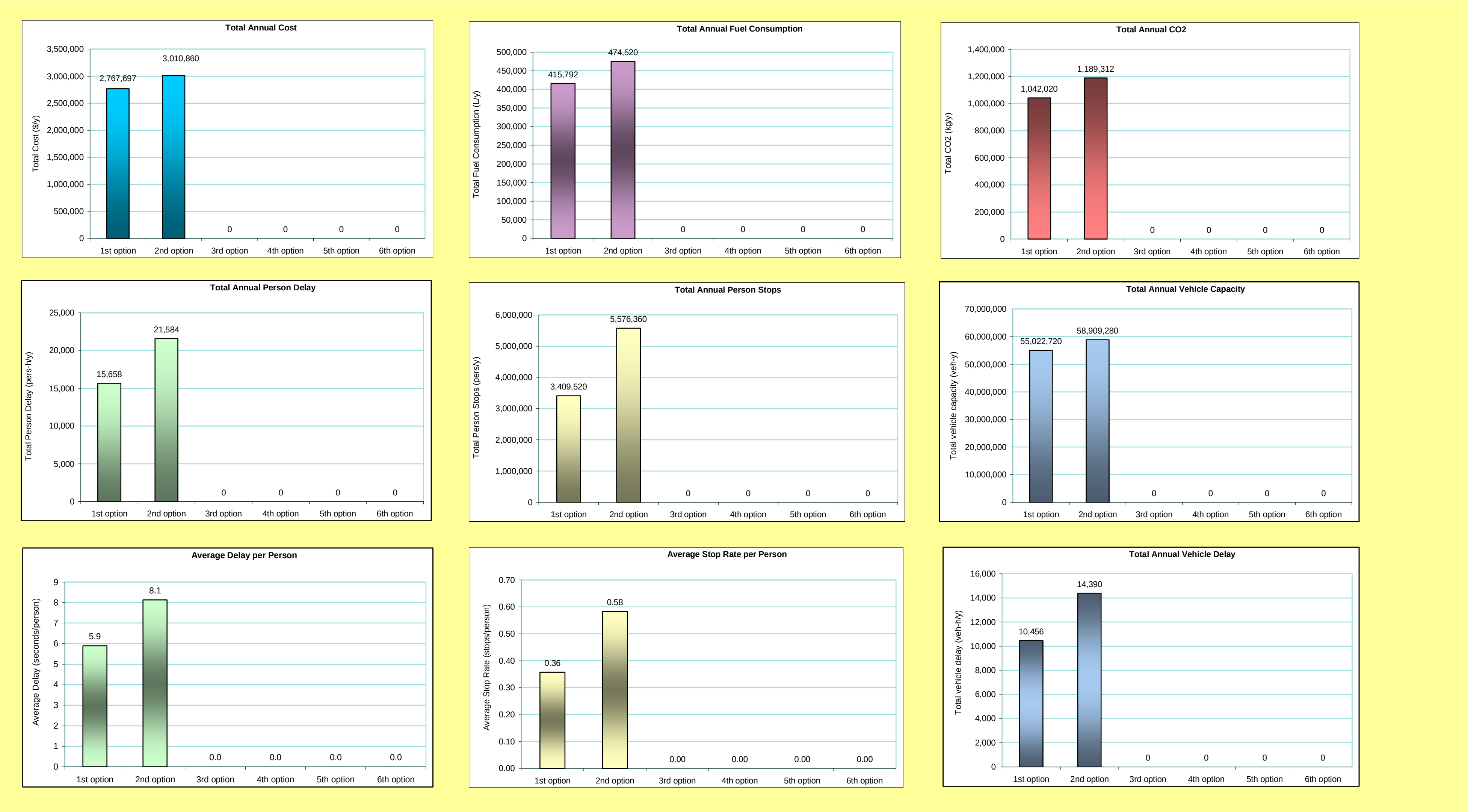

Figure U6 – Case Study 1 (S00028) – 1996 aaSIDRA "Annual Sums Comparisons"

Annual sums for aaSIDRA results © **Akcelik & Associates Pty Ltd 2000-2004** **Version 4, September 2004**

Calculation of ANNUAL SUMS

See "Combined Cases" sheet for calculating weighted average of Options A to F as cases (event scenarios)

Design Option / Case: A

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	384,259	56,736	142,128	217	9,518	316	816,960	0	1,225,440	1,480,800	2,198	0	3,302	361,920	0	542,880	9.7	0.44
2	PM Peak	480	370,555	53,088	133,008	207	8,765	294	804,960	0	1,207,680	1,370,400	2,112	0	3,168	332,160	0	498,240	9.4	0.41
3	Business Hours	3160	1,646,866	247,112	618,728	939	40,796	1,378	3,776,200	0	5,662,720	17,421,080	6,446	0	9,670	1,390,400	0	2,085,600	6.1	0.37
4	Medium Off-Peak	2200	587,598	88,880	222,860	337	14,520	495	1,381,600	0	2,072,400	15,118,400	1,870	0	2,794	446,600	0	671,000	4.9	0.32
5	Light Off-Peak	2440	194,322	29,524	73,932	110	4,734	163	463,600	0	695,400	18,829,480	561	0	830	141,520	0	214,720	4.3	0.31
Total per year >>			3,183,600	475,340	1,190,656	1,809	78,332	2,647	7,243,320	0	10,863,640	54,220,160	13,188	0	19,764	2,672,600	0	4,012,440	6.5	0.37
Total per day >>			8,722	1,302	3,262	5	215	7	19,845	0	29,763	148,548	36	0	54	7,322	0	10,993		
Percentage of "Period 1" to daily total >>			9%	9%	9%	9%	9%	9%	9%	NA	9%	2%	13%	NA	13%	10%	NA	10%		
Percentage of "Period 2" to daily total >>			9%	8%	8%	9%	9%	8%	8%	NA	8%	2%	12%	NA	12%	9%	NA	9%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Design Option / Case: B

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	393,274	62,976	157,824	250	12,691	387	816,960	0	1,225,440	2,458,560	1,939	0	2,909	514,560	0	771,840	8.5	0.63
2	PM Peak	480	383,674	59,472	148,944	240	11,918	362	804,960	0	1,207,680	2,835,360	1,987	0	2,981	511,680	0	767,520	8.9	0.64
3	Business Hours	3160	1,790,962	282,188	706,892	1,128	56,374	1,722	3,776,200	0	5,662,720	21,045,600	8,658	0	12,988	2,240,440	0	3,362,240	8.3	0.59
4	Medium Off-Peak	2200	647,812	102,300	256,080	407	20,240	620	1,381,600	0	2,072,400	14,920,400	3,014	0	4,510	772,200	0	1,157,200	7.8	0.56
5	Light Off-Peak	2440	214,988	33,916	85,156	134	6,661	205	463,600	0	695,400	17,331,320	976	0	1,464	256,200	0	383,080	7.6	0.55
Total per year >>			3,430,709	540,852	1,354,896	2,159	107,885	3,297	7,243,320	0	10,863,640	58,591,240	16,575	0	24,851	4,295,080	0	6,441,880	8.2	0.59
Total per day >>			9,399	1,482	3,712	6	296	9	19,845	0	29,763	160,524	45	0	68	11,767	0	17,649		
Percentage of "Period 1" to daily total >>			9%	9%	9%	9%	9%	9%	9%	NA	9%	3%	9%	NA	9%	9%	NA	9%		
Percentage of "Period 2" to daily total >>			9%	8%	8%	8%	8%	8%	8%	NA	8%	4%	9%	NA	9%	9%	NA	9%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Figure U7 – Case Study 1 (S00028) – 2001 aaSIDRA "Annual Sums"

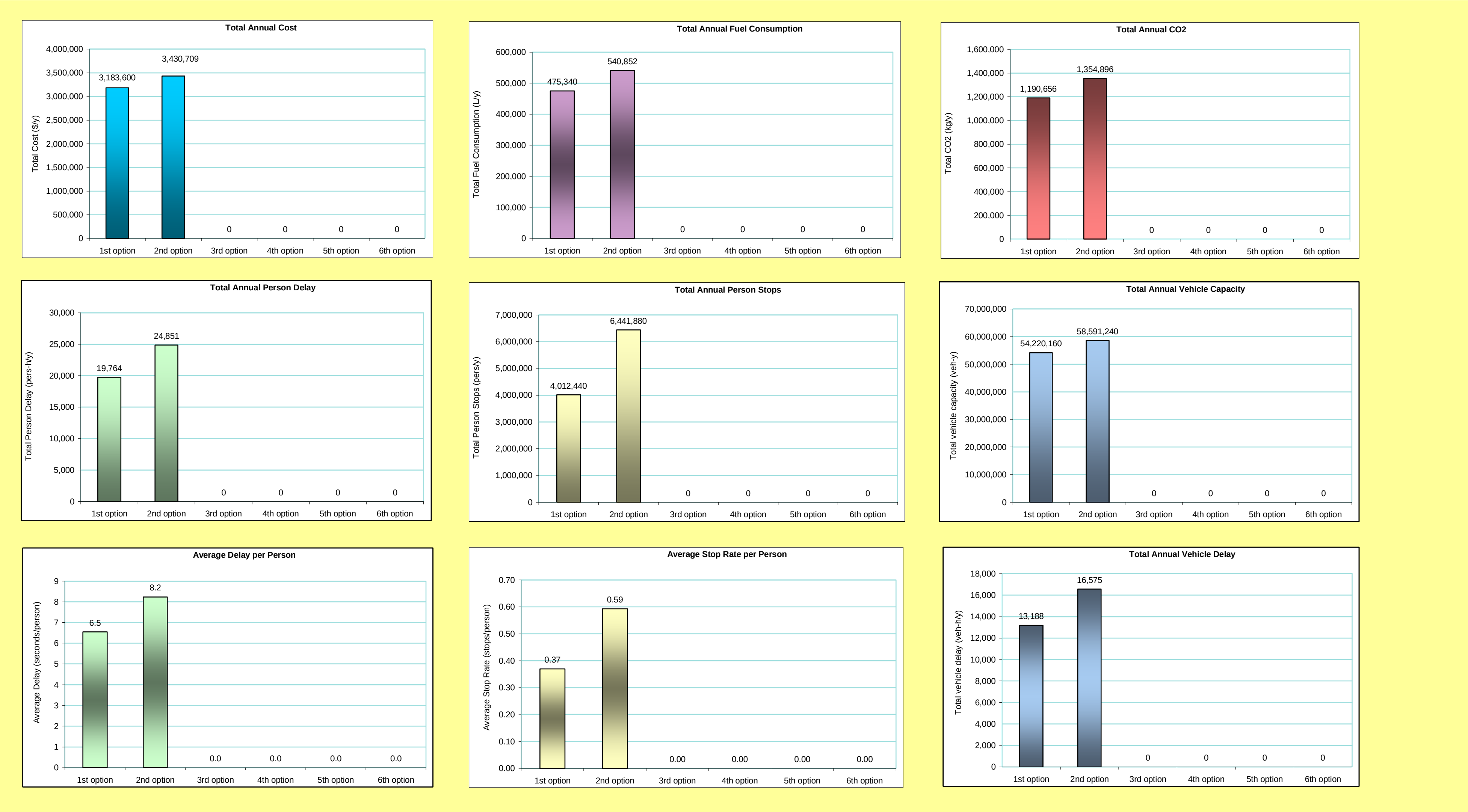

Figure U8 – Case Study 1 (S00028) – 2001 aaSIDRA "Annual Sums Comparisons"

Annual sums for aaSIDRA results © Akcelik & Associates Pty Ltd 2000-2004 Version 4, September 2004

Calculation of ANNUAL SUMS

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aaSIDRA

See "Combined Cases" sheet for calculating weighted average of Options A to F as cases (event scenarios)

Design Option / Case: A

Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay (Average)	Person stops (Average)
Default values set in Defaults sheet			Total per YEAR																Average	
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	473,654	67,248	168,576	261	11,213	371	942,240	0	1,413,120	942,240	3,576	0	5,366	462,240	0	693,600	13.7	0.49
2	PM Peak	480	420,442	59,184	148,224	232	9,749	326	884,160	0	1,326,240	948,960	2,774	0	4,162	384,480	0	576,960	11.3	0.44
3	Business Hours	3160	1,884,055	281,240	704,364	1,074	46,547	1,567	4,269,160	0	6,402,160	16,264,520	8,026	0	12,040	1,630,560	0	2,445,840	6.8	0.38
4	Medium Off-Peak	2200	669,262	101,200	253,660	383	16,588	563	1,568,600	0	2,354,000	14,649,800	2,178	0	3,278	519,200	0	778,800	5.0	0.33
5	Light Off-Peak	2440	227,335	34,404	86,376	129	5,539	190	541,680	0	812,520	18,451,280	659	0	976	165,920	0	248,880	4.3	0.31
Total per year >>			3,674,748	543,276	1,361,200	2,079	89,635	3,018	8,205,840	0	12,308,040	51,256,800	17,214	0	25,822	3,162,400	0	4,744,080	7.6	0.39
Total per day >>			10,068	1,488	3,729	6	246	8	22,482	0	33,721	140,430	47	0	71	8,664	0	12,997		
Percentage of "Period 1" to daily total >>			10%	9%	9%	10%	10%	9%	9%	NA	9%	1%	16%	NA	16%	11%	NA	11%		
Percentage of "Period 2" to daily total >>			9%	8%	8%	8%	8%	8%	8%	NA	8%	1%	12%	NA	12%	9%	NA	9%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Design Option / Case: B

Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay (Average)	Person stops (Average)
Default values set in Defaults sheet			Total per YEAR																Average	
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	456,125	73,008	182,928	290	14,765	449	942,240	0	1,413,120	2,340,480	2,309	0	3,466	617,280	0	926,400	8.8	0.66
2	PM Peak	480	422,837	65,520	164,064	265	13,157	399	884,160	0	1,326,240	2,817,600	2,227	0	3,336	573,600	0	860,640	9.1	0.65
3	Business Hours	3160	2,031,311	320,108	801,692	1,280	64,053	1,953	4,269,160	0	6,402,160	20,900,240	9,954	0	14,947	2,584,880	0	3,877,320	8.4	0.61
4	Medium Off-Peak	2200	736,846	116,160	291,060	462	23,056	706	1,568,600	0	2,354,000	14,938,000	3,454	0	5,170	882,200	0	1,324,400	7.9	0.56
5	Light Off-Peak	2440	251,296	39,772	99,552	156	7,808	242	541,680	0	812,520	16,926,280	1,147	0	1,708	297,680	0	446,520	7.6	0.55
Total per year >>			3,898,414	614,568	1,539,296	2,453	122,839	3,749	8,205,840	0	12,308,040	57,922,600	19,091	0	28,626	4,955,640	0	7,435,280	8.4	0.60
Total per day >>			10,681	1,684	4,217	7	337	10	22,482	0	33,721	158,692	52	0	78	13,577	0	20,371		
Percentage of "Period 1" to daily total >>			9%	9%	9%	9%	9%	9%	9%	NA	9%	3%	9%	NA	9%	9%	NA	9%		
Percentage of "Period 2" to daily total >>			8%	8%	8%	8%	8%	8%	8%	NA	8%	4%	9%	NA	9%	9%	NA	9%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Figure U9 – Case Study 1 (S00028) – 2006 aaSIDRA "Annual Sums"

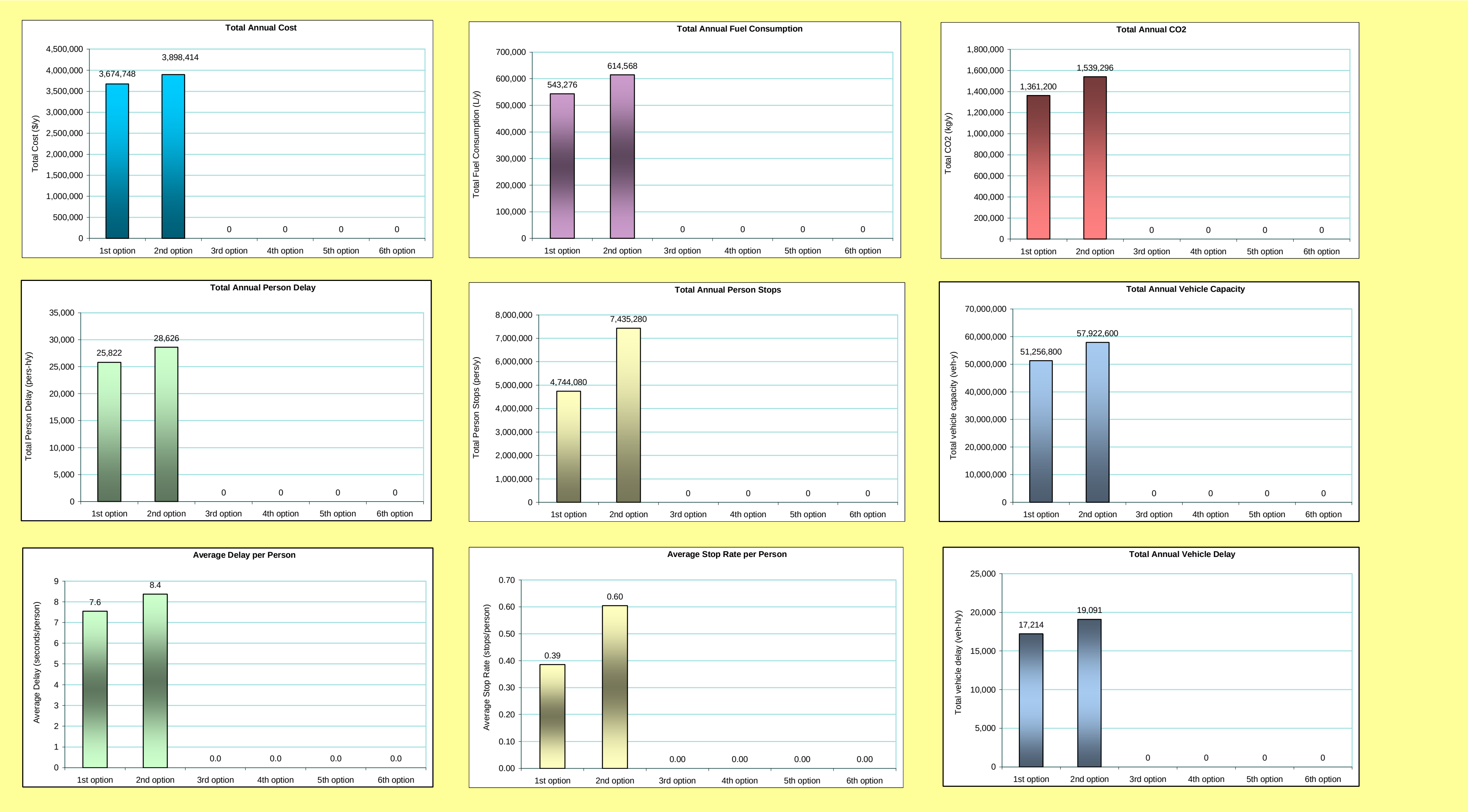

Figure U10 – Case Study 1 (S00028) – 2006 aaSIDRA “Annual Sums Comparisons”

Annual sums for aaSIDRA results © Akcelik & Associates Pty Ltd 2000-2004 Version 4, September 2004

Calculation of ANNUAL SUMS

See "Combined Cases" sheet for calculating weighted average of Options A to F as cases (event scenarios)

Design Option / Case: A

Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX		Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
Default values set in Defaults sheet			Total per YEAR																	Average	
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)		(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	625,205	81,360	203,952	324	13,306	436		1,066,560	0	1,599,840	1,066,560	7,070	0	10,608	663,840	0	995,520	23.9	0.62
2	PM Peak	480	485,270	66,096	165,600	262	10,805	360		964,800	0	1,447,200	964,800	3,936	0	5,904	444,480	0	667,200	14.7	0.46
3	Business Hours	3160	2,120,328	314,104	786,524	1,204	52,077	1,751		4,733,680	0	7,100,520	13,464,760	9,922	0	14,884	1,883,360	0	2,828,200	7.5	0.40
4	Medium Off-Peak	2200	753,016	113,740	285,120	431	18,678	636		1,757,800	0	2,635,600	14,187,800	2,552	0	3,828	596,200	0	893,200	5.2	0.34
5	Light Off-Peak	2440	249,026	37,820	94,672	142	6,076	210		592,920	0	888,160	18,380,520	732	0	1,098	183,000	0	273,280	4.5	0.31
Total per year >>			4,232,846	613,120	1,535,868	2,363	100,941	3,393		9,115,760	0	13,671,320	48,064,440	24,213	0	36,322	3,770,880	0	5,657,400	9.6	0.41
Total per day >>			11,597	1,680	4,208	6	277	9		24,975	0	37,456	131,683	66	0	100	10,331	0	15,500		
Percentage of "Period 1" to daily total >>			11%	10%	10%	10%	10%	10%		9%	NA	9%	2%	22%	NA	22%	13%	NA	13%		
Percentage of "Period 2" to daily total >>			9%	8%	8%	8%	8%	8%		8%	NA	8%	2%	12%	NA	12%	9%	NA	9%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Design Option / Case: B

Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX		Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
Default values set in Defaults sheet			Total per YEAR																	Average	
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)		(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	519,298	83,040	208,080	330	16,853	512		1,066,560	0	1,599,840	2,203,680	2,722	0	4,080	733,920	0	1,100,640	9.2	0.69
2	PM Peak	480	463,037	71,712	179,616	291	14,434	438		964,800	0	1,447,200	2,808,960	2,482	0	3,720	638,400	0	957,600	9.3	0.66
3	Business Hours	3160	2,258,673	355,816	891,120	1,422	71,321	2,174		4,733,680	0	7,100,520	20,780,160	11,186	0	16,811	2,919,840	0	4,379,760	8.5	0.62
4	Medium Off-Peak	2200	827,354	130,460	326,920	519	25,916	794		1,757,800	0	2,635,600	14,863,200	3,894	0	5,830	998,800	0	1,498,200	8.0	0.57
5	Light Off-Peak	2440	275,403	43,432	109,068	173	8,564	264		592,920	0	888,160	16,984,840	1,244	0	1,879	326,960	0	488,000	7.6	0.55
Total per year >>			4,343,764	684,460	1,714,804	2,736	137,088	4,181		9,115,760	0	13,671,320	57,640,840	21,528	0	32,320	5,617,920	0	8,424,200	8.5	0.62
Total per day >>			11,901	1,875	4,698	7	376	11		24,975	0	37,456	157,920	59	0	89	15,392	0	23,080		
Percentage of "Period 1" to daily total >>			9%	9%	9%	9%	9%	9%		9%	NA	9%	3%	10%	NA	10%	10%	NA	10%		
Percentage of "Period 2" to daily total >>			8%	8%	8%	8%	8%	8%		8%	NA	8%	4%	9%	NA	9%	9%	NA	9%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Figure U11 – Case Study 1 (S00028) – 2011 aaSIDRA "Annual Sums"

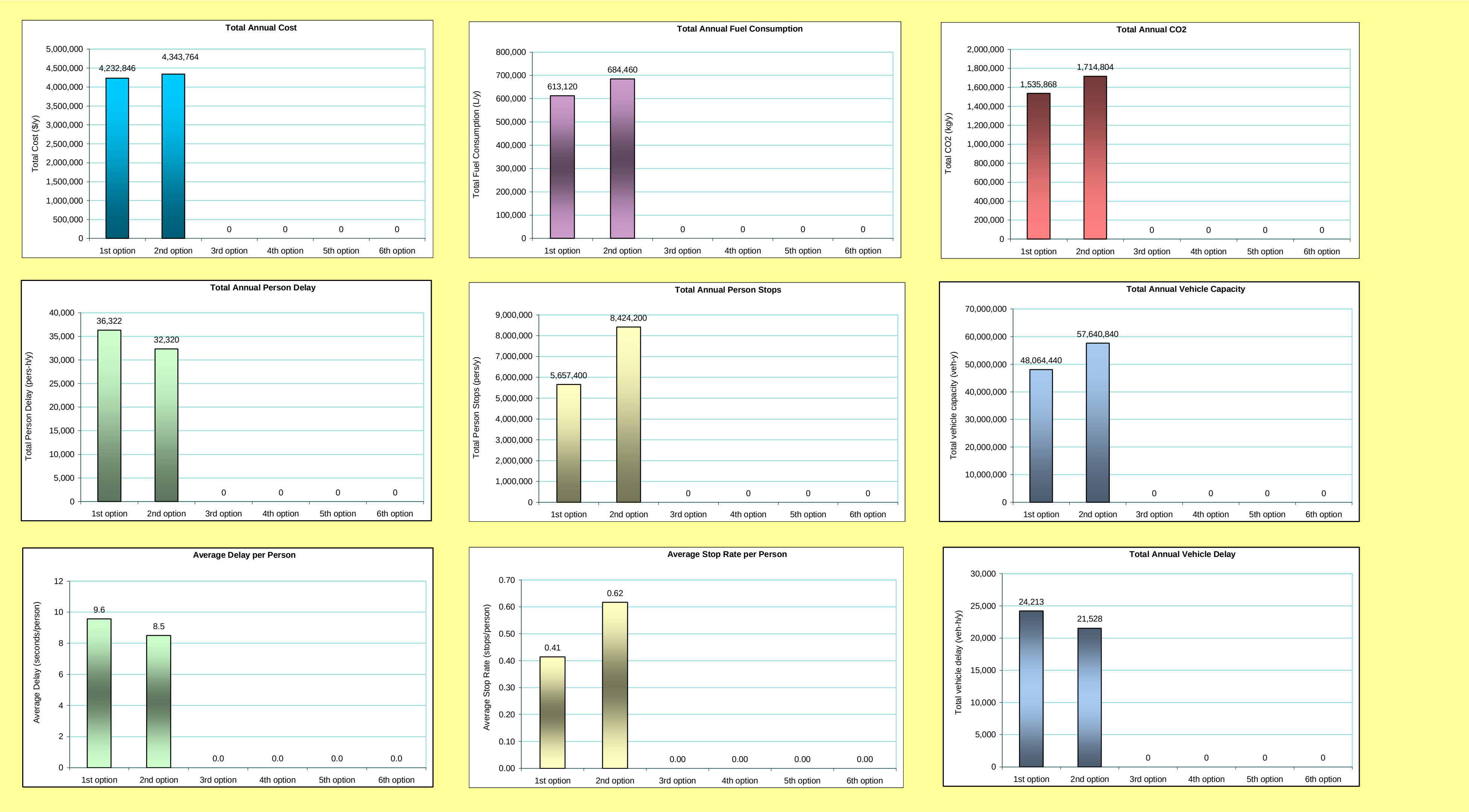

Figure U12 – Case Study 1 (S00028) – 2011 aaSIDRA "Annual Sums Comparisons"

JPT

Annual sums for aaSIDRA results © Akcelik & Associates Pty Ltd 2000-2004 Version 4, September 2004

Calculation of ANNUAL SUMS

See "Combined Cases" sheet for calculating weighted average of Options A to F as cases (event scenarios)

akcelik & associates aaTraffic aaSIDRA

Design Option / Case: A

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	1,226,568	120,432	301,776	532	18,038	569	1,191,840	0	1,787,520	1,044,960	25,834	0	38,750	1,715,040	0	2,572,800	78.0	1.44
2	PM Peak	480	593,189	75,264	188,496	304	11,962	398	1,044,960	0	1,567,680	1,044,960	6,605	0	9,912	515,520	0	773,280	22.8	0.49
3	Business Hours	3160	2,410,164	352,340	882,272	1,359	58,650	1,959	5,232,960	0	7,849,440	9,849,720	13,146	0	19,750	2,177,240	0	3,267,440	9.1	0.42
4	Medium Off-Peak	2200	831,952	125,620	314,820	475	20,680	702	1,936,000	0	2,904,000	13,802,800	2,882	0	4,334	668,800	0	1,003,200	5.4	0.35
5	Light Off-Peak	2440	275,086	41,724	104,676	156	6,734	232	653,920	0	980,880	18,326,840	805	0	1,220	202,520	0	305,000	4.5	0.31
Total per year >>			5,336,958	715,380	1,792,040	2,826	116,064	3,860	10,059,680	0	15,089,520	44,069,280	49,271	0	73,966	5,279,120	0	7,921,720	17.6	0.52
Total per day >>			14,622	1,960	4,910	8	318	11	27,561	0	41,341	120,738	135	0	203	14,463	0	21,703		
Percentage of "Period 1" to daily total >>			17%	13%	13%	14%	12%	11%	9%	NA	9%	2%	40%	NA	40%	25%	NA	25%		
Percentage of "Period 2" to daily total >>			8%	8%	8%	8%	8%	8%	8%	NA	8%	2%	10%	NA	10%	7%	NA	7%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Design Option / Case: B

Default values set in Defaults sheet			Total per YEAR																Average	
Flow Period Ref. No.	Flow Period Description	Total Hours per year	Cost	Fuel	CO2	HC	CO	NOX	Vehicle flow	Ped flow	Person flow	Vehicle capacity	Vehicle delay	Ped delay	Person delay	Vehicle stops	Ped stops	Person stops	Person delay	Person stops
			($/y)	(L/y)	(kg/y)	(kg/y)	(kg/y)	(kg/y)	(veh/y)	(ped/y)	(pers/y)	(veh/y)	(veh-h/y)	(ped-h/y)	(pers-h/y)	(veh/y)	(ped/y)	(pers/y)	(secs/pers)	(stops/pers)
1	AM Peak	480	585,355	93,408	234,048	372	19,027	576	1,191,840	0	1,787,520	2,072,640	3,182	0	4,771	852,960	0	1,279,680	9.6	0.72
2	PM Peak	480	503,304	77,904	195,120	316	15,710	476	1,044,960	0	1,567,680	2,794,080	2,746	0	4,118	704,160	0	1,056,480	9.5	0.67
3	Business Hours	3160	2,505,185	394,368	988,132	1,580	79,253	2,414	5,232,960	0	7,849,440	20,619,000	12,608	0	18,897	3,295,880	0	4,945,400	8.7	0.63
4	Medium Off-Peak	2200	912,736	143,880	360,580	574	28,622	876	1,936,000	0	2,904,000	14,781,800	4,312	0	6,468	1,108,800	0	1,663,200	8.0	0.57
5	Light Off-Peak	2440	304,122	48,068	120,536	190	9,467	290	653,920	0	980,880	17,001,920	1,391	0	2,074	358,680	0	539,240	7.6	0.55
Total per year >>			4,810,702	757,628	1,898,416	3,033	152,080	4,632	10,059,680	0	15,089,520	57,269,440	24,239	0	36,328	6,320,480	0	9,484,000	8.7	0.63
Total per day >>			13,180	2,076	5,201	8	417	13	27,561	0	41,341	156,903	66	0	100	17,316	0	25,984		
Percentage of "Period 1" to daily total >>			9%	9%	9%	9%	10%	9%	9%	NA	9%	3%	10%	NA	10%	10%	NA	10%		
Percentage of "Period 2" to daily total >>			8%	8%	8%	8%	8%	8%	8%	NA	8%	4%	9%	NA	9%	8%	NA	8%		

Total flow per day is AADT
(Annual Average Daily Traffic)

Figure U13 – Case Study 1 (S00028) – 2016 aaSIDRA "Annual Sums"

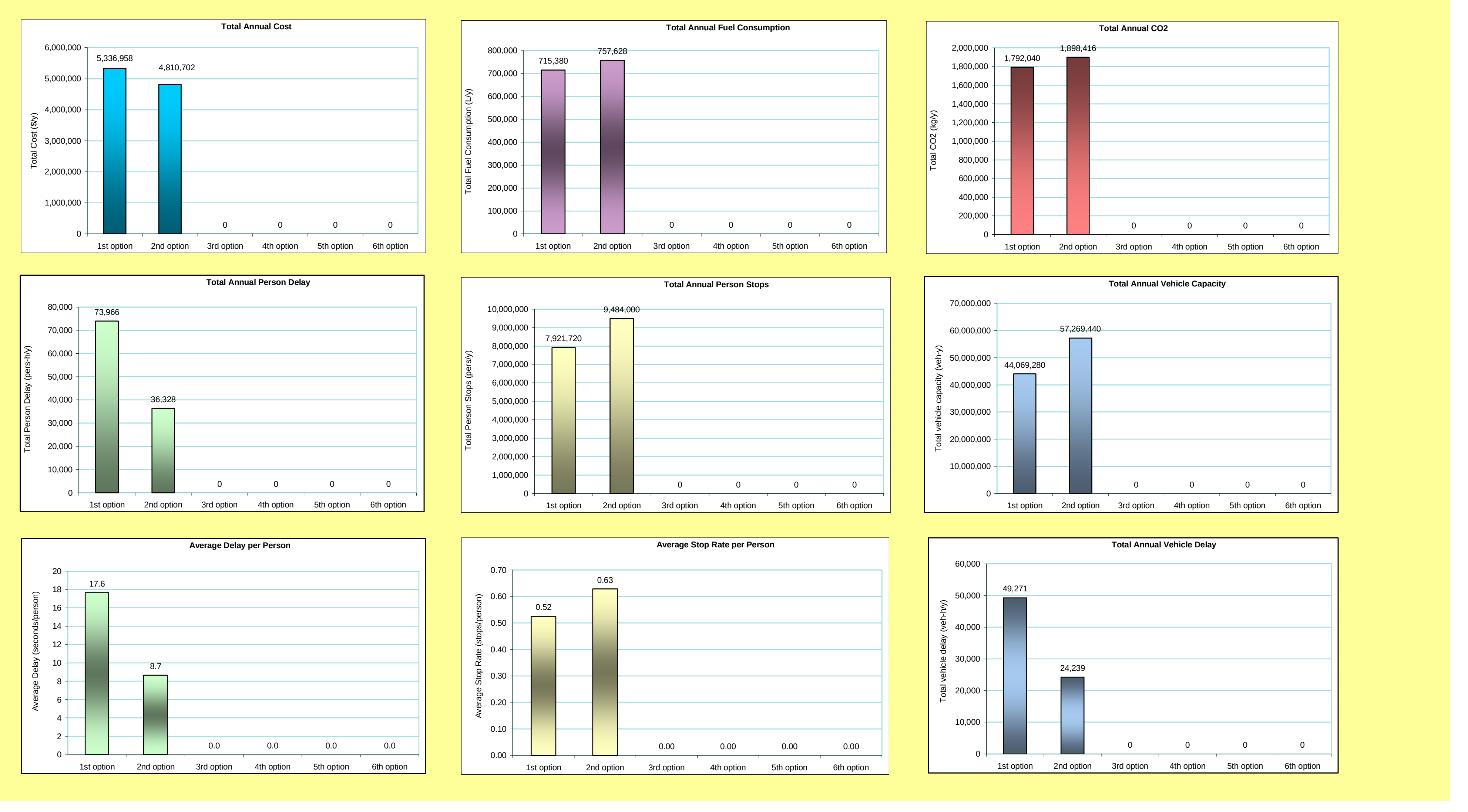

Figure U14 – Case Study 1 (S00028) – 2016 aaSIDRA "Annual Sums Comparisons"