Identify, evaluate and recommend bus priority interventions
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Executive summary

In 2010, AECOM was appointed by the NZ Transport Agency (NZTA) to research the development of a tool to assist road controlling authorities in their selection of bus priority treatments appropriate for given road and traffic situations.

The principal project objective was to develop a procedure, which would be practical, easily accessible and which could easily be disseminated to end users.

The work concentrated on the development of a set of analytical algorithms for the assessment of the effectiveness of the various types of bus priority treatments at intersections and on road segments. This analytical model was used to develop a computerised procedure, which would be able to meet the project objective.

The computerised procedure analyses a raft of bus priority treatments, rates them in the order of priority according to their suitability for a given situation, and finally displays the two most appropriate treatments. This procedure has been named the bus priority analysis tool (BAT). BAT is unique in that it has been specifically designed and developed for this purpose using as its basis the Microsoft Excel 2007 platform with Visual Basic for Application. BAT is therefore a dedicated product for distribution by the NZTA, which cannot be obtained commercially.

Literature review

The first task of the literature review was to establish whether there were any international attempts to compare different bus priority treatments with each other. The review revealed numerous well documented studies where the performance of individual bus priority treatments was assessed by computer simulation.

Nevertheless, a comparative analysis of different bus priority treatments and the identification of the appropriate treatments for a given situation have not been documented in the literature. Therefore BAT is a pioneering development.

The second task was to identify the types of bus priority treatments applied locally and internationally. This was a general literature review, which identified over 20 types of treatments. Each of these treatments was thoroughly scrutinised by the project team. The decision criteria for selection or rejection of the treatment for the further investigation were whether:

- the treatment was commonly applied
- the appropriate conditions for its installation existed in New Zealand
- it could easily be adopted to the New Zealand conditions, and
- the cost of the treatment was not excessive.

As a result 11 bus priority treatments were selected for the further analysis. Some of these treatments have already been applied in New Zealand, while the remaining treatments are potentially suitable for implementation here.

Performance of the selected treatments

The final task of the literature review focused on the quantified performance measures of the selected bus priority treatments. The purpose was to gather material for the development of the analytical model.

The accuracy of the output of the algorithms relies heavily on robust default values. The default values of interest were the reduction of delay to buses and the increased delay to other vehicles. These values are different for each of the bus priority treatments.

As a result of this, the project team was able to identify a range of values measured on site as well as those obtained from the computer simulation studies. Due to a wide distribution of the reported data, it was decided to define the useable ranges within the mean, median or mode values.

Analytical model

The analytical model is the engine of this research. It tests the effectiveness of bus priority treatments. It contains a set of algorithms, which enable the estimation of benefits of the potential bus priority treatments in the context of the existing situation on site.

The development of the analytical model is a theoretical work based on real-life inputs obtained from the literature, surveys and calculations using probabilities and the values of delays, saturation flows, traffic signal splits, and other operational characteristics observed on surveyed major arterials.

By comparing the effectiveness of the selected treatments, the analytical model selects the most appropriate treatment for a given situation.

The key performance indicators (KPIs) are an important component of the analysis, because they enable the decision maker to influence the model to identify the most appropriate treatment to meet the preset decision maker's objective. There are four KPIs:

1. overall bus and car traveller delay
2. reduced car growth rate over 10 years
3. lane person throughput in 10 years
4. cost of vehicle emission.

The KPIs are allocated a percentage weight totalling 100%. In most cases a different bus priority treatment would be appropriate for, for example, minimising the overall travel time than for reducing emissions.

There are two types of input data – site specific and general. The site-specific data, such as traffic volumes, number of buses, cost estimates of the potential treatments, project budget, lane configuration or road segment length, are well known to the end user and have to be provided by them. General input data, concerning the performance measures of different treatments, has been provided by the project team as default values, because the user will not be familiar with most of them.

The analytical algorithm was designed to:

- screen the input data to identify the applicable alternative treatments
- analyse the benefits of the treatments
- select the appropriate treatment and an alternative treatment, and
- calculate a rough benefit–cost ratio (BCR).

The initial screening of the input data eliminates the treatments which are inappropriate in a given situation. The benefits of the bus priority treatment are based on the estimate of the reduced travel time or delay to all travellers in the transit lane and increased travel time to other travellers. The total of these travel times indicates how successful the proposed treatment is expected to be.

The algorithm calculates the impact on all vehicles on each approach to the intersection, or on the bus/transit lane users and the general purpose traffic lane users. The analysis is comprehensive, interrogating vehicle arrivals on red and on green, at the end of the green phase (where a green time extension will allow additional vehicles through), on the opposite approach and on the side roads. Each of the approaches at the intersection is analysed separately and the total effect on the intersection is obtained by totalling the individual impacts.

The model selects and displays two treatments deemed to be appropriate for a given situation: the appropriate bus priority treatment (the highest ranking) and the alternative treatment (ranking the second highest). The magnitude of the benefits is not shown. In addition to the benefits of the treatment the algorithm produces an economic indicator: an indicative BCR for the intersection treatments and a total cost for the transport corridor treatments (with the warning if it exceeds the budget).

The researchers acknowledge that the model is only a first generation application tool developed on the basis of the available existing data. It identifies and prioritises a number of treatments deemed appropriate for more detailed appraisal through project feasibility or scheme assessment report work. Since the application of bus priority treatments is gaining momentum on a national scale, it can be expected that there would be an increasing number of technical staff involved in bus priority treatments, whose experience in this field may be limited. The model is intended to be a practical tool for these users.

In general, the model provides a simplified procedure to identify appropriate bus priority treatments for a given situation, but there are numerous things that BAT does not do, especially:

- the model is not a microscopic simulation model and therefore cannot simulate the performance of individual vehicles
- the model is not an economic evaluation tool, it therefore is not a substitute for the EEM economic evaluation procedures and does not materially reduce the overall extent of work required at the PFR/SAR stage to satisfy NZTA requirements
- the model does not analyse the interface between intersection and road segment, as it is based on two separate modules – the intersection and the road segment.

BAT is a computerised tool kit developed as the product of this research project on the basis of the analytical model discussed above. The details are presented in the BAT user manual (AECOM 2011).

The user manual covers the following topics: software requirement and settings, the concept of the BAT, information required before using BAT, the step-by-step interface guide, and frequently asked questions

Conclusions

The development of the procedure to analyse a range of bus priority treatments and select the appropriate one for a specific situation is a pioneering work, and as such sets the base for the further development. It does not provide all the answers.

The research team developed a ‘live’ decision-assisting tool available as a desktop application. It is an easily used and disseminated computerised application for practitioners. It is envisaged that after its release by the NZTA, BAT will be tested by end users and their feedback will be used for further refinements of the model and computerised process.

Abstract

The purpose of the research topic was to develop a practical decision-assisting tool for identifying appropriate bus priority interventions for any given situation based upon route and intersection characteristics.

In developing our proposed methodology the research team was keen to ensure the final product would be an active 'live' decision assisting tool available at one's desktop and not simply a forgettable piece of research landing on a shelf with limited life and audience. With this approach applied throughout the study, the final tool was developed in a manner that is both relevant to today's situations and takes future scenarios into consideration.

The principal objective of this research therefore was to develop an easily disseminated computerised application for practitioners to identify appropriate bus priority treatments. The resulting bus priority assessment tool (BAT) is unique in that it is not an off-the-shelf modelling product but has been specifically designed and developed for this research work using Microsoft Excel 2007 and Visual Basic for Applications (VBA).

This research report describes the development of BAT, and includes a copy of the *BAT user manual* as appendix D.

1 Introduction

1.1 Purpose

The purpose of the research was to develop a practical decision assisting tool for identifying appropriate bus priority interventions for any given situation, based upon route and intersection characteristics.

1.2 Objectives

The principal objective therefore was to develop an easily disseminated computerised application for practitioners to identify appropriate bus priority treatments to significantly reduce congestion and improve trip time reliability in Auckland, Wellington and Christchurch. The development had three stages: input, process and output. The enabling objectives of this work are shown below, consistent with section 1.1, which outlines the purpose of the research.

The enabling objectives were:

1 **To identify a range of bus priority treatments, which could be adapted to suit varying locations and traffic operating conditions**. This was achieved by drawing upon literature and practical experiences from overseas, and local bus priority practices and techniques, to identify treatments with particular relevance for New Zealand.

2 **To develop a practical, applicable and easy to understand procedure for identifying appropriate bus priority treatments for any given situation**. The procedure had to be easily disseminated by the NZTA. This was achieved by the development and testing of an analytical model capable of identifying appropriate bus priority measures for a given situation within the prevailing constraints. This development drew on various inputs from literature and surveys.

To achieve these objectives the research team secured the involvement of a steering group, convened from the NZTA and regional and local authorities in Auckland, Wellington and Christchurch.

1.3 Outcome

To attain the research objective, AECOM developed the bus priority assessment tool (BAT). BAT is unique in that it was specifically designed and developed for this research using Microsoft Excel 2007 with Visual Basic for Application (VBA). Therefore BAT is not an off-the-shelf modelling product.

In developing BAT, the research team was keen to ensure the final product would be an active 'live' decision-assisting tool, not simply a forgettable piece of research landing on a shelf with a limited life and audience. Such a philosophy was applied throughout the study, resulting in the final decision tool, which is a computerised procedure available at one's desktop. The procedure was built on the basis of representative traffic and road data available at the time. However the default data inputs can be modified and updated in the future as new ideas evolve.

1.4 Structure of the report

This research report comprises six main chapters:

Chapter 1 – Introduction. This outlines the purpose, objectives and structure of the research report.

Chapter 2 – Literature review. An international literature review identified various types of bus priority interventions and their core attributes specific to the research topic within New Zealand, Australia, the UK and the USA.

Chapter 3 – Development of the analytical model. An analytical model was developed as a theoretical tool to underpin the research proposal and its objectives. As a theoretical model it contains a set of algorithms, based on real-life inputs obtained from the literature, surveys and calculations using probabilities and the values surveyed on major arterials. The purpose of this model was to test the effectiveness of selected bus priority treatments for two applications, at 1) intersections and 2) road segments. An appropriate set of bus priority treatments for transport corridors can be produced by the analysis of a combination of intersections and road segments representing the corridor. Both applications are based on three stages: 1) input, 2) process and 3) output.

Chapter 4 – Calibration and verification of the analytical model. This involved testing the case studies of bus priority treatments with the model and analysing the differences between the model outputs and the implemented treatments. The model was also peer reviewed by external experts in passenger transport.

Chapter 5 – Launching the bus priority assessment tool (BAT). The focus was on converting the theoretical model into a practical tool called the bus priority assessment tool (BAT). A principal project objective was the development of an easily disseminated computerised application for practitioners to identify appropriate bus priority treatments, following the input, process and output stages. The development of BAT and its supporting user manual is described in this chapter.

Chapter 6 – Conclusion and recommendations. The final section of this report draws together the findings of this research topic, focusing on a discussion of how this model could be applied to the New Zealand context, and further research, which could be undertaken to further explore the benefits of BAT for users, in identifying appropriate bus priority treatments and the benefits and costs for any given situation.

Appendices – The appendices provide further supporting details and information pertaining to the research. This includes the literature review, background details into the development of the analytical computerised model called bus assessment tool (BAT), the default values used and a glossary of terms used in the research report. Appendix D is the *BAT user manual* which contains a user checklist guide for compiling mandatory data to be entered into BAT, eg traffic counts and existing intersection/transport corridor configurations.

2 Literature review

2.1 Introduction

This chapter describes an international literature review and identification of various types of bus priority interventions and their core attributes specific to the research topic within New Zealand, Australia, the UK and USA.

The literature review was conducted in two stages, these being:

1. A general literature review which investigated the range of bus priority treatments applied locally and internationally and selected suitable treatments for the New Zealand urban environment (appendix A)
2. A detailed literature review which focused on specific quantified performance indicators of selected bus priority treatments (appendix B).

2.2 Objectives

The literature review objectives were to:

- identify a wide range of bus priority treatments, potentially suitable for application on the New Zealand urban arterials, and gather material for the default values needed for an analytical model of intersection and road segment bus priority treatments (see sections 2.3.1 and 2.3.2)
- identify and explore bus priority projects, which give a quantified description of the prevailing situation before the implementation of a bus priority treatment, the specifics of the treatment and the quantified benefits resulting from the treatment
- produce a brief description of each of the relevant schemes presenting the initial situation, the applied treatment and the quantified results.

2.3 Bus priority treatments

The general literature review identified a wide range of bus priority treatments applied or investigated both overseas and in New Zealand. The most useful publications discussing features of the various treatments were Currie (2006), Department for Transport (2004), Maunsell-AECOM (2008), Government of Western Australia (2004) and VicRoads (2003). Turnbull and DeJohn (2000) presented a comparative review of the off-side (in the median) and the near-side (kerb) bus lanes, and the advantages of the queue jump lanes (Bodé 2010).

Some of these treatments have already been applied in New Zealand, while others are potentially suitable for implementation here. As a result of this review 22 treatments were assessed as applicable to New Zealand conditions. After a detailed scrutiny, the list was reduced to 11 treatments appropriate for the purpose of the research work. The selected treatments for intersection and road segments are shown in appendix B, figures B1.1 and B1.3. Sections B6 and B7 of appendix B provide further details of these types of treatments.

2.3.1 Intersection bus priority treatment data

The default values of interest for the intersection bus priority treatment were the reduction in delay for buses and the increased delay for other vehicles at an intersection. These values are different for each of the bus priority treatments.

The literature review focused on retrieving the specific data concerning the performance of the installed and monitored bus priority treatments. Unfortunately, in spite of reviewing a large number of publications, the research team was able to find only a small amount of data that was relevant to this project. The UK and Brisbane AECOM offices contributed to the literature review. The Auckland team reviewed and collated the supplied information for the purpose of the report.

Gardner et al (2009) reviewed the performance of bus priority at traffic signals. Useful information on the performance of buses and general traffic at intersections equipped with a transit signal priority was provided by Barton (2003), Jepson et al (1999) and Liao (2006). Bodé (2010) supplied information on the benefits of queue jump lanes for buses.

The literature review identified the range of values measured on site as well as those obtained from the computer simulation studies. Due to a wide distribution of the reported data, the research team decided to define the useable ranges within the mean, median or mode values. Therefore the values used for this work were determined as follows:

- reduction of bus delay with a transit active signal – range of 7.5s/bus to 9.0s/bus
- side road traffic delay increase with a transit active signal – range of 3.0s/veh to 3.6s/veh
- main road traffic delay reduction with a transit active signal – average 1.5s/veh
- bus jump lane reduction of bus delay – range of 43s/bus to 69s/bus for lanes longer than 100m
- reduction of bus travel time variability with any priority treatment – range of 8% to 50%
- modal shift from cars to public transport with any bus priority treatment – a highly conservative range of 1% to 2% per annum over 10 years
- the minimum number of buses to return benefits – 15bus/h.

2.3.2 Road segment bus priority treatment data

The default values of interest for road segment bus priority treatment were the reduction of travel time for buses and the increased delay for other vehicles on the road segments. These values are different for each of the bus priority treatments.

Bauer et al (2005) produced a comparison of the performance of high occupancy vehicle (HOV) lanes with bus lanes and general purpose traffic lanes. The Australian Transport Council (2009) reported that the patronage growth rates on the Liverpool–Parramatta Transitway scheme were around 30% in year 2, decreasing gradually to around 10% by year 5. Vuchic (2007) noted a 10% to 30% annual growth for several years recorded in many North American cities.

Some details of bus lane performance were provided by Boorer (2010), Ussher (2010) and Gravitas (2010), while Nee et al (2002), and Kwon and Varaiya (2007) discussed the performance of the HOV (T2 and T3) lanes. Ian Wallis Associates (2008) reviewed international experience with bus priority measures.

The literature review identified the range of values measured on site as well as those obtained from the computer simulation studies. The values retrieved were:

- reduction of bus delay with the bus lane – range of 48.9s/bus-km to 65.2s/bus-km
- additional delay for other traffic with the bus lane – range of 28.2s/veh-km to 33.8s/veh-km
- travel time saving for T2 and T3 vehicles in the transit lane – range of 29.0s/veh-km to 69.3s/veh-km.

The details of this literature review are presented in appendix B. In spite of a comprehensive search the literature review did not find sufficient data to draw any meaningful assessment of the impacts of other bus priority measures.

2.4 Conclusion

The literature review confirmed the uniqueness of the BAT model. There have been various attempts to model the performance of individual bus priority treatments by computer simulation, but a comparative analysis of different bus priority treatments and the identification of the appropriate treatments for a given situation have not been documented in the literature. The most appropriate tool for the analysis of performance of a priority treatment is microsimulation. For instance, Davol (2001) used microsimulation for modelling public transport signal priority strategies, Gan et al (2002) modelled bus lane preferential treatments, Liao (2006) modelled bus signal priority based on geographical positioning systems (GPS) etc. But none of these studies can be compared to the BAT modelling.

A general literature review on the range of worldwide bus priority treatments revealed 11 treatments that were considered appropriate for New Zealand's urban environment. A further detailed literature review identified quantified benefits of these treatments to buses in terms of travel time saving, modal shift and reduction of travel time variability which are consistent with the overarching research objectives. Also quantified was the increased delay to other vehicular traffic. All quantified data was taken forward into the development of default values in the analytical model described in chapter 3 of this report.

3 Development of the analytical model

3.1 Introduction

The analytical model was the engine of our research for testing the effectiveness of several bus priority treatments at intersections and on road segments.

It contains a set of algorithms, which enables estimation of the benefits of the potential bus priority treatments in the context of the existing on-site situation. The analytical model is a theoretical work based on real-life inputs obtained from the literature, surveys and calculations using probabilities and the values of delays, saturation flows and traffic signal splits etc observed on surveyed major arterials.

The analytical model deals with two types of applications: intersection and transport corridor. Each of these applications has three stages: model input, process and output. These are explained briefly in the following sections. For a more detailed explanation of the thinking behind the algorithms, the assumptions on which they are based, and the developed set of the algorithms, refer to appendix B.

3.2 Model input

The analytical model relies on a large number of inputs. The accuracy of these inputs is essential to the veracity of the model and the quality of the output. There are two categories of input: user input data (section 3.2.1) and inaccessible default data (section 3.2.2).

3.2.1 User input data

There are two types of user input data – mandatory and optional.

3.2.1.1 Mandatory data

The mandatory data is site specific and well known and understood by the user. Examples of this type of user input data in the model include: traffic volumes, number of buses and road segment length. A check list in the *BAT user manual* in appendix D provides further details on the type of input data necessary.

Key performance indicators

Key performance indicators (KPIs) are an important component of the analysis. Weighting of KPIs is a mandatory user input for both intersections and road segments. By allocating a high weight to one of the KPIs the decision maker will influence the model to identify the most appropriate treatment, for example, to minimise the overall travel time or reduce the future car growth rate. Therefore KPIs serve the purpose of conveying the road controlling authority (RCA) sentiments. There are four KPIs which address the project's purpose of reducing congestion and improving bus trip time reliability.

These indicators are:

- overall bus and car traveller delay
- reduced car growth rate over 10 years
- lane person throughput in 10 years
- cost of vehicle emission.

The user will weigh each of these KPIs according to their importance in terms of the user's objectives. The sum of weighting for all four KPIs will equal to 100%. The most useful output is obtained when a 100% weighting is applied to one of the four KPIs. For example, weighting emission at 100% identifies the RCA's commitment to reducing pollution; the model will indicate the appropriate treatment to achieve it.

3.2.1.2 Optional data

The optional data is of a general nature; the model contains the default values. The user may accept or override the default values. They are:

- for intersections
  - number of signal cycles per hour
  - existing signal cycle phase split (main approach green time percentage)
  - car occupancy
  - bus occupancy
  - traffic growth rate
  - opposite and side approaches traffic flow as a percentage of the main approaching flow
- for road segments
  - HOVs T2%
  - HOVs T3%
  - car occupancy
  - bus occupancy
  - traffic growth rate.

3.2.2 Inaccessible default data

Built-in default data which is inaccessible cannot be overwritten by the user. AECOM identified the most representative values of this input and inserted them as default values in the model. The user cannot access these values.

Examples of this type of inaccessible default values in the model include bus delay reduction and other traffic delay increases specific to each of the selected bus priority treatments. Refer to appendix D for a list of default values.

3.3 Substantiation of the default values

Both the accessible and inaccessible default values contained within the model are derived from AECOM's research which concentrated on three sources: international and local publications, data obtained from local authorities and surveys conducted in Auckland, and AECOM's own calculations from the first principles, where there was no other way of getting the necessary data. When a default value was derived from more than one source, the results were reconciled to produce the single most robust value. The discussion of these sources follows:

- Literature review

  The literature review attempted to identify the value of delay to buses and other vehicles as reported in local and international publications. The values were measured on site or obtained by computer simulations. In spite of a large number of reviewed publications, only a limited amount of information consistent with the purpose of this review was found.

Section B8 of appendix B provides more information on values identified from the literature review.

- Data obtained from monitoring New Zealand transit lanes and own surveys

  Various Auckland, Wellington and Christchurch RCAs monitor some of the transport system operational features, which occasionally include bus and transit lanes. These monitoring reports provided valuable data for this research work.

  Several surveys were conducted across the Auckland region, which provided some of the data that could not be found elsewhere. Data obtained from the surveys were considered to be representative of average values for the morning peak on typical arterial routes. Since the surveys were conducted on typical four-lane approaches to the central business district (CBD), the research team considered them to be representative for Wellington and Christchurch as well.

- Calculations

  As the data retrieved from overseas publications, local reports and the surveys did not cover all of the bus priority treatments to be investigated for this research, it was necessary to calculate the average delays to buses and other affected vehicles for some of the priority treatments from the basic measurements at intersections, such as the timing of the bus phase, signal splits, traffic flows on side roads, etc.

3.4 Analytical algorithm

AECOM developed the algorithm to estimate the effects of each of the analysed bus priority treatments on the performance of buses and other vehicles. The algorithm takes into account reduced delay or reduced travel time for buses and potentially adverse effects of the bus priority measure on other traffic. The analytical algorithm was designed to:

- screen the input data to identify the applicable range of alternative treatments
- analyse the benefits of the treatments
- select the appropriate treatment and an alternative treatment
- calculate a rough benefit–cost ratio (BCR).

The initial screening of the input data allows for the elimination of treatments which are inappropriate in a given situation. For instance, if there are no right-turning buses, the bus right turn treatments are excluded from the analysis. Similarly, if the cost of the treatment exceeds the budget, the treatment will be excluded. The treatments not rejected by the screening process constitute the sample to be analysed.

The benefits of the bus priority treatment are based on the estimate of reduced travel time or delay for the bus passengers (or all travellers in the transit lane), and the increased travel time for other travellers. The total of these travel times indicates how successful the proposed treatment is expected to be. The algorithm calculates the impact on all vehicles on each approach to the intersection, or on the bus/transit lane users and the general purpose traffic lane users.

The analysis is comprehensive, investigating the arrival of vehicles at red and green lights, at the end of the green phase (where a green time extension will allow additional vehicles through), on the opposite approach and on the side roads.

Each of the approaches at the intersection is analysed separately and the total effect on the intersection is obtained by adding the individual impacts. The algorithms for estimating bus and other vehicle delays at the intersection are presented in section B8 of appendix B.

The transport corridor model has two components: individual intersections and individual road segments. Each intersection can have a different bus priority treatment and has to be analysed individually. This follows the same concept as that used for the intersection model by analysing approaches at the intersection separately and calculating the overall effect on the intersection due to the bus priority treatment.

Unlike the individual intersections, it would not be practical to treat the road segments individually, so a uniform bus priority treatment has to be adopted for a group of adjacent road segments. The model identifies critical road segments along the route and bus priority treatment will be applied to these as well as the upstream segments. The algorithms for estimation of the bus and other vehicle travel time on the road segments are presented in section B9 of appendix B.

An important input to the analysis is the user philosophy expressed by the KPIs – for instance a different treatment may be more appropriate when the user intends to reduce the car traffic growth than when they aim to reduce vehicle emissions. It has to be noted that the effects of the treatment are analysed over a 10-year period, which gives a much more reliable result than the analysis for a single year.

The treatment that shows the highest benefit is identified as the appropriate treatment. The treatment which is second in terms of the amount of benefits is elected as the alternative treatment. Other treatments are not displayed. However, if the user wants to find out which treatment rates next in the order of benefits, they can eliminate the highest-ranking treatment (the appropriate treatment) by increasing its cost above the budget. In this manner the alternative treatment will be shown as the appropriate treatment, and another treatment will appear as the alternative treatment.

In addition to the benefits of the treatment, the algorithm also produces the economic indicator (an indicative BCR) for the intersection treatments. It has to be recognised that in this work the BCR is an add-on rather than the essence. The reason for this is that the inputs to the economic indicator are rough. The cost estimates will be provided by the user and the research team does not have any means of controlling the accuracy of these estimates. This is one of the reasons why the economics are excluded from the treatment selection process, and the BCR produced by the model is indicative only. For the same reason the assessment of the incremental BCR between the treatments deemed 'appropriate' and 'alternative' was omitted from the model.

The indicative BCR is estimated on the basis of travel time costs for a single year only. It excludes vehicle operating costs, accident costs and any other consideration, such as congestion relief. A single year benefit is multiplied by a simplified discount factor of 10 to produce an indicative assessment of the net present value of the benefits.

There is no BCR estimation for the road segment or transport corridor. The only economic indicator for the transport corridor is the warning to the user, which appears when the total cost of all the appropriate treatments for the intersections and road segments in the corridor exceeds the proposed budget.

3.5 Model output

Eleven bus priority treatments were identified and considered suitable for application in New Zealand. Of these 11 treatments, five are suitable as intersection treatments, while the remaining six are applicable as road segment treatments. The 11 treatments as illustrated in appendix B, figures B1.1 and B1.3 are listed in table 3.1.

Table 3.1 List of intersection and road segment treatments

Intersection treatments	Road segment treatments
Bus advance	With-flow bus lane
Transit active signal	Contra-flow bus lane
Queue Jump lane	Reversible bus lane
Bus right turn only	Bus gate
Bus gate for bus right turn	T2 transit lane
	T3 transit lane

Sections B6 and B7 of appendix B provide further details on these types of treatments.

The model output will provide the user with two potential treatments for the intersection (the appropriate treatment and an alternative treatment), and two treatments for the road segment. In the transport corridor analysis each intersection will show two treatments, while a consistent segment treatment (or two treatments for a longer corridor) will be recommended for the full length of the corridor.

The differences in each of the model type outputs can be summarised as follows:

- intersection model – both treatments are accompanied by a rough BCR, which does not, however, play a role in the selection process
- transport corridor model – this identifies the most appropriate and an alternative treatment for each intersection, and for groups of road segments between intersections.

3.6 Limitations of the analytical model

The researchers acknowledge that BAT is only a first generation application tool developed on existing data available. Any solution that BAT recommends will entail a multi-faceted suite of influences and decisions which will determine the actual treatment provided on site. BAT identifies and prioritises a number of treatments deemed appropriate for more detailed appraisal through project feasibility or scheme assessment report work. Since the application of bus priority treatments is gaining momentum on a national scale, it can be expected there will be an increasing number of technical staff involved in bus priority treatments, whose experience in this field may be limited. BAT is intended to be a practical tool for these users.

In general, BAT provides a simplified procedure to identify appropriate bus priority treatments for a given situation, but there are numerous things that BAT does not do. This includes:

- **BAT is not a microscopic simulation model**

  Unlike the microscopic simulation model, BAT cannot model the performance of individual vehicles, does not have the capability to take into consideration the degree of saturation, speed/volume relationship, queue building and dissipation mechanisms etc, or to produce trip time reliability as an output.

  Instead, a simple approach has been adopted, where the input traffic volume is restricted to 900 vehicles per hour per lane. Although this assumption may appear crude, it represents a maximum flow observed on the urban arterials and has been considered representative by the research team.

  As such, BAT treats trip time reliability as a corollary of the travel time or delay improvements. This approach/philosophy is consistent with section 7.2 of the *Economic evaluation manual volume 2*

(EEM) NZTA (2010). The EEM states that reliability is related to delay and the reliability benefit is a function of the reduction in trip time.

An assessment of the 11 treatments analysed in this research in terms of their impact on bus trip time reliability is shown below, where (H) describes high impact and (M) and (L) medium and low impact respectively: bus advance (M), transit active signal (H), queue jump lane (H), bus right turn only (M), bus gate for bus right turn (L), 'with-flow' bus lane (H), T2 and T3 transit lanes (M), contra-flow bus lane (H), reversible bus lane (H) and mid-block bus gate (H).

- **BAT is not an economic evaluation tool**

  BAT is not a substitute for the EEM economic evaluation procedures and does not materially reduce the overall extent of work required at the project feasibility report (PFR)/scheme assessment report (SAR) stage to satisfy NZTA requirements.

  The inputs to BAT are rudimentary and the resulting BCR is indicative. The economic considerations are not part of the process for selecting the appropriate treatments.

- **BAT is not a comparison tool**

  BAT does not contain a mechanism for comparing different performance measures, such as vehicle delay against car growth rate; or different treatments with and without an additional lane. However, the BAT user can analyse the difference by changing the input and re-running the model.

  The following example illustrates this point. The analysis of the 'with-flow' bus lanes and transit lanes offers two alternatives – converting the existing general purpose traffic lane or adding a lane. Adding a lane is an expensive solution, but it avoids creating delays for traffic. The cost of the additional lane would be lower if there is a space in the berm or median to accommodate it.

  BAT does not provide direct comparison between different treatments with and without an additional lane. However, the end user can analyse these configurations separately by changing the input and re-running the model. The consideration will be the impact on general traffic and the costs. In a typical situation of two lanes, one lane is converted to a bus/transit lane – the cost is low, but general traffic is delayed. If this delay must be avoided, an additional lane has to be added. If there is space to do it, the costs will be lower than if there is a need to encroach on the property boundaries. However the decision on whether general traffic is to be delayed or not depends on the RCA's policies, eg if the reduction of the car traffic growth rate is to be achieved, adding a lane would be inappropriate.

  In the model a queue jump lane is defined as an additional short lane that allows buses to bypass a queue. As such, it is an intersection feature. Such a lane involves construction costs, but does not affect the performance of the general purpose traffic lanes.

  The with-flow bus lane runs full distance between the intersections and is analysed as a link between two intersections. As such, it is a road segment feature. BAT does not analyse the interface between the intersection and the bus lane, which means that the distance between the end of the bus lane and the intersection is not taken into consideration.

  BAT is based on two separate modules – the intersection analysis and the analysis of a road segment. These two modules can be combined to analyse the transport corridor, but cannot be used for a direct comparison of the intersection versus road segment treatment. An indirect comparison of the performance of the intersection treatment (eg queue jump lane) with the road segment treatment (eg bus lane) can be done by analysing each treatment separately, but the only comparative output would be an indicative BCR.

- **BAT does not model the interface between intersection and road segment**

  BAT is based on two separate modules – the intersection and the road segment. These two modules can be combined to analyse the transport corridor, but BAT does not analyse the interface between the intersection and the road segment. This means that the distance between the end of the road segment treatment and the intersection treatment is not taken into consideration. For instance, a with-flow bus lane runs full distance between intersections and is analysed as a link between two intersections.

BAT does not materially reduce the overall extent of work required at the PFR/SAR stage to satisfy NZTA requirements. However the model gives the user an initial idea of what priority treatments are suitable for New Zealand practice and appropriate in their situation. The benefit BAT offers in its current development phase is the identification of potential bus priority interventions on a specific route, based on the level of detail available and provided by users as input into BAT. The ability to understand the potential cost and benefits associated with each option also offers an added advantage to users in determining likely budgets and social economic factors associated with the treatment identified.

The quality of the input determines how good the output is. The important contributors to the accuracy of the analysis and its output are:

1. The site-specific inputs
2. How the user modifies the default values that are accessible to them
3. The values the research team adopted as the inaccessible default values
4. Whether the assumptions adopted by the research team in determining the representative traffic and operating conditions lead to a realistic representation of these conditions by the model.

The output will benefit substantially if the user has a good understanding of the site and is able to provide a sound set of input data. If the user relies on the default values, the output will tend to represent a generalised situation rather than the specific site. Although the research team was careful to identify the most representative situations and develop a robust set of default values and algorithms, it has to be accepted that there could be sites and conditions where the operational situations will materially differ, leading to sub-optimum outputs of the model. It is therefore necessary to subject the treatments identified by the model to a PFR or a SAR analysis as required by the NZTA, before the decision on implementation is reached.

4 Calibration and verification of the model

4.1 Introduction

The calibration and verification of the analytical model converted the theoretical work into a practical tool. The model calibration was achieved by comparing the data within the model against data obtained from on-site surveys and any necessary adjustments were made.

Verification of the analytical model was achieved by comparing the outputs of the model against bus priority treatment case studies. This involved testing the case studies to determine and explain the differences between the model outputs and the implemented treatments on site.

It should be noted that the case studies deal with road segments or public transport corridors rather than with individual intersections and do not contain information on the cost of the installed bus priority treatments. This is due to the lack of 'before' data for the intersections where bus priority treatments have been installed, despite intensive search by the research team.

In some cases the adopted scheme implemented on site will be decided by a political directive, rather than technical considerations. The model demonstrates that by adopting different objectives of the treatment, eg reduction of car growth vs emission reduction the resulting treatments for a specific site will differ. These objectives are represented in the model by the weighting of the KPIs.

The analytical model has been peer reviewed by external experts in passenger transport. The comments received from the project steering group were most valuable during this model calibration and verification phase.

4.2 Case studies

The purpose of the case studies was to compare the output of the analytical model with the bus priority treatments implemented by councils on arterial roads.

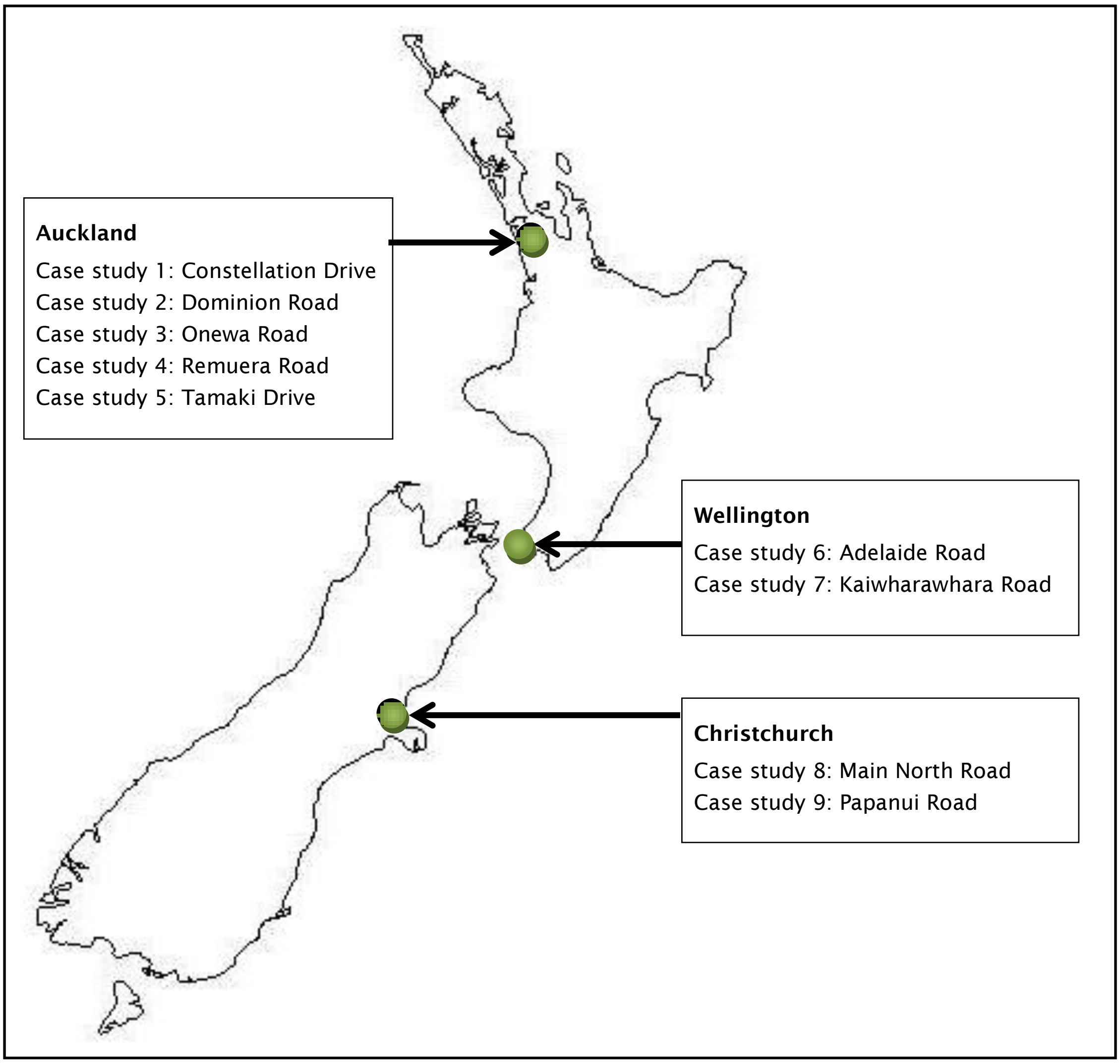
For each case study, the morning peak data representing the location before any treatment had been installed was inserted into the BAT model. The inserted data represented the situation the decision maker faced prior to the installation of bus priority treatment.

Nine case studies from Auckland, Christchurch and Wellington were selected and tested using the analytical model. Their locations are shown in figure 4.1. The following sections discuss the case studies according to their:

- background – the site conditions prior to implementing a treatment
- model inputs –the data input into the model
- analysis and model outputs – a discussion of the outputs
- council implemented treatment – bus priority treatment implemented on site
- conclusion – the model's output versus the decision made by the council.

Some of the model inputs were obtained from council documents, while the missing values were substituted with the model default values.

Figure 4.1 Case study locations



4.2.1 Case study 1: Constellation Drive, Auckland

4.2.1.1 Background

Constellation Drive is a four-lane urban arterial road with a flush median and wide berms. There are two road segments between East Coast Road and Home Place (350m and 700m long), with three signalised intersections.

4.2.1.2 Treatment installed by the RCA

Initially the RCA installed a T3 lane but later converted it to a T2 lane.

4.2.1.3 Model inputs

For the analysis, the number of buses had to be increased to 15 buses per hour[1], as this is the minimum bus volume required by the model.

Table 4.1 Model inputs – Constellation Drive, Auckland

Traffic volume (veh/h)	Buses (bus/h)	Bus occupancy	Car occupancy	Proportion T2 (%)
1120	11	17	1.15	13%

4.2.1.4 Analysis and model outputs

The site operation was analysed for two scenarios:

1 With the contra-flow lane as a valid option

2 If the contra-flow lane is not allowed.

A total of four runs were completed for each of the scenarios described above. Each run corresponded to a weighting of one of the KPIs at 100%, as shown below:

1 Reduced overall delay weighted at 100%

2 Reduced car growth rate weighted at 100%

3 Maximised person throughput weighted at 100%

4 Reduced vehicle emissions 100%.

See table 4.2 for the results of the analysis.

Table 4.2 Analysis and model outputs – Constellation Drive, Auckland

Test no.	Contra-flow lane	KPI	Weighting	Model output	
				Appropriate treatment	Alternative treatment
1	Scenario 1	Overall delay	100%	Contra-flow bus lane	T2 lane
2	Scenario 1	Car growth	100%	Contra-flow bus lane	Bus lane
3	Scenario 1	Throughput	100%	T2 lane	T3 lane
4	Scenario 1	Emissions	100%	Contra-flow bus lane	T2 lane
5	Scenario 2	Overall delay	100%	T2 lane	T3 lane
6	Scenario 2	Car growth	100%	Bus lane	T3 lane
7	Scenario 2	Throughput	100%	T2 lane	T3 lane
8	Scenario 2	Emissions	100%	T2 lane	T3 lane

[1] The model requires 15 buses per hour as a minimum bus volume. This is a conservative figure but reflects the number of buses travelling on key strategic urban arterials in Auckland, Christchurch and Wellington.

4.2.1.5 Discussion

The outcome of the analysis depends on how the decision-making authority views the importance of each of the KPIs. The analysis showed the contra-flow bus lane would be an appropriate treatment, reducing the overall delay, future car growth and emissions.

However if this treatment was excluded from consideration, another appropriate treatment would be a T2 lane. Therefore the model confirms that the RCA's decision to convert the originally installed T3 lane into a T2 lane would increase the effectiveness of the lane.

4.2.2 Case study 2: Dominion Road, Auckland

4.2.2.1 Background

Dominion Road is a four-lane urban arterial road with a flush median and no berms. There are three road segments between Mt Albert Road and View Road (2000m, 1200m and 400m long), with four signalised intersections.

4.2.2.2 Treatment installed by the RCA

The site had already been treated by the implementation of a bus lane. However, an analysis by Auckland Transport (2011) re-evaluated the corridor and identified three treatments. The most appropriate of these was a T3 lane followed by a bus lane and then a T2 lane. The differences in productivity rating between the three treatments were marginal.

Table 4.3 Model inputs – Dominion Road, Auckland

Traffic volume (veh/h)	Buses (bus/h)	Bus occupancy	Car occupancy	Proportion T2 (%)
1080	33	37	1.30	18%

4.2.2.3 Analysis and model outputs

The site operation was analysed for scenario two only ('contra-flow lane not allowed') as there was no possibility of a contra-flow lane (the road is in a densely built-up urban environment with retail outlets and numerous pedestrian crossings).

A total of four runs were completed for this scenario, each run corresponding to a weighting of one of the KPIs at 100%, as shown below:

1 Reduced overall delay weighted at 100%

2 Reduced car growth rate weighted at 100%

3 Maximised person throughput weighted at 100%

4 Reduced vehicle emissions 100%.

See table 4.4 for the results of the analysis.

Table 4.4 Analysis and model outputs – Dominion Road, Auckland

Test no.	KPI	Weighting	Model output	
			Appropriate treatment	Alternative treatment
1	Overall delay	100%	T2 lane	T3 lane
2	Car growth	100%	Bus lane	T3 lane
3	Throughput	100%	T2 lane	T3 lane
4	Emissions	100%	T2 lane	T3 lane

4.2.2.4 Discussion

The model showed that a T2 lane would be an appropriate treatment reducing delay and emissions and increasing throughput. However if the purpose of the scheme was to reduce future car growth rate, an appropriate treatment would be a bus lane. It indicated that the effect of the bus lane treatment already installed by the RCA had been to reduce the growth rate of car traffic.

4.2.3 Case study 3: Onewa Road, Auckland

4.2.3.1 Background

Onewa Road is a four-lane urban arterial road with no median or berms. There are two road segments between Birkenhead Avenue and Sylvan Avenue (1600m and 900m long), with three signalised intersections. Three schools abutting the road generate a lot of turning movements during the AM peak.

4.2.3.2 Treatment installed by the RCA

The implemented treatment on site is a T3 lane. However, a recent analysis by Auckland Transport (2011) re-evaluated the corridor and identified three treatments, the most appropriate being a bus lane followed by a T3 lane and then a T2 lane.

Table 4.5 Model inputs – Onewa Road, Auckland

Traffic volume (veh/h)	Buses (bus/h)	Bus occupancy	Car occupancy	Proportion T2 (%)
1590	26	38	1.44	14%

4.2.3.3 Analysis and model outputs

The site operation was analysed for two scenarios:

1 With the contra-flow lane as a valid option

2 If the contra-flow lane is not allowed.

A total of four runs were completed for each of the scenarios, each run corresponding to a weighting of one of the KPIs at 100%, as shown below:

1 Reduced overall delay weighted at 100%

2 Reduced car growth rate weighted at 100%

3 Maximised person throughput weighted at 100%

4 Reduced vehicle emissions 100%.

See table 4.6 for the results of the analysis.

Table 4.6 Analysis and model output – Onewa Road, Auckland

Test no.	Contra-flow lane	KPI	Weighting	Model output	
				Appropriate treatment	Alternative treatment
1	Scenario 1	Overall delay	100%	Contra-flow bus lane	T2 lane
2	Scenario 1	Car growth	100%	Contra-flow bus lane	Bus lane
3	Scenario 1	Throughput	100%	T2 lane	T3 lane
4	Scenario 1	Emissions	100%	Contra-flow bus lane	T2 lane
5	Scenario 2	Overall delay	100%	T2 lane	T3 lane
6	Scenario 2	Car growth	100%	Bus lane	T3 lane

Test no.	Contra-flow lane	KPI	Weighting	Model output	
				Appropriate treatment	Alternative treatment
7	Scenario 2	Throughput	100%	T2 lane	T3 lane
8	Scenario 2	Emissions	100%	T2 lane	T3 lane

4.2.3.4 Discussion

The model showed that the contra-flow bus lane would be an appropriate treatment to reduce overall delay, future car growth and emissions.

However if this treatment was excluded from consideration, another appropriate treatment would be a T2 lane. The model outcome indicated that the currently installed T3 lane had resulted in under-utilisation of the road. The reason for the installation of a T3 lane could be the high number of vehicles turning into and out of schools and side roads, which would be highly disruptive to the smooth operation of the T2 lane.

4.2.4 Case study 4: Remuera Road, Auckland

4.2.4.1 Background

Remuera Road is a four-lane urban arterial road with no median or berms. There are four road segments, with five signalised intersections between Omahu Road and Middleton Road. The spacing between intersections varies from 200m to 700m.

4.2.4.2 Treatment installed by the RCA

The implemented treatment on site is a bus lane. However, a recent analysis by Auckland Transport (2011) re-evaluated the corridor and identified three treatments, the most appropriate being a bus lane followed by a T3 lane and then a T2 lane. The difference in productivity rating of these treatments is small.

Table 4.7 Model inputs – Remuera Road, Auckland

Traffic volume (veh/h)	Buses (bus/h)	Bus occupancy	Car occupancy	Proportion T2 (%)
1110	23	31	1.29	20%

4.2.4.3 Analysis and model outputs

The site operation was analysed for one scenario (‘contra-flow lane not allowed’), as there was no possibility of a contra-flow lane within the existing location due to side fictions of retail/commercial outlets.

A total of four runs were completed for this scenario as described above. Each run corresponded to a weighting of one of the KPIs at 100%, as shown below:

1 Reduced overall delay weighted at 100%

2 Reduced car growth rate weighted at 100%

3 Maximised person throughput weighted at 100%

4 Reduced vehicle emissions 100%.

See table 4.8 for results of the analysis.

Table 4.8 Analysis and model outputs – Remuera Road, Auckland

Test no.	KPI	Weighting	Model output	
			Appropriate treatment	Alternative treatment
1	Overall delay	100%	T2 lane	T3 lane
2	Car growth	100%	Bus lane	T3 lane
3	Throughput	100%	T2 lane	T3 lane
4	Emissions	100%	T2 lane	T3 lane

4.2.4.4 Discussion

The analytical model showed that a T2 lane would be an appropriate treatment to reduce the overall delay, total people throughput and emissions.

However, if the objective was to reduce the future growth of car volumes, then the appropriate treatment would be a bus lane, followed by a T3 lane as an alternative treatment. The objective of reducing growth in car volumes is consistent with both – the implemented treatment and the results of the Auckland Transport (2011) analysis.

4.2.5 Case study 5: Tamaki Drive, Auckland

4.2.5.1 Background

Tamaki Drive is both a strategic urban arterial and a scenic route, hugging the Auckland coastline. It is a four-lane corridor, with no berms and a flush median, which lacks continuity with no signalised intersections on the 1km segment of the road analysed for the research.

4.2.5.2 Treatment installed by road controlling authority

The implemented treatment on site is a T2 lane. However, a recent analysis by Auckland Transport (2011) re-evaluated the corridor and identified three treatments, the most appropriate being a T2 lane followed by a T3 lane and then a bus lane. These three treatments showed significant differences in performance.

4.2.5.3 Model inputs

For the analysis, the number of buses had to be increased to 15 buses per hour, as this is the minimum bus volume required by the model.

Table 4.9 Model inputs – Tamaki Drive, Auckland

Traffic volume (veh/h)	Buses (bus/h)	Bus occupancy	Car occupancy	Proportion T2 (%)
1440	13	27	1.29	21%

4.2.5.4 Analysis and model outputs

The site operation was analysed for two scenarios:

1 With the contra-flow lane as a valid option

2 If the contra-flow lane is not allowed.

A total of four runs were completed for each of the scenarios described above. Each run corresponded to a weighting of one of the KPIs at 100%, as shown below:

1 Reduced overall delay weighted at 100%

2 Reduced car growth rate weighted at 100%

3 Maximised person throughput weighted at 100%

4 Reduced vehicle emissions 100%.

See table 4.10 for results of the analysis

Table 4.10 Analysis and model outputs – Tamaki Drive, Auckland

Test no.	Contra-flow lane	KPI	Weighting	Model output	
				Appropriate treatment	Alternative treatment
1	Scenario 1	Overall delay	100%	Contra-flow bus lane	T2 lane
2	Scenario 1	Car growth	100%	Contra-flow bus lane	Bus lane
3	Scenario 1	Throughput	100%	T2 lane	T3 lane
4	Scenario 1	Emissions	100%	Contra-flow bus lane	T2 lane
5	Scenario 2	Overall delay	100%	T2 lane	T3 lane
6	Scenario 2	Car growth	100%	Bus lane	T3 lane
7	Scenario 2	Throughput	100%	T2 lane	T3 lane
8	Scenario 2	Emissions	100%	T2 lane	T3 lane

4.2.5.5 Discussion

The model showed that the contra-flow bus lane would be an appropriate treatment to reduce overall delay, future car growth and emissions. If the maximisation of the people throughput is the aim, a T2 lane is more appropriate.

However if the contra-flow lane is not allowed, the most appropriate treatment would be a T2 lane. Therefore the analytical model is consistent with both the RCA's decision to install the T2 lane, and with the results of the Auckland Transport (2011) analysis. A bus lane would be an appropriate solution for reducing the growth of car traffic.

4.2.6 Case study 6: Adelaide Road, Wellington

4.2.6.1 Background

Adelaide Road is a four-lane urban arterial road with a flush median lacking continuity and no berms. It consists of a 600m road segment from Hospital Road to Rugby Street, with signalised intersections at each end. A contra-flow lane cannot be considered due to a high-density urban environment with frontage shops.

4.2.6.2 Treatment installed by road controlling authority

The implemented treatment on site is a bus lane.

4.2.6.3 Model inputs

A few model inputs that were not available were replaced by model default values. These are marked with an asterisk (*) in the table below.

Table 4.11 Model inputs – Adelaide Road, Wellington

Traffic volume (veh/h)	Buses (bus/h)	Bus occupancy	Car occupancy	Proportion T2 (%)
1370	28	40*	1.40*	10%*

* Model default values.

4.2.6.4 Analysis and model outputs

The site operation was analysed for one scenario ('contra-flow lane not allowed').

A total of four runs were completed for this scenario as described above. Each run corresponded to a weighting of one of the KPIs at 100%, as shown below:

1. Reduced overall delay weighted at 100%
2. Reduced car growth rate weighted at 100%
3. Maximised person throughput weighted at 100%
4. Reduced vehicle emissions 100%.

See table 4.12 for the results of the analysis.

Table 4.12 Analysis and model outputs – Adelaide Road, Wellington

Test no.	KPI	Weighting	Model output	
			Appropriate treatment	Alternative treatment
1	Overall delay	100%	T2 lane	T3 lane
2	Car growth	100%	Bus lane	T3 lane
3	Throughput	100%	T2 lane	T3 lane
4	Emissions	100%	T2 lane	T3 lane

4.2.6.5 Discussion

The analysis showed that the bus lane, as installed by the RCA, was an appropriate treatment aiming at the reduction of car traffic growth. However if any one of the other KPIs were favoured, a T2 lane would be a preferred solution.

4.2.7 Case study 7: Kaiwharawhara Road, Wellington

4.2.7.1 Background

Kaiwharawhara Road is a four-lane urban arterial road with no median or berms. There is a 400m road segment from Old Porirua Road to Hutt Road with a signalised intersection at Hutt Road. A contra-flow lane is not viable due to the high-density industrial/commercial environment.

4.2.7.2 Treatment installed by road controlling authority

The implemented treatment on site is a bus lane.

4.2.7.3 Model inputs

For the analysis the number of buses had to be increased to 15 buses per hour, as 15 buses is the minimum bus volume required by the model. Model inputs which were not available were replaced by model default values. These are marked with an asterisk (*) in table 4.13.

Table 4.13 Model inputs – Kaiwharawhara Road, Wellington

Traffic volume (veh/h)	Buses (bus/h)	Bus occupancy	Car occupancy	Proportion T2 (%)
1360	8	40*	1.40*	10%*

* Model default values.

4.2.7.4 Analysis and model outputs

The site operation was analysed for one scenario ('contra-flow lane is not allowed').

A total of four runs were completed for this scenario as described above. Each run corresponded to a weighting of one of the KPIs at 100%, as shown below:

1 Reduced overall delay weighted at 100%

2 Reduced car growth rate weighted at 100%

3 Maximised person throughput weighted at 100%

4 Reduced vehicle emissions 100%.

See table 4.14 for results of the analysis.

Table 4.14 Analysis and model outputs – Kaiwharawhara Road, Wellington

Test no.	KPI	Weighting	Model output	
			Appropriate treatment	Alternative treatment
1	Overall delay	100%	T2 lane	T3 lane
2	Car growth	100%	Bus lane	T3 lane
3	Throughput	100%	T2 lane	T3 lane
4	Emissions	100%	T2 lane	T3 lane

4.2.7.5 Discussion

The analysis showed that the bus lane, as installed by the RCA, was an appropriate treatment aiming at the reduction of car traffic growth. However if any of the other KPIs were favoured, a T2 lane would be a more appropriate solution.

4.2.8 Case study 8: Main North Road, Christchurch

4.2.8.1 Background

Main North Road is a four-lane urban arterial road with no median or berms. There are five road segments from QEII Drive to Harewood Road (350m, 450m, 210m, 280m and 250m long), with six signalised intersections.

4.2.8.2 Treatment installed by the RCA

The implemented treatment on site is a bus lane.

4.2.8.3 Model inputs

For this case study, some model inputs were not available and were replaced by model default values. These are marked with an asterisk (*) in table 4.15.

Table 4.15 Model inputs – Main North Road, Christchurch

Traffic volume (veh/h)	Buses (bus/h)	Bus occupancy	Car occupancy	Proportion T2 (%)
1120	22	40*	1.40*	10%*

*Model default values.

4.2.8.4 Analysis and model outputs

The site operation was analysed for one scenario ('contra-flow lane not allowed').

A total of four runs were completed for this scenario as described above. Each run corresponded to a weighting of one of the KPIs at 100%, as shown below:

- Reduced overall delay weighted at 100%
- Reduced car growth rate weighted at 100%
- Maximised person throughput weighted at 100%
- Reduced vehicle emissions 100%.

See table 4.16 for results of the analysis.

Table 4.16 Analysis and model outputs – Main South Road, Christchurch

Test no.	KPI	Weighting	Model output	
			Appropriate treatment	Alternative treatment
1	Overall delay	100%	T2 lane	T3 lane
2	Car growth	100%	Bus lane	T3 lane
3	Throughput	100%	T2 lane	T3 lane
4	Emissions	100%	T2 lane	T3 lane

4.2.8.5 Discussion

The analysis showed that a T2 lane would be an appropriate treatment to reduce an overall delay, total people throughput and emissions. However if the objective was to reduce the future growth of car volume, the appropriate treatment would be a bus lane, confirming the RCA's preference.

4.2.9 Case study 9: Papanui Road, Christchurch

4.2.9.1 Background

Papanui Road is a four-lane urban arterial road with no median or berms. There are five road segments from Harewood Road to Bealey Avenue (450m, 1200m, 350m, 170m and 1000m long), with six signalised intersections.

4.2.9.2 Treatment installed by the RCA

The implemented treatment on site is a bus lane.

4.2.9.3 Model inputs

For this case study, some model inputs were not available and were replaced by model default values. These are marked with an asterisk (*) in table 4.17.

Table 4.17 Model inputs – Papanui Road, Christchurch

Traffic volume (veh/h)	Buses (bus/h)	Bus occupancy	Car occupancy	Proportion T2 (%)
1130	22	40*	1.40*	10%*

*Model default values.

4.2.9.4 Analysis and model outputs

The site operation was analysed for one scenario ('contra-flow lane not allowed').

A total of four runs were completed for this scenario as described above. Each run corresponded to a weighting of one of the KPIs at 100%, as shown below:

1 Reduced overall delay weighted at 100%

2 Reduced car growth rate weighted at 100%

3 Maximised person throughput weighted at 100%

4 Reduced vehicle emissions 100%.

See table 4.18 for results of the analysis

Table 4.18 Analysis and model outputs – Papanui Road, Christchurch

Test no.	KPI	Weighting	Model output	
			Appropriate treatment	Alternative treatment
1	Overall delay	100%	T2 lane	T3 lane
2	Car growth	100%	bus lane	T3 lane
3	Throughput	100%	T2 lane	T3 lane
4	Emissions	100%	T2 lane	T3 lane

4.2.9.5 Discussion

The analysis showed that a T2 lane would be an appropriate treatment. It would reduce an overall delay, total people throughput and emissions. However if the objective was to reduce the future growth of car volume, the appropriate treatment would be the bus lane, as installed by the RCA.

4.3 Internal review

An internal review by AECOM's research team sought to test and calibrate the analytical model against the results of implemented and monitored bus priority treatment case studies from Auckland, Wellington and Christchurch. The results of the analytical model output and case study findings were compared and any changes were undertaken prior to the external peer review process. It has to be noted that the Christchurch case studies predate the 2010–11 earthquakes and therefore the data used by the research team has not been affected.

4.4 Peer review

An independent peer reviewer was engaged at the outset of the research project. This was to ensure the peer reviewer was kept consistently up to date with the progress of the development of the analytical model.

At the conceptual development stage, the peer reviewer provided advice on:

- short-listing of suitable intersection and road segment treatments for the New Zealand environment
- the feasibility of the overall concept of the analytical model.

The algorithms for calculating KPIs for the intersection model and the transport corridor model were also reviewed by the peer reviewer during the analytical development stage.

4.5 Conclusion

The research team supported by the steering group and peer reviewers concluded that the analytical model was fit for purpose. Verification of the analytical model was achieved by comparing the outputs of the model against bus priority treatment case studies. This involved testing the case studies to determine and explain the differences between the model outputs and the implemented treatments on site.

The model findings substantiated the decisions made by the RCAs regarding the installation of bus priority treatments. Where differences did occur between the model output and the RCA's implemented treatments, the model was able to explain the philosophy applied by the RCAs through the interruptions of the four KPI weightings. In some cases, the adopted scheme implemented on site was decided by a political directive, rather than technical considerations. The model demonstrated that by adopting different objectives of the treatment, eg reduction of car growth vs emission reduction, the resulting treatments for a specific site would differ.

5 Launching the bus priority assessment tool (BAT)

5.1 Introduction

The BAT is a computerised tool kit developed as the product of this research project on the basis of the analytical model discussed in chapter 3. A copy of the *BAT user manual* is available in appendix D of this report.

5.2 Purpose of BAT

BAT was developed in order to concur with the research objective of providing a practical, applicable and easy to disseminate procedure for selecting appropriate bus priority treatments. The BAT enables users, such as local authorities and practitioners, to identify appropriate bus priority treatments for any given situation. BAT is capable of providing broad indications of appropriate bus priority treatments based on average values and situations. The default values adopted in the model are averages and are expected to represent most of the situations with adequate accuracy. However, there may be situations falling outside the acceptable range. It is therefore necessary to subject the treatments identified by the model to a PFR or SAR analysis as required by the NZTA, before making a decision on implementation.

5.3 Development of BAT

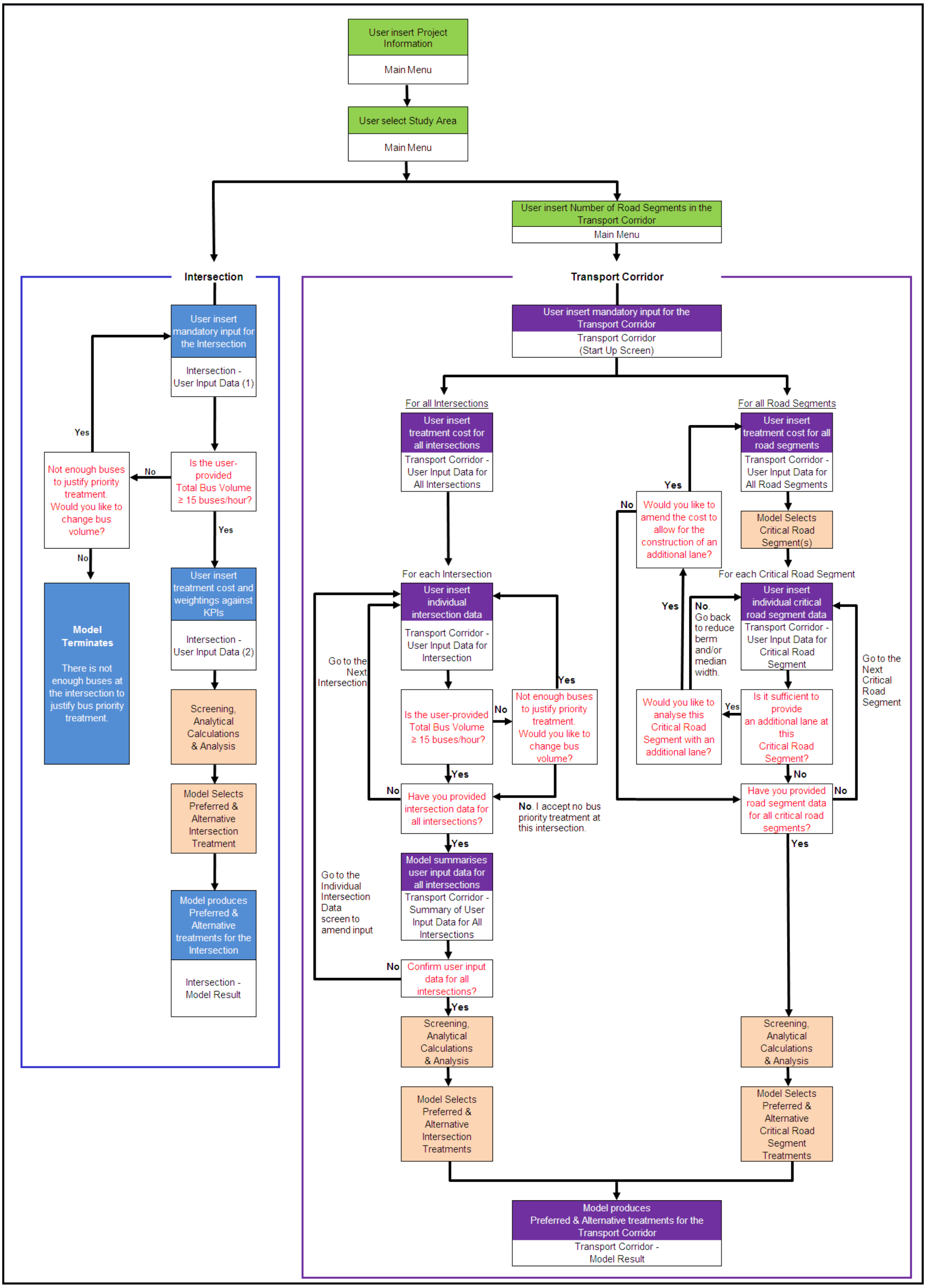
BAT was created in Microsoft Excel 2007 with built-in macros, which were developed using Visual Basic for Applications (VBA). The decision-assisting framework shown in figure 5.1 is the backbone of BAT, which follows the three stages of the analytical toolkit: input, process and output.

5.4 BAT user manual

To provide step-by-step instructions guiding the user through the use of BAT, the AECOM research team compiled a user manual, covering the following topics:

- software requirement and settings
- concept of the BAT
- information required before using BAT
- step-by-step interface guide
- frequently asked questions (FAQ).

Figure 5.1 BAT decision assisting process



6 Conclusions and recommendations

6.1 Conclusions

This research focused on the development of a practical decision-assisting tool for identifying appropriate bus priority interventions for any given situation. The interventions are based upon route and intersection characteristics to reduce congestion and improve trip time reliability in the major urban areas of Auckland, Wellington and Christchurch.

The research outcome was the development of an easily disseminated computerised application for practitioners to identify appropriate bus priority treatments following the three stages of input, process and output. This was achieved through the development of BAT. BAT is unique in that it was specifically designed and developed for this research using Microsoft Excel 2007 and Visual Basic for Applications (VBA) and therefore it is not an off-the-shelf modelling product.

The researchers openly acknowledge that BAT is only a first generation application tool developed with existing data, and that any solution which BAT recommends will entail a multi-faceted suite of influences and decisions which will determine the actual treatment provided on site.

The benefit BAT offers in its current development phase is the identification of potential bus priority interventions on a specific route, based on the level of detail available and provided by users as input into BAT. The ability to understand the potential cost and benefits associated with each option also offers an added advantage to users in determining likely budgets and social economic factors associated with the treatment identified.

6.2 Applying the analytical model in the New Zealand context

The core function in the development of the BAT model has been to draw on global and international best practices to identify appropriate bus priority interventions applicable to the New Zealand context. Of the 22 bus priority treatments identified, only 11 were deemed to be applicable to the New Zealand context (specifically the metropolitan regions of Auckland, Christchurch and Wellington). The development of BAT as a tool to assist users is capable of providing broad indications of potential priority bus interventions for any given urban situation based on average values. BAT has been developed to represent typical urban intersections and arterials in New Zealand.

6.3 Implementation issues and barriers to the application of BAT

This section identifies potential implementation issues and barriers regarding the application of BAT and recommends how these issues may be overcome by RCAs.

6.3.1 Data collection and limitations

The model relies on a large number of inputs influencing the quality of outputs. The accuracy of these inputs is essential to the veracity of the model and the quality of output desired. The lack of accurate data will pose varying limitations on the results which could undermine the benefits of BAT in assisting users make decisions.

The following areas require due consideration to ensure the accuracy of inputs.

1. **The site-specific inputs**

   Section 3.2 outlined the input data necessary for BAT. The BAT check list (appendix D) should be disseminated to RCAs, and third parties collecting and monitoring traffic data for RCAs. A physical definition of the study area is essential to determine actual conditions on site, with tube count[2]s and traffic signal settings as a useful supplement.

2. **How the user modifies the default values that are accessible to them**

   The user can override the default values, which are displayed on the screen. Site-specific data is a preferred input to the generalised default values provided in the model.

   The output will benefit substantially if the user has a good understanding of the site and is able to provide a sound set of input data. If the user relies on the default values, the output will tend to represent a generalised situation rather than the specific site. Although much attention was paid by the research team to identifying the most representative situations and developing a robust set of default values and the algorithms, it has to be accepted that there could be sites and conditions where the operational situations will materially differ, leading to sub-optimum outputs of the model. It is therefore necessary to subject the treatments identified by the model to a PFR or SAR analysis as required by the NZTA, before the decision on implementation is reached.

3. **The values used as inaccessible default values**

   Some of the default values are inaccessible to the user. The research team decided to protect these inputs as they are less understood by the user. If they are substituted with the values outside of the acceptable range, the model output might be distorted.

   The research team will be able to change the inaccessible default values if users provide substantiation of such changes.

6.3.2 Software capabilities

BAT has been developed using Microsoft Excel 2007 and has not been tested using other Excel versions.

6.4 Further research

This research is a pioneering work, and as such sets the base for development, but does not provide all the answers. The research team has developed a ‘live’ decision assisting tool available as a desktop application. BAT’s current design is relevant to urban situations as at 2010/11 and is designed to enable future updates and modifications to the default values as new ideas evolve and data becomes available. It is expected that after its release by the NZTA, it will be tested by end users, and their feedback will be used for further refinements.

The potential for further research and refinement, with the ability to provide decision makers with more robust decision-assisting capabilities, may include the following:

[2] Tube counts collect traffic flow data on streets. They count axles rather than vehicles, but can classify vehicles based on the pattern of axle detections to determine the proportion of vehicles by type, ie motorcycle, car and heavy commercial vehicles.

- Better information could be provided on the default values and different types of bus priority interventions.
- The toolkit could incorporate hyperlinks to the source material to provide information on the used default values in the analytical model and guidance on various bus priority interventions to better understand the rationale of the selected intervention. This would result in having all the information at one's finger tips, thus reducing the need for the production of a hard copy manual, saving costs associated with printing and distribution.
- The tool kit could be enhanced to offer help instructions.
- The toolkit could incorporate built-in help functions to assist the user in applying the computerised tool. Again this would provide all the data at one's finger-tips and reduce the need for printing and distribution of manuals.

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Appendix A: Literature review

A1 Introduction

A1.1 Purpose

The purpose of the literature review was to assess the performance and effectiveness of established bus priority interventions through a selective review of case studies from New Zealand, Australia, the UK and USA and identify the key lessons applicable to the New Zealand situation.[3]

The objectives were to:

- identify a wide range of bus priority treatments, potentially suitable for application on the New Zealand urban arterials and motorways
- identify and explore bus priority projects, which give a quantified description of the prevailing situation before the implementation of a bus priority treatment, the specifics of the treatment and the quantified benefits resulting from the treatment
- produce a brief description of each of the relevant schemes presenting the initial situation, the applied treatment and the quantified results.

The review enabled the identification and development of screening criteria, to be used during planning stages, for the successful implementation of managed lanes in New Zealand. Performance targets and effectiveness indicators for operational measures were also identified (eg increases in the number of buses in HOV lanes and increased vehicle occupancy rates) where data existed.

A1.2 Scope of work

The work was based on:

- data collection
- identifying the types of bus priority interventions commonly recognised internationally, to eliminate ambiguities
- summarising New Zealand's legal framework for the establishment of special vehicle lanes
- reviewing and identifying existing and proposed managed lane treatments in New Zealand
- assessing lessons learnt through selected case studies of bus priority interventions implemented in New Zealand, Australia, the UK and USA.

[3] The audience for this appendix was, in the first instance, the research team and project steering group. The aim was to inform members of the available data that had the potential to assist the team in undertaking milestone two of the research project, which was the development of the analytical model. Consequently, the information in this appendix is current as at the time of the research. The literature review was completed in 2010 and is based on material/references published and publicly available at the time.

A1.3 Literature review structure

This appendix comprises seven main sections:

1 Introduction, purpose and structure

2 Definition of bus priority interventions highlighting terminology for types of bus priority interventions available in New Zealand, Australia, the UK and USA

3 The legislative framework for the provision of special vehicle lanes in New Zealand

4 Development of bus priority interventions in New Zealand

5 Case studies of bus priority interventions highlighting a selective review of case studies and a core set of attributes for the success of bus priority interventions in New Zealand, Australia, the UK and USA.

6 Lessons learnt from the case studies: a summary of the case studies and international findings on bus priority interventions

7 A summary of bus priority interventions and their planning and implementation, drawing on parallel lessons learnt through New Zealand and international experience.

A2 What types of bus priority interventions exist?

A2.1 What is a bus lane?

A bus lane is a traffic lane intended for the use of buses.

Bus lanes are marked for the primary use of buses, but cyclists and motorcyclists may also be allowed to use the lane.

Typically, bus lanes operate adjacent to general traffic and are demarcated using signage and road markings. Bus lanes may use coloured surface pavement markings to distinguish them from general purpose lanes (see figure A2.1).

Figure A2.1 Examples of bus lanes

Bus lane, Manukau City, New Zealand
Source: Harvey 2006

Bus lane, UK
Source: FreeFoto.com

A2.2 Contra-flow bus lanes

There are also contra-flow bus lanes where all general traffic travels in one direction and only buses travel in the opposing direction. This is generally introduced where there are one-way gyratory systems. Figure A.2.2 illustrates examples of contra-flow bus lanes in the UK.

Figure A2.2 Examples of contra-flow bus lanes in the UK

Source: AECOM 2010

These contra-flow bus lanes operate 24 hours a day and require physical segregation at the start and end. While they are good at providing cuts in journey time and circumnavigating gyratory systems, there are issues with the operation of these lanes. The design of the entry and exit can be problematic. Limited space can also provide safety issues for cycles in the lane and private vehicles wishing to access premises and homes from the bus lane. Operation of the lane, and driver and pedestrian behaviour, also need to be considered given the increased chance of pedestrian/bus conflicts especially where a lane operates in contra-flow. In these instances collisions tend to be more severe for pedestrians, given the size of the vehicle and generally higher speeds.

A2.3 What is a busway?

Busways are special types of bus-only lanes that are generally segregated from general purpose lanes.

Busways are usually separated from the general traffic by physical barriers or grade separation (rather than just coloured lane markings). This allows buses to bypass traffic and to operate at higher speeds and prevents general traffic from utilising a busway.

Busways are one of many components of bus rapid transit (BRT) systems. A number of international examples of busways exist, including the widely publicised Curitiba BRT.

Northern Busway, which recently opened on state highway (SH) 1, is the first busway within New Zealand. Access is limited to buses only; however, provision for conversion to a high occupancy vehicle (HOV) lane has been considered within the design should this be warranted at a later date. Figure A2.3 provides an illustration of a busway within an urban environment/state highway environment.

Figure A2.3 Examples of busway

SH1 Northern Busway, Auckland, New Zealand
Source: www.nzherald.co.nz/topic/story.cfm?c_id=348&objectid=10489998&ref=rss)

South-East Busway and stations, Brisbane, Australia
Source: http://en.wikipedia.org/wiki/File:South-East_Busway,_Brisbane.jpg

A2.4 What is a bus gate?

Bus gates are placed at a point on a road to restrict access to buses only

A bus gate is installed by legal order and can either rely on compliance with signing, traffic signals, or transponder-operated bollards[4]. They are generally used to remove through-traffic from an area, allowing buses special access such as in town/city centres.

Figure A2.4 Examples of bus gate enforcement treatments, Oxford UK

Bus gate enforcement using raised bollards

Enforcement using bus only signs

Source: AECOM 2010

[4] Automatic bollards installed to restrict access for non-permitted vehicles will lower for permitted vehicles fitted with transponders (devices designed to receive a specific signal and automatically transmit a specific reply).

Key to the success of this type of scheme is compliance and enforcement. Experience has shown that such measures require plenty of advance signing to ensure vehicles other than buses are directed away before the gate point. The use of retractable bollards is now rare as they have proved to be expensive to maintain and the time spent moving up and down can cause unnecessary delays to buses. Figure A2.4 illustrates examples of these two types of bus gate enforcement restrictions.

A2.5 What is a bus-only link?

A bus-only link provides priority bypass to buses at intersections.

A variation on bus lanes and bus gates is the provision of bus-only links over short sections of road. These allow buses to bypass junctions and areas prone to congestion. This form of treatment is very much site specific as it depends on land being available and the removal of kerbside parking or other general traffic lanes. Figure A2.5 illustrates bus-only links in Bristol and in Auckland.

Figure A2.5 Examples of bus-only links, Bristol, UK and Auckland, New Zealand

Bristol, UK

Source: AECOM

Northcote Road/Lake Road roundabout, Auckland, New Zealand

Source: Google maps

A2.6 What is a high occupancy vehicle (HOV)?

A HOV is a passenger vehicle carrying more than a specified minimum number of passengers. HOVs include carpools, vanpools, and buses. HOV requirements are often indicated as 2+, (two or more passengers required).

Source: www.vtpi.org/tdm/tdm61.htm

It is universally accepted that a HOV is a vehicle carrying two or more people.

The aim in providing priority to HOVs is to improve people-moving capacity (rather than vehicle-moving capacity) on congested motorways/corridors.

Strictly speaking, based on this definition, any vehicle (eg a light goods and/or heavy goods vehicle) with two or more persons is eligible to use a HOV lane.

A2.7 What are high occupancy vehicle lanes?

HOV lanes are limited to carrying high occupancy vehicles and certain other qualified vehicles.

Source: www.vtpi.org/tdm/tdm61.htm

HOV lanes aim to maximise the number of people travelling on a given carriageway by increasing the average number of vehicle occupants. The 'people carrying' capacity of a given road is increased through the provision of 'free' dedicated lanes, which support passenger transport modes (ie buses, vanpools) and vehicles carrying specific numbers of occupants (2+, 3+, 4+); as stated by road signage and/or road markings (see figure A2.6).

Single occupant vehicles (SOVs) are prohibited from using these dedicated lanes, to encourage more car sharing, reduce the number of SOV trips on the network, and thereby reduce congestion and emissions. This is also a method of utilising spare capacity in existing bus lanes.

HOV lanes established in the US highway network are typically located closest to the median and are separated by line markings or by other forms of access control (eg jersey barriers) (refer to Maunsell AECOM 2008).

Within New Zealand's urban environment, HOV lanes have been established in the far left lane adjacent to the kerbside pavements and are separated by line markings. The success of HOV lanes in delivering optimal benefits to road users depends on specific management tools. This is discussed in more detail in sections A4 and A5.

Figure A2.6 Examples of HOV lane configurations

Transit lane, Constellation Drive, Auckland
Source:
www.northshorecity.govt.nz/?src=/transport_and_roads/News/Transport-update.htm

HOV lane, USA example
Source:
http://ops.fhwa.dot.gov/freewaymgmt/publications/hov/11_Int_HOV_Conf_%20Proc.pdf)

In practice and in legislation within New Zealand the term 'transit lanes' has replaced 'HOV lanes'. Transit lanes by definition perform the same objectives as HOV lanes. In Australia, transit lanes allow cars with two or more passengers (T2 or T3) to use the lane as well as cyclists, taxis, emergency vehicles and motorcycles in most situations.

This paper refers to HOV lanes rather than transit lanes. A discussion on the use of this terminology (transit vs HOV) may be appropriate at a regional special vehicle lane forum.

A2.8 What are high occupancy toll (HOT) lanes?

HOT lanes provide free (or reduced cost) access for transit vehicles (ie buses) and other vehicles carrying the required number of passengers; and charge a fee to other vehicles not meeting the requirements.

Source: TRB International Perspectives on Road Pricing, Conference Proceedings 34.

HOT lanes can be considered to be a hybrid form of a HOV lane. HOT lanes perform the functions of 'free/no charge' HOV lanes, but also offer single occupant motorists the choice to either travel in a congested 'free' lane, or pay a toll in return for reduced travel time and enhanced travel time reliability (see figure A2.7).

HOT lanes are becoming a viable option in support of carpooling and public transport initiatives, while distributing any remaining capacity to other traffic.

HOT lane operations in the USA have been combined with value pricing initiatives, and can allow road authorities to manage congestion in real time. Tolls are adjusted throughout the day to ensure that all traffic in the HOT lane, including HOV traffic, is free-flowing.

Figure A2.7 Examples of HOT lanes

HOT lane, USA
Source: www.tfhrc.gov/pubrds/05jul/images/dor2.jpg

HOT lane, SR-91 Express Lanes, CA, USA
Source: www.tfhrc.gov/pubrds/05jul/images/dor2.jpg

A2.9 What are no-car lanes?

No-car lanes give priority for essential vehicles, facilitating the movement of goods as well as people in congested urban centres.

Source:
www.dft.gov.uk/pgr/regional/buses/bpf/busprioritythewayahead12/busprioritythewayaheadhtmlve1073?page=11

A no-car lane can be considered to be a hybrid bus lane. They have been introduced relatively recently to the UK as an alternative to bus lanes, where bus flows are too low to justify an exclusive lane (as reported in Maunsell AECOM 2008).

These lanes may offer added benefits through increasing road capacity in some situations by segregating wider vehicles from standard vehicle lanes. No other international application is known. The NZTA's (2007) *Travel demand management manual* has incorporated the use of a no-car lane for buses, freight and goods vehicles and motorcycles. Figure A2.8 illustrates no-car lane arrangements.

Figure A2.8 Examples of no-car lanes

No-car lane, UK
Source: Freefoto.com 2008

No-car lane, UK
Source: Freefoto.com 2008

A3 New Zealand legislation for special vehicle lanes

New Zealand legislation refers to any lane that seeks to give priority over a general traffic lane as a ‘special vehicle lane’. Two rules are relevant to the application of a special vehicle lane:

1 Land Transport (Road User) Rule 2004

2 Land Transport Rule: Traffic Control Devices 2004 (including amendments).

The Rules enable RCAs to identify and establish specific priority lanes (such as HOV lanes, bus only lanes, freight lanes, flexi-lanes and no-car lanes, ie a cycle lane or other). Neither Rule covers the establishment of a HOT lane.

The establishment of a HOT lane that imposes a road user toll is governed by the Land Transport Management Act 2003 (LTMA)[5]. Under sub-section 46(6) of this Act, an RCA can only establish a HOT lane if it is part of a road tolling scheme. Tolls imposed on the lane cannot be collected to manage day-to-day congestion. Tolls can only be collected under the LTMA to fund new roads (Chapman Tripp 2008).

A robust due diligence of HOT lane principles has yet to be established to clearly differentiate between a toll lane to manage day-to-day congestion, and more traditional forms of road pricing schemes which seek to finance infrastructure.

The outcome may be that the existing legislation for tolling is rightfully applicable to road pricing schemes which seek to generate revenue for new infrastructure, but would not be reasonably sound for meeting national goals for travel demand management (TDM) or traffic management (particularly increasing the efficiency of passenger transport and freight nationally) where demand for alternative management tools is required on specific transport corridors.

For further reference to the discussion on managed lanes and the New Zealand legislative and planning framework, the reader should refer to Maunsell AECOM (2008b).

[5] LTMA 2003, section 5, part 2, Tolling Roads Schemes and Concession Agreements

A4 Development of bus priority interventions in New Zealand

A4.1 Overview

The impetus for priority lane development within New Zealand occurred in the early 1980s with the Onewa Road transit lane as the first type of special vehicle lane to be operational within New Zealand.

The development and implementation of special vehicle lanes in New Zealand has primarily been focused on major metropolitan centres where significant reductions in the travel journey times of buses have been severely affected by increasing travel congestion associated with increased traffic volumes of SOVs. Since 1995, the implementation and planning of various types of special vehicle lanes has increased in response to the demand for improved travel journey times for buses and alternative choices for travel (bus or HOV) on congested sections of the network.

Table A4.1 provides a chronological history of special vehicle lane development in New Zealand. This table focuses on special vehicle lanes which have been implemented over a total or combined length of >1.5km.

Table A4.1 A chronological history of special vehicle lanes in New Zealand (>1.5km)

Location Region Operator	Implementation date	Type of managed lane (>1.5km)	Key feature
Onewa Road, Auckland North Shore City Council	1982	HOV lane 3+	Eastbound only, kerbside lane, AM operation, HOV 3+ occupants (cars), taxis
The Esplanade, Wellington Hutt City Council	1995	Bus and taxi lane	Non-adjacent kerbside AM and PM peak operation only
Dominion Road, Auckland Auckland City Council	1998	Bus lane	Kerbside bus lane, peak directional AM and PM periods only
Great South Road, Auckland Auckland City Council & Manukau City Council	2004	Bus lane	Kerbside bus lane, peak directional AM and PM periods only
Bader Drive, Auckland Manukau City Council	2005	Bus lane	Kerbside bus lane, peak periods only
Mt Eden, Auckland Auckland City Council	1998	Bus lane	Kerbside bus lane, peak directional AM and PM periods only
Constellation Drive, Auckland North Shore City Council	2005	HOV lane 3+	Kerbside lane, peak periods only, HOV 3+ occupants (cars), taxis
Mana Esplanade, Wellington NZTA	2005	HOV lane 2+	Kerbside lane, AM and PM weekday and weekend operation, HOV 2+ occupants (cars)
Forrest Hill Road, Auckland North Shore City Council	2007	Transit lane	Kerbside lane, peak periods only, HOV 3+ occupants (cars), taxis

Location Region Operator	Implementation date	Type of managed lane (>1.5km)	Key feature
Remuera Road, Auckland Auckland City Council	2008	Bus lane	Kerbside bus lanes, peak directional AM and PM periods only,
Northern Busway Auckland NZTA	2008	Busway	Buses and potential HOVs
Main North Road, Christchurch Christchurch City Council & NZTA	2010	Bus lane	Buses, motorcycles, cyclists
Papanui Road, Christchurch Christchurch City Council	2010	Bus lane	Buses, motorcycles, cyclists
Main South Road, Christchurch Christchurch City Council & NZTA	Planned	Bus lane	Buses, motorcycles, cyclists
Colombo Street (south), Christchurch Christchurch City Council	Planned	Bus lane	Buses, motorcycles, cyclists
Riccarton Road, Christchurch Christchurch City Council	Planned	Bus lane	Buses, motorcycles, cyclists
Ferry Road/Main Road, Christchurch Christchurch City Council	Planned	Bus lane	Buses, motorcycles, cyclists
Queenspark Route, Christchurch Christchurch City Council	Planned	Bus lane	Buses, motorcycles, cyclists

This section reviews and provides a contextual framework for the development of managed lanes in New Zealand, beginning with a discussion on the experience and development of the various types of managed lanes identified in section A4.2 within the following cities and concluding with a discussion on the status of long-term managed lanes networks being established within New Zealand.

- Auckland
- Christchurch
- Dunedin
- Wellington
- Hamilton
- New Plymouth
- Queenstown
- Nelson

Later sections of this paper focus on selected individual case studies to assess the 'lessons learnt' from various types of managed lanes currently proposed or in operation, to identify a core set of attributes of success in the implementation of managed lanes and how this compares to international findings for managed lanes.

A4.2 Development of bus priority interventions in New Zealand

A4.2.1 Bus lanes

Bus lanes were introduced to New Zealand over 10 years ago with Auckland City being the first city to introduce bus lanes on Mt Eden and Dominion Roads during the mid-1990s. Bus lanes are the most common form of managed lanes in New Zealand and have proven to be successful corridor measures with patronage levels in Auckland and Wellington having significantly increased, and as a result, so have bus frequencies. Figure A4.1 illustrates examples of bus lanes implemented on arterials and CBD locations in Auckland and Wellington.

Figure A4.1 Examples of New Zealand bus lanes

Bus lane, Manukau City
Source: Harvey 2006

Bus lane, Wellington's CDB
Source: AECOM 2008

Bus lanes are dedicated lanes for bus services at specified periods to overcome congestion along the roads. Lengths of a bus lane can vary between short sections on the approach to intersections that are matched to the length of stationary traffic queues, or longer continuous lengths between intersections. The longer continuous lanes have been implemented in Auckland and Wellington providing the benefits of a lane unaffected by the variability of traffic queues and speeds, hence improving the certainty and reliability of travel times. Christchurch City Council has implemented short sections of bus advance areas in operation with a number of studies commissioned to investigate the implementation of nearside bus lanes on Papanui Road, Main South Road and Main North Road (5.5km). Hamilton City Council has recently implemented two sections of bus bypass lanes on Anglesea Street (300m) and Hukanui Road (500m).

The majority of bus lanes in New Zealand operate during the morning and afternoon peak periods and require the removal of kerbside parking in order to operate efficiently. Most bus lanes are situated nearside in New Zealand with the exception of an offside bus and taxi lane operating on The Esplanade by Hutt City Council, and a shorter section of an offside bus only lane, existing on the North Shore at the intersection of Constellation Drive/northern motorway (northbound) where the lane is clearly marked for use by 'bus only' and fully green to improve visibility and prevent non compliance.

Most RCAs in New Zealand have restricted taxis from using bus lanes. Wellington City Council held a taxi trial in late 2008 on selected bus lane routes within Wellington City to assess operational and performance measures of taxis using special vehicle lanes. Pre-commencement of the trial required taxi driver training on lane usage, similar to training offered to bus drivers in the Auckland region. Taxi use of a bus lane is limited to a section of The Esplanade, Petone and the Onewa Road transit lane, in North Shore City. Figure A4.2 illustrates Hutt City Council's bus and taxi lane in Petone.

Bus lanes also provide space for cyclists and motorcycles unless specifically excluded by a sign. Austroads' recommended design widths for bus lanes are 3m and 4.2m or greater. The 3m wide bus lane discourages any passing manoeuvres between buses and cyclists, whereas the wider 4.2m lane is the minimum safe width for the bus to overtake a cyclist within the lane.

Bus lane configurations across the country have largely been dependent on the existing corridor width and on the ability to widen an existing transport corridor. The first generation bus lanes were implemented within the available road space and are often 3m wide with the removal of kerbside parking and minor road works where necessary. In light of the design widths and increased users of the lane, current generation bus lane schemes may require higher levels of road widening or reallocation of a general traffic lane to a bus lane for either peak hour or 24-hour operation.

Figure A4.2 Example of offside bus and taxi lane, The Esplanade, Petone

Source: AECOM 2008

The lanes are given a painted colour treatment to improve their visibility; this is done at the start of each bus lane and at the left turn at an intersection to the side street. Fifty metres is the commonly observed distance[6] prior to a left turn into a side street or intersection and not more than 100m apart. The lanes are also marked with a longitudinal continuous white lane line and painted white text in the lane itself. Roadside signage indicating the bus lane is also installed at regular intervals of 150m to 200m and at each side road.

The standards for special vehicle lanes, which were prepared for the Auckland Bus Priority Initiatives Steering Group (BPISG) in 2005, have been used for the design of the pavement markings and signage of bus lanes within the Auckland region. These standards have also been applied across New Zealand at the request of the NZTA in order to move towards a national standard for pavement marking, surface colouring and signage of special vehicle lanes (refer to figure A4.4).

[6] North Shore City Council is an exception with 60m turning prior to an intersection. This applies to both bus and transit lanes.

A4.3 Busway

Northern Busway, which recently opened on SH1, is the first purpose-built busway within New Zealand. Access is limited to buses only; however, provision for conversion to a HOV lane has been considered within the design should this be warranted at a later date (see figure A4.3).

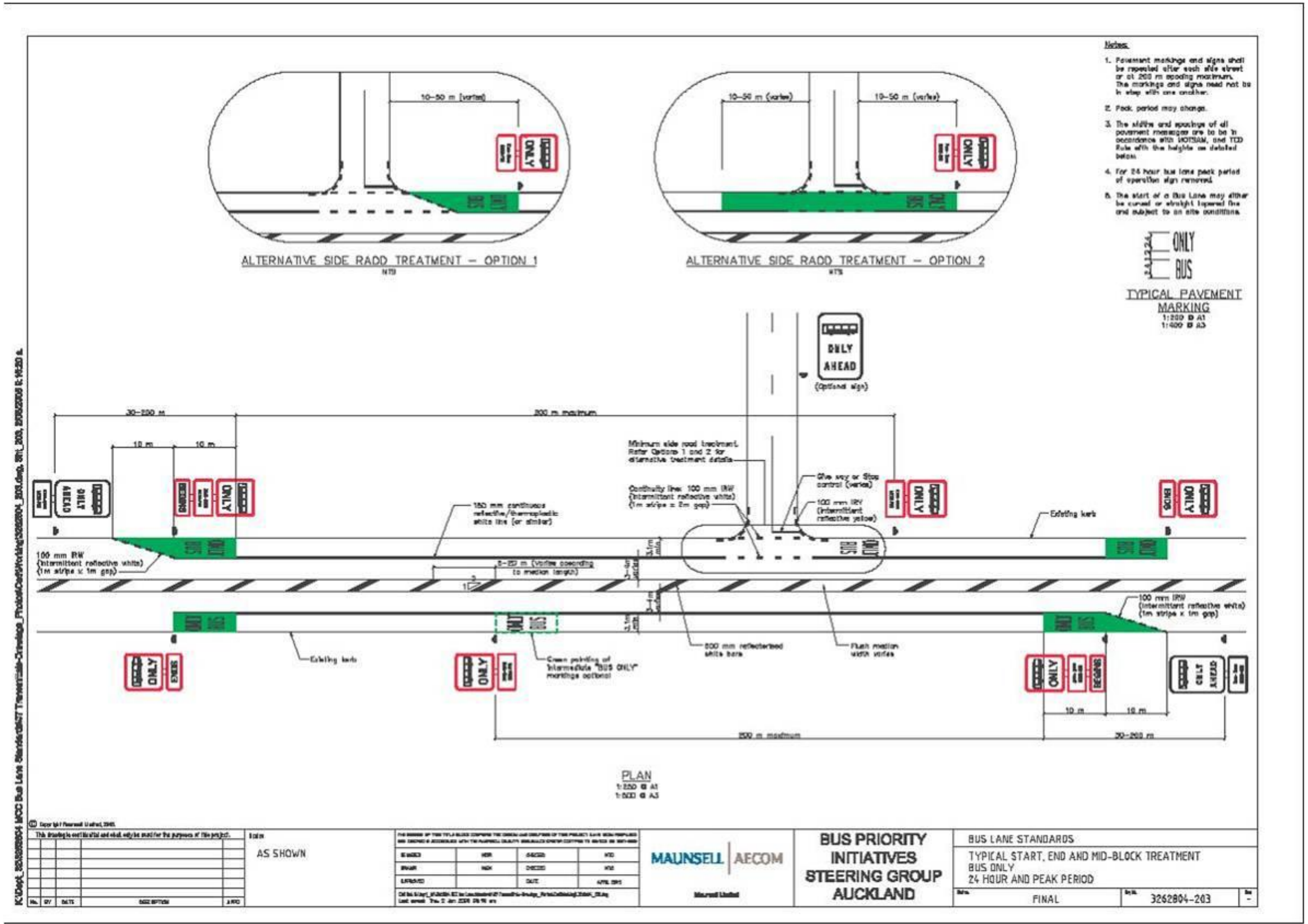
There has been wider consideration of busway facilities, for example *the Wellington region, Ngauranga to airport strategic study* (Opus 2008) identified an option to provide a segregated busway within the Wellington CBD which in future could potentially be further upgraded to support a light rail system.

Figure A4.3 Northern Busway, Auckland

Riding Auckland's Northern Busway approaching Sunnynook bus station
Source: AECOM 2008

Riding the Northern Busway
Source: AECOM 2008

Figure A4.4 Example of bus lanes surface colouring, pavement marking and signage (BPISG 2005)



A4.4 HOV lanes

Few HOV lanes have been implemented in New Zealand compared with bus lane development to date. This reflects the inherent nature of policies which have largely focused on improving passenger travel and travel journey times of buses on key arterial routes.

North Shore City Council has taken the lead in the implementation of HOV lanes, following the successful implementation of the Onewa Road transit lane. More recently, the NZTA has sought to provide T2 priority at motorway on-ramps for motorists entering Auckland's state highway, as part of its ramp metering programme to manage the flow on state highway corridors. The Northern Busway may also allow HOVs to use the facility following a review on the performance and operation of buses within the corridor (NZTA 2007).

Wellington City Council has also identified the potential need for HOV lanes on specific corridors where bus volumes would not warrant a dedicated facility, but buses and other users would benefit from the provision of an HOV lane (refer to section A4.6, case study 3).

Wider consideration of HOV provisions is occurring as a result of recent national and regional strategies and policies which require RCAs to provide an appropriate level of support to HOVs within and across regions.

For RCAs which are considering, or have implemented, an HOV lane, there is the realisation that HOV provisions can offer greater flexibility to the RCA over bus lanes in that a RCA has the ability to adjust vehicle numbers within the lane as required. This is a significant management tool. It is likely in future that a number of early bus lane schemes, implemented in cities where predicted bus frequencies have not increased, could be converted to HOV lanes based on performance indicators of the scheme and political mandates.

North Shore City Council has developed its own design guidelines for the provision of HOV lanes on its arterial network. Copies of these guidelines are available from the council.

The standards for special vehicle lanes (BPISG 2005), have been used for the design of pavement markings and signage of bus lanes within the Auckland region. These standards have also been applied across New Zealand at the request of the NZTA in order to move towards a national standard for pavement marking, surface colouring and signage of special vehicle lanes (see figure A4.5).

A4.5 HOT lanes

As discussed in section A2, HOT lanes are a form of managed lanes which offer similar benefits to HOV lanes with the added opportunity to provide any available capacity within the facility to SOV users at a fixed or variable fee, subject to the time of day and the travel conditions in adjacent lanes.

No HOT lanes have been implemented in New Zealand, nor is there any legalisation to support HOT lanes as a demand management tool on existing corridors. Legalisation is focused on road tolling as a means of revenue generation to fund new infrastructure.

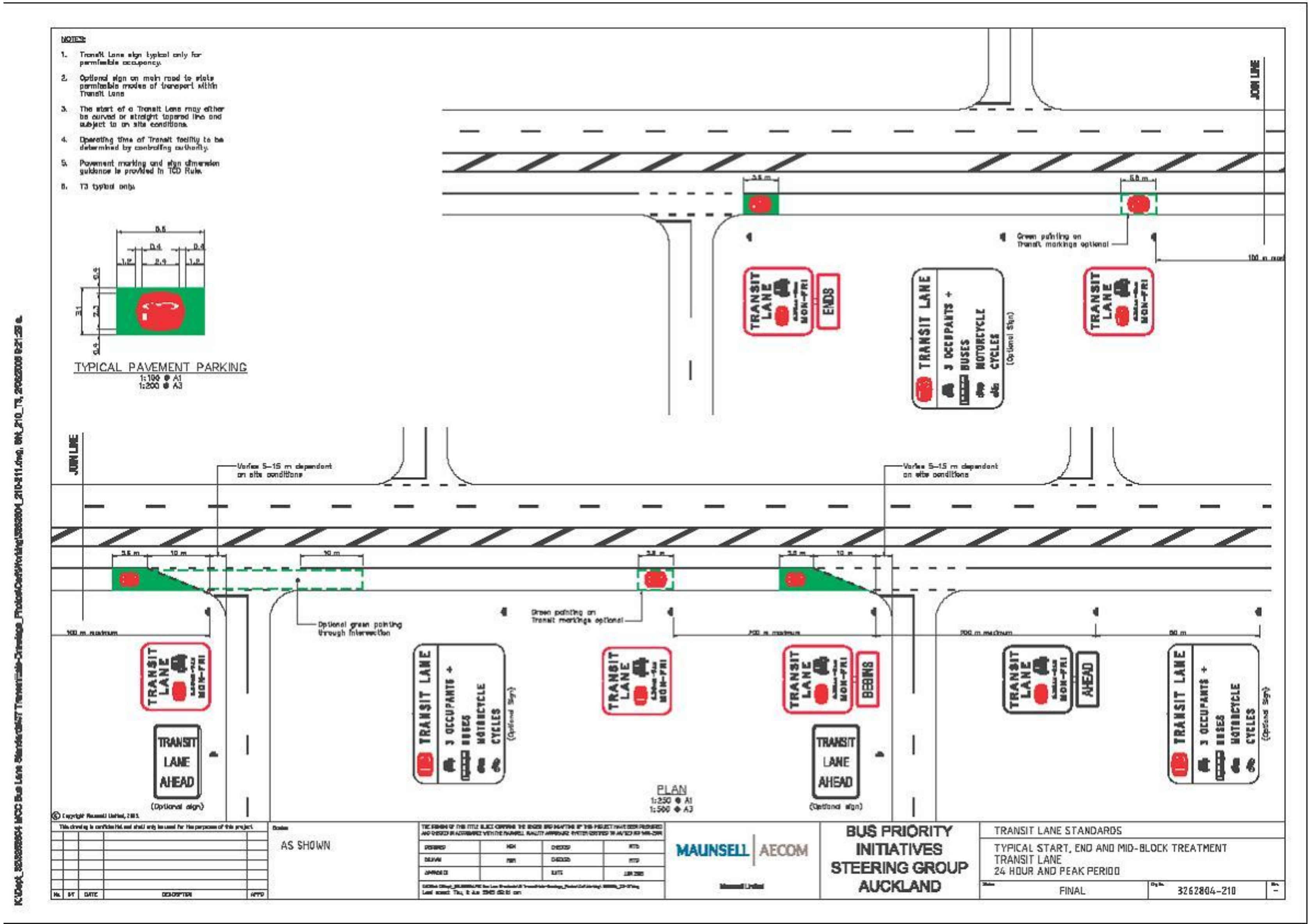
Several studies have investigated the implementation of HOT lanes.

The *Wakatipu transportation strategy* (Transit NZ et al 2006) stems from studies conducted to analyse the future growth of the region to 2026. These studies found that both the town centre and Frankton Rd (SH6A) were congested and if left unchecked would have a large negative effect on the viability and growth potential of Queenstown and neighbouring areas. The strategy suggests that the average speed along a 6km section of SH6A (which is regulated to 80km/h) is 50km/h during peak periods and if nothing is done this will reduce to 20km/h by 2026.

Currently underway is an options assessment report for bus priority lanes along SH6A. HOT and HOV lanes were initially discussed, but the approach has been to simplify the project to bus priority lanes only with the ability to expand the range of vehicles able to use the lanes in the future through variations in bylaws.

The Nelson to Brightwater study (Transit NZ 2006) identified that the travel time on SH6 which took eight minutes in 2006 would take 26 minutes in 2021, but only if the immediate projects were adopted. If not, the projected travel time would be even longer. The preferred package identified a HOV lane to operate during peak hours for use by HOVs, buses and freight vehicles. A second option identified a new road corridor to accommodate increased capacity. The total cost for improvements over the next 25 years is in excess of $140 million. Given the cost of the packages identified, there is realisation that a HOT lane may be necessary in the future.

Figure A4.5 An example of HOV surface colouring, pavement marking and signage (BPISG 2005)



A4.6 Network plans for managed lanes – a long-term vision

It is apparent from the literature review and discussion with RCAs that the impetus for priority lane development[7] within New Zealand did not stem from a planned long-term vision of a managed lanes network.

Instead, managed lanes have traditionally been implemented in an ad hoc tradition, often the result of one the following scenarios:

- as an alternative and viable form of travel to address constrained corridor congestion
- pre-empted alternative transport solutions implemented in advance of future corridor congestion
- an afterthought – this form of implementation is often the most detrimental to the success of a managed lane as later sections of this report will highlight.

This ad hoc approach to the development of managed lanes is still in practice in a number of locations within New Zealand. However, many RCAs have realised that due to the number of lanes being implemented within a city, there is a need for wider consideration of the form and function of managed lanes to be implemented and an understanding of which key transport corridors would benefit from these.

The following case studies highlight the development of the Auckland city's (2004) Buses First Programme; North Shore City's Northern Busway and bus priority measures (NSCC 2006); Wellington City Council's (2007) *Choose to take the bus* and the CCC and ECan's (2006) *Metro strategy 2006–2012*. These programmes have all been developed to various levels of detail to identify where managed lanes could be implemented and the likely types of managed lane networks arising.

While some RCAs have identified the need for managed lanes, several RCAs have identified that such facilities are not warranted given the level of available capacity within existing networks. One such example is the *New Plymouth strategic study* (Transit NZ and New Plymouth District Council (2008), which identifies sufficient capacity until 2026 with very few future plans for road upgrades.

Case study 1: Auckland City Council[8]

Auckland City Council 'Buses First Programme'

Auckland city's 'Buses First Programme' was developed in 2004 identifying key arterial corridors where priority to buses would be given to strengthen linkages between places of work, employment and play.

This plan is supported by the city's transport strategy *Connecting people and places* (Auckland City Council 2005) and *Liveable arterials plan* (Auckland City Council 2008), which identifies the corridor function that will guide and support the integrated development of the city's land use and transport network.

A number of corridors identified with the Buses First Programme have successfully been implemented through the reallocation of road capacity to buses or temporary removal of kerbside parking for bus lanes during peak periods. While the city has identified peak-hour bus lanes, it is also planning and

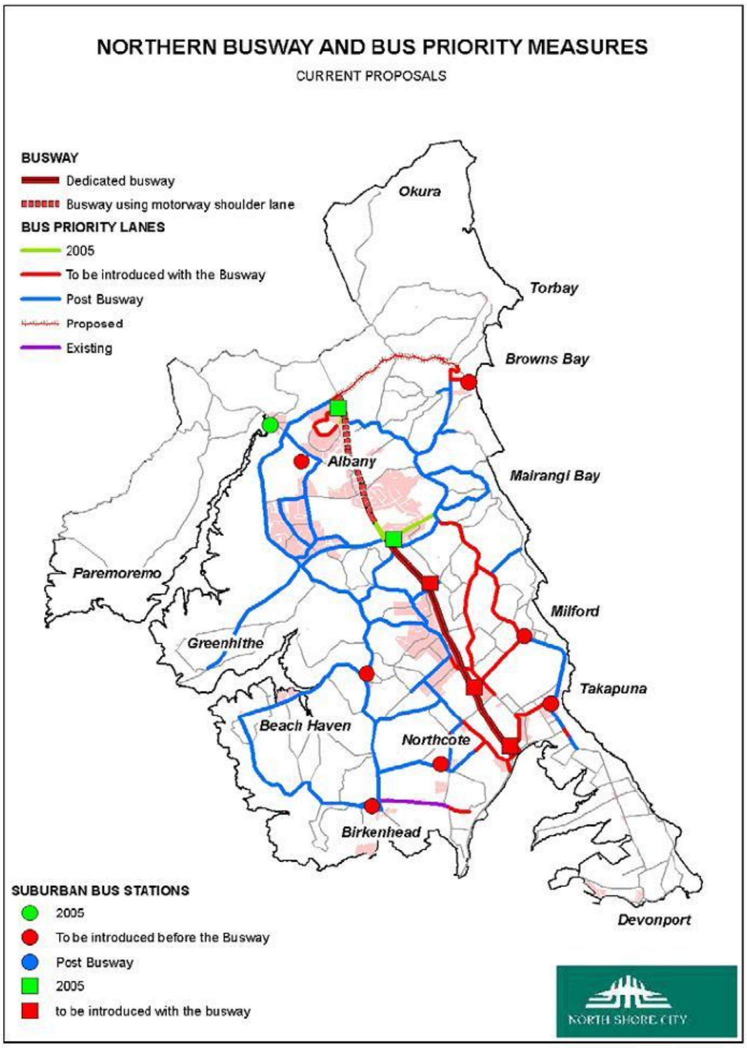
[7] Within the context of special vehicle lanes as opposed to toll roads

[8] Auckland City Council was amalgamated into Auckland Council in November 2010.

implementing two urban busways – the central transit corridor and Dominion Road upgrade[9] which will provide dedicated bus transit ways within the central urban area.

Although the city's current policy is to support buses only, in future an opportunity to consider other forms of managed lanes, for example, HOV lanes, event lanes (World Cup lanes) and no-car lanes on corridors identified in the following figure A4.6 may provide further benefits to the council in the movement of both people and goods.

Figure A4.6 Buses First Programme (2004)



Source: Auckland Council website

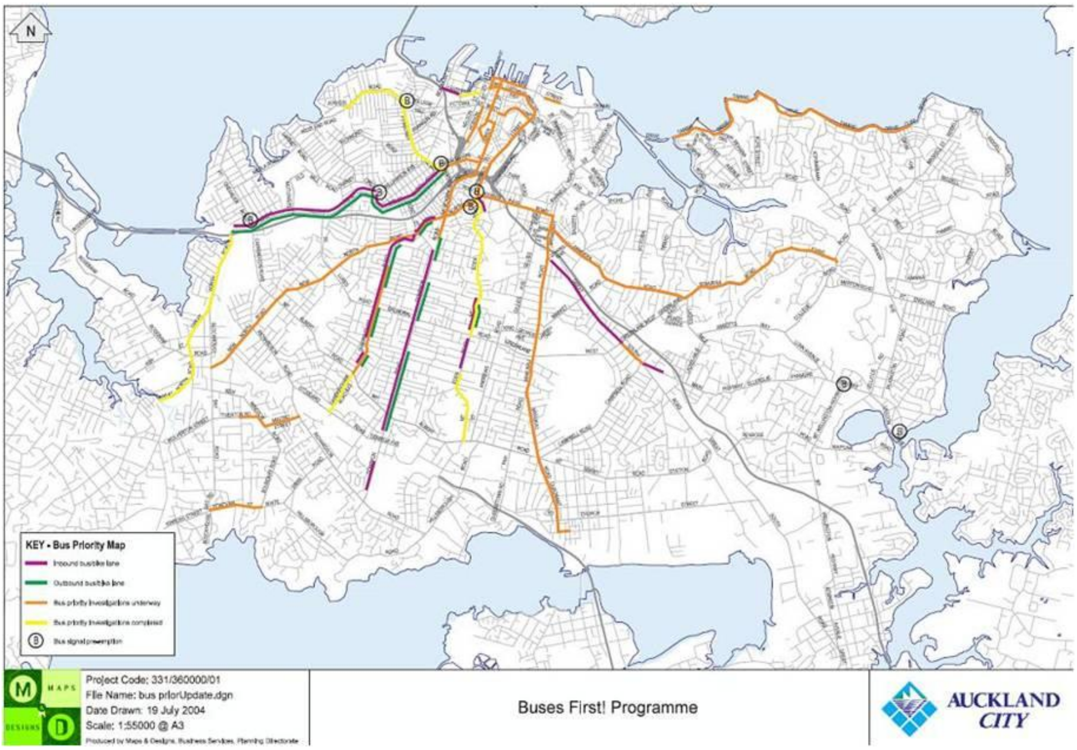
[9] The central transit corridor, now known as the Central Connector has been completed, but the Dominion Road upgrade is still in the planning stage.

Case study 2: North Shore City Council[10]

North Shore City Transport Strategy 2006

North Shore City Council Transport Strategy (NSCC 2006) (part C) identifies key arterial corridors where managed lanes would provide the most benefit to various user groups such as buses, motorcycles, cyclists and HOVs. Figure A4.7 illustrates proposals identified through North Shore City and how such measures complement the Northern Busway which opened in 2007. Many of the corridors identified for improvements have been and are currently heavily congested during morning peak periods (figure A4.7 reproduces NSCC's transport strategy map C2). Monitoring of existing facilities by NSCC demonstrates that such improvements can significantly relieve congestion on key transport corridors, by providing an alternative means of travel for residents. A case study of Onewa Road is provided in section A5 of this appendix.

Figure A4.7 Northern Busway and NSCC managed lane schemes (bus and HOV)



Source: www.aucklandtransport.govt.nz/improving-transport/strategies/TransportStrategies/Documents/Original/AT_NSCC_Policy_TransportStrategy2006_PartC.pdf

Case study 3: Wellington City Council

Wellington City Council – Bus priority plan 2007: 'Choose to take the bus'

Wellington City Council (WCC) has a 10-year plan to progressively implement bus lanes on all key routes to ensure bus services operate as reliably and efficiently as possible. Passenger transport services will be improved along the identified growth spine to support denser urban development than is envisaged.

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[10] North City Council was amalgamated into Auckland Council in November 2010

WCC's bus priority plan identifies the need for additional capacity to the road network and sees mass transport as feasible, efficient and an effective way of achieving this. Buses currently carry 28% of the city's commuters at peak travel times but are also hampered by congestion. By re-engineering the road corridor and reallocating road space to give buses priority on key transport routes to and from the city centre, additional capacity can be created to move greater numbers of people on the road network.

WCC officers are quick to highlight that this plan is not anti-car but will improve mobility for a growing number of people wanting to move about the city for work and recreation. The council has identified corridors where alternative managed lane arrangements such as HOVs could be a more reasonable alternative to dedicated bus lanes where bus frequencies and patronage levels are low.

The plan's objective has therefore identified practical bus priority measures which can be readily implemented throughout the city to give priority to buses. The plan aligns with the *Regional land transport strategy 2010–2040* (RLTS) (WCC 2010), *Urban development strategy* (WCC 2006b) and the WCC (2006a) *Transport strategy* outcomes and priorities. Figure A4.8 highlights the WCC bus priority network which identifies the priority of the schemes to be implemented with 'green' being first priority corridors, followed by 'blue' and 'red' highlighted corridors. The 'green' corridors highlighted include the central city and bus lanes to and from the central city to:

- Ngauranga
- Karori
- Brooklyn
- Island Bay
- Newtown
- Kilbirnie.

The pace of the bus and transit lanes to be implemented is dependent on the success of each scheme, thus determining the need for the next scheme to be rolled out (WCC 2008).

The plan sets out the following goals:

- Support a passenger transport service that is attractive to users by enabling services to operate faster and provides more reliable trips.
- Put in place measures which future proof the performance of bus service trips as the road network becomes more congested.

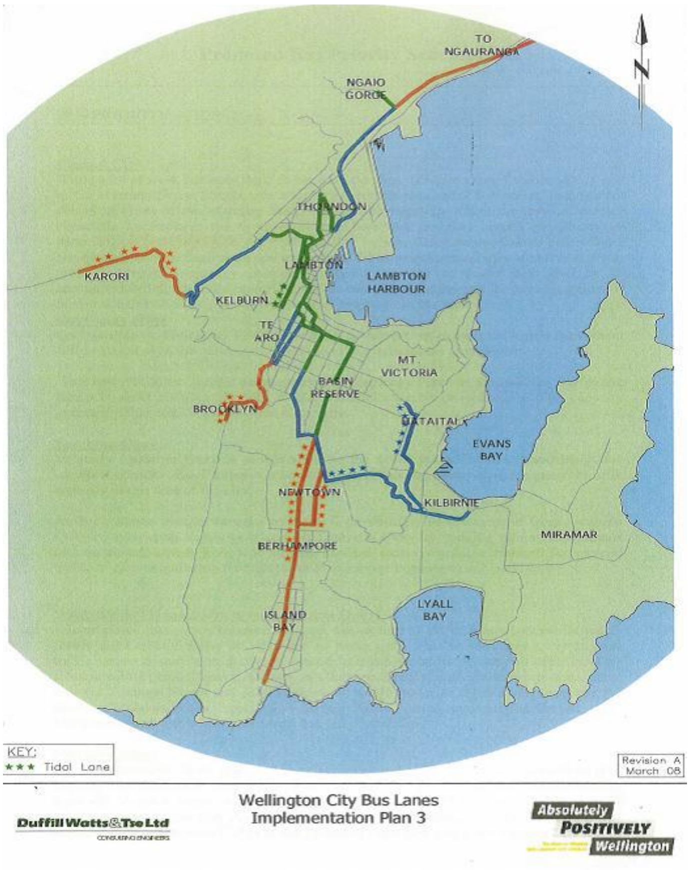
The plan identifies that the outcomes of the above and implementation of the bus plan is only possible if other external linked factors are implemented, such as increasing capacity for freight and private vehicle movements on the state highway corridor between Ngauranga and the airport to improve access to the central city and to move traffic across the city.

The plan clearly states that the council will need to revisit current objectives, which set out to install bus priority measures where there is no disadvantage to motorist needs, if wider benefits are to be achieved. As in many cities in New Zealand where bus lanes have been implemented, the first generation bus lanes have mainly been easy to do by utilising parking clearways or surplus capacity in the road to achieve priority for buses without disadvantaging or adversely impacting on other road users.

Performance indicators to measure the success of bus priority schemes have been identified and will continue to be monitored. Further possible performance indicators identified by the council, or a series of measures, could be applied to the total passenger transport network, such as:

- cap growth on cars travelling to the central city during morning peaks based on 2005 figures
- increase the percentage of journey to work by bus trips
- introduce travel time savings of X minutes per bus
- reduce travel journey times for buses by X%.

Figure A4.8 Wellington city bus priority plan



Source: WCC (2008) www.wellington.govt.nz/haveyoursay/meetings/committee/Strategy_and_Policy/2008/17Apr0915/pdf/2_App_1_Bus_Lane_Investigations.pdf

The council has completed a preliminary assessment of potential managed lane routes for bus and transit lanes (see figure A4.8). The implementation plans identify that further study and closer scrutiny is required of the effects and benefits of each scheme developed.

A key feature of WCC's bus priority plan is the consideration and use of dynamic lane line technology on selected sections of corridors. Dynamic lane line is being considered where there are limited funds and widening of an existing corridor is not a feasible reality. WCC has prepared a summary estimate showing that for the possible schemes identified it will cost in the order of $333 million to achieve them all. However, if dynamic lane line technology is used then the cost of providing bus priority measures is reduced to about $16 million. Figure A4.9 illustrates a proposed corridor treatment using dynamic lane line technology.

Figure A4.9 Conceptual dynamic lane line technology on a street in Wellington

a) Proposed AM tidal flow

b) Proposed off-peak tidal flow

c) Proposed PM tidal flow

d) Existing layout

Source:
www.wellington.govt.nz/haveyoursay/meetings/committee/Strategy_and_Policy/2007/12Apr0915/pdf/1_App_4_Tidal_Lane_Perspective_Photos.pdf

The plan identifies the need for a supporting communication plan to be developed and rolled out to provide key messages and material on the rationale of the bus priority measures and benefits for the public, stakeholders and communities involved.

Section A5.1.7 details a case study for the proposed implementation of bus lanes at Courtenay Place, Wellington.

Case study 4: Christchurch City Council

Christchurch Metro strategy 2006–2012

Christchurch City Council (CCC 2006) has a six-year plan *Metro strategy 2006–2012* to progressively implement bus lanes on 10 key routes to ensure bus services operate as reliably and efficiently as possible. The aim is to have a bus system where 95% of trips arrive within five minutes of scheduled times, and 100% of trips do not depart timing points earlier than scheduled.

The driving force behind implementing bus priority lanes in Christchurch is to help lessen congestion in the city. A CCC (2006) document 'Everybody wins when the bus comes first' suggests that congestion in the city will increase by 160% by 2021. This will create 78km of congested roads compared with the current 24km. At this stage, other forms of managed lanes have not been proposed as the idea is to first provide priority for public transport (buses, cyclists and possibly taxis) and then if the need arises in the future, the legislation can be changed so that these lanes can be used by other vehicles.

The CCC, Environment Canterbury (ECan) and the NZTA are working together to provide routes along the entire length of the city bus network. At the time of writing this document the following scheme assessments have been undertaken by various consultants for the CCC and NZTA:

- Main North Rd (NZTA)
- Papanui Rd/Main North Rd (CCC)
- Queenspark Route (CCC)
- Colombo St/City South (CCC)
- Main South Rd (NZTA).

Although the above is divided into five areas the NZTA schemes are extensions of the work CCC is doing but are situated on the state highway. Main North Rd is an extension of Papanui Rd/Main North Rd, and the Main South Rd connects to the Hornby Mall to the Exchange scheme. In addition to the bus routes there are nine interchanges (with cycle facilities) planned to be developed to support the bus service. In the future, covered, secure and safe cycle facilities will be provided at strategic points along the bus routes.

The outcomes of the Main North Rd route and an assessment of the scheme are provided as a case study in section A5.

A5 A review of case studies with bus priority interventions

The format of this section and case studies are consistent with previous work undertaken by AECOM for the NZTA in Maunsell AECOM (2008b). This enables readers of both documents to make comparisons between New Zealand and other international managed lane examples such as HOT lanes which include bus priority interventions.

The subheadings in table A5.1 provide an overview of the assessment guide used to identify issues from reports and discussions with various stakeholders in the development of managed lanes in Australia, New Zealand, the UK and USA.

Not all aspects of the subheadings in table A5.1 can be provided for all case study examples. This is either due to a lack of web-based data, archive records and/or scheme knowledge from the original project managers who are no longer with the respective RCAs. In some cases current council and RCA project managers are managing schemes implemented over five or more years ago.

Table A5.1 The assessment guide to managed lanes

Planning • Site selection • Mandate • Screening criteria • Supporting TDM measures	**Costs** Costs have been difficult to establish, hence section A6 provides just an overview of costs associated with New Zealand projects
Management • Monitoring • Flexibility • Public education and promotion • Maintaining the ability to operate effectively • Dealing with concerns	**Operation** • Permitted users • Hours of operation • Priority for low emission vehicles • Enforcement issues
Design • Infrastructure • Lane configuration and signage • Supporting infrastructure	

A5.1 The New Zealand experience

Section A4 highlighted the contextual development of managed lanes within New Zealand. This section examines priority interventions for buses on the selective corridors listed in table A5.2.

Table A5.2 New Zealand case studies

Location	RCA	Operational	Proposed
Auckland	ACC NSCC	Dominion Road, bus lane Onewa Road, transit lane	
Christchurch	NZTA	Main North Road, bus lane	
Tauranga	NZTA	Hewletts Road, Tauranga	
Wellington	NZTA HCC WCC	Mana Esplande, transit lane The Esplanade, Petone, bus and taxi lane	 Courtenay Place, bus lane

A5.1.1 Onewa Road, transit lane (T3), Auckland

A5.1.1.1 Planning

Mandate and site selection

The mandate and site selection of Onewa Road as the country's first bus and HOV lane resulted from the passing of the Urban Transport Act 1980 and the new urban transport responsibilities conferred on the then Auckland Regional Authority (ARA), now Auckland Transport. The ARA was keen to develop low-cost traffic management schemes that maximised existing road space by encouraging HOVs and public transport.

Onewa Road was selected as a potential candidate due to its high morning peak congestion and relatively high travel on buses.

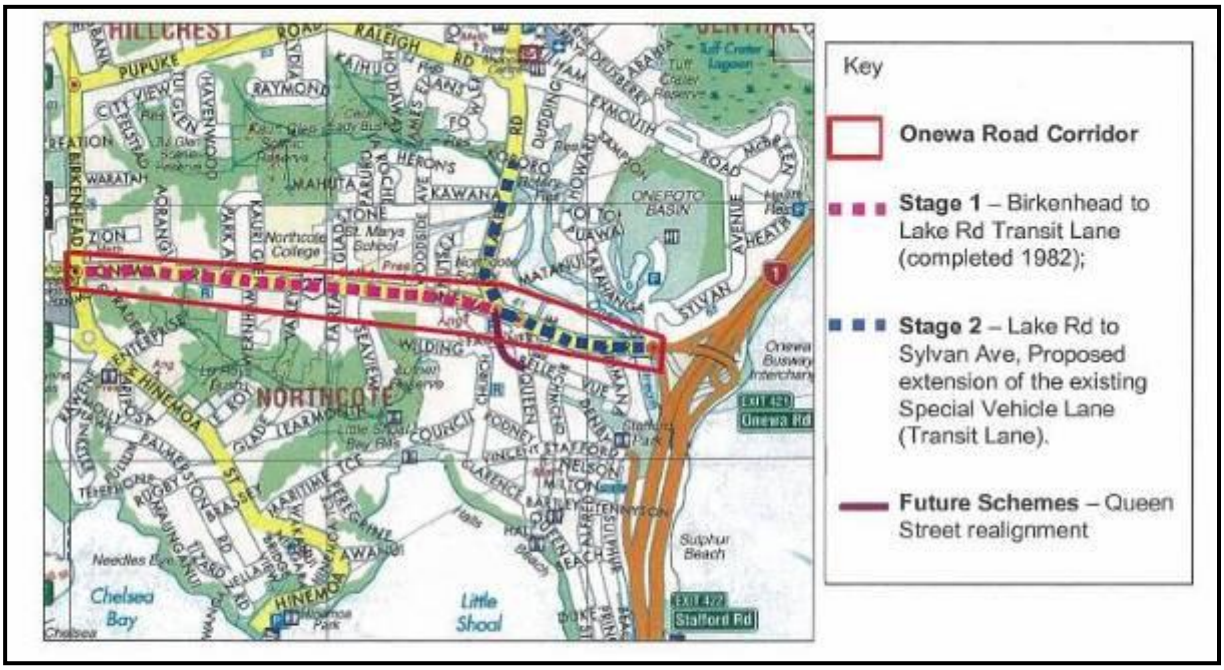
A joint working party, with members from ARA, Ministry of Transport, the then Ministry of Works and Development, Northcote Borough Council, Birkenhead City Council and Birkenhead Transport Ltd was established to oversee the development of the scheme.

The implementation of a priority lane on Onewa Road was initially introduced as a six-month trial. Based on its success the lane has been extended from its original operation to SH1 (Traffic Design Group 1991).

With the local authority amalgamation in 1989, the new NSCC assumed responsibility for the full length of Onewa Road and surrounding road network. Between 1991 and 2007, NSCC undertook a number of investigations into the extension of the existing transit lane to SH1 (Maunsell AECOM 2006).

Figure A5.1 illustrates the development of stage I and II phases of the Onewa Road transit lane.

Figure A5.1 Locality of Onewa Road transit lane development on Onewa Road



Source: Maunsell AECOM 2006

A5.1.1.2 Management

Monitoring

Information and enforcement signage are posted along the corridor to provide visual reference for motorists of a managed lane ahead, the permitted users of the lane and operational times. Figure A5.2 provides an illustration of signage and of enforcement officers on Onewa Road.

In 2003, the council's parking wardens received warrants from the Ministry of Transport to undertake enforcement of the Onewa Road transit lane. Prior to 2003 enforcement of the lane was the responsibility of the New Zealand Police. Evidence indicates, from subsequent monitoring of the lane that non-compliance users dramatically dropped, with the average number of complying cars having more than doubled since January 2002 from around 150 to 314 per day in March 2003 (Murray 2003). Non-complying vehicles average less than 5% of all transit lane users. The removal of non complying vehicles from the lane enhanced free flow on the lane for permitted users, reducing travel time between Birkenhead Ave and Lake Road from four to seven minutes during peak hours. This is a significant travel time saving when compared with travel times in the general traffic lane which are between 30 and 40 minutes to cover the same section of road (Murray 2003). With the proposed extension of the Onewa Road transit lane to SH1, priority users of the lane will be able to gain significantly higher benefits on this corridor. Currently HOVs and buses must merge with general traffic downstream, thus eroding some of the benefits gained upstream.

Enforcement is a key management tool for effective operation of the lane and wider network. Enforcement has not only reduced non-compliance but has also given impetus to increased use of the lane. Evidence indicates that the carrying capacity on Onewa Road increased both in the transit lane and general traffic lane, while bus patronage on the transit lane increased dramatically, as did HOV usage within the lane. As such the transit lane carried 68% of all commuters in 27% of all vehicles on Onewa Road (Murray 2003).

Monitoring of the lane is critical to its successful ability to maintain and attract complying users, thus enabling the RCA to increase people carrying capacities on key transport corridors.

Funding to provide a high level or appropriate level of enforcement is necessary throughout the whole life of a scheme. Included within this budget is the need for ongoing public education and promotion material to gently remind users of the lane intent and penalty for non-compliance.

The success of the Onewa Road transit lane and enforcement, as the country's first priority scheme, has seen the roll out of similar priority schemes across New Zealand.

Public education and promotion

The council has undertaken a significant amount of public education and promotion of its managed lanes including the Onewa Road transit lane. A variety of media has been used to advocate the function of the lanes and operational hours. In addition to this, the success of the Onewa Road transit lane has been dependent on enforcement and monitoring for compliance which has enabled the council to maintain the efficient operation of the lane and advocate for its extension. The success of the lane's functionality and ability to serve is demonstrated in the scheme's on-going reference by other RCAs within New Zealand and internationally (Faber Maunsell 2007).

A5.1.1.3 Design

The development of the Onewa Road transit lane resulted from the removal of kerbside parking and re-marking of road space to accommodate two eastbound lanes.

The Onewa Road transit lane has been operational since 1982 during the AM peak period and operates over a 2.5km kerbside (or nearside) stretch of the Onewa Road Corridor. The implementation of the transit (T3) lane is a prime example of how such a transit lane can successfully operate in an urban environment when peak-hour flows are reaching capacity. As previous research indicates, the length of the lanes needs to be long enough within the context of the network to ensure sufficient journey time savings and encourage modal shift and carpooling (Maunsell AECOM 2008b). This nearside T3 lane operates from Birkenhead Road to Lake Road with current works underway to extend its operation from Lake Road to the SH1 interchange. Current travel times in the Onewa Road transit lane have been reduced by 80%, saving car poolers and bus commuters half an hour in travel time. Bus services are keeping to timetables, with patronage rising by 25%. In 2004, the NSCC was awarded the BP Transport Award in recognition of this significant achievement.[11]

The NSCC has established guidelines on the width of transit lanes within its city. A copy of these can be requested from the council. It is noted, however, that the existing transit lane on Onewa Road is substandard, operating with a kerbside lane width of 3.5m while the offside general traffic lanes are 3m

[11] See www.scoop.co.nz/stories/BU0404/S00007.htm

wide. This standard differs from NSCC's new standard of special vehicle lanes of 4.2m to 4.5m wide. Typically 4.2m wide lanes have been adopted for NSCC's new schemes for bus and transit lanes.

The standards for special vehicle lanes, which were prepared for the Auckland Bus Priority Initiatives Steering Group in 2005 (which at the time included representatives from the Auckland Regional Council, Auckland City Council, Manukau City Council, North Shore City Council, Waitakere City Council, New Zealand Police, Transit New Zealand, Bus and Coach Association and Land Transport NZ)[12] have been used for the design of the pavement markings and signage of transit lanes within the NSCC.

A5.1.1.4 Operation

The new kerbside lane was marked and signed as a T3 lane reserved for use by buses, HOV3+, emergency vehicles and cyclists during peak periods.

Historically, the permitted users of the Onewa Road transit lane are buses, HOVs (specifically as a T3 lane, meaning that cars with three or more persons per vehicle can use the lane), motorcycles and cyclists. In the earlier 2000s taxis were also permitted to use the T3 lane. The T3 lane carries approximately two-thirds of the inbound commuters on Onewa Road – 28% of the total HOVs (accounting for just 27% of all vehicles on Onewa Road) and 40% in buses. This gives an average of 2.7 persons per vehicle across both lanes compared with Auckland's overall average of 1.1 persons per vehicle (Murray 2003).

Figure A5.2 Transit lane manual enforcement and signage

This photo highlights the T3 enforcement signage on Onewa Road stating permitted users of the lane.

Additional manual enforcement is carried out by NSCC's wardens using videoed images of transport violations. The owner of the vehicle is fined $150.

Developments in intelligent transport system (ITS) applications are still in their infancy with respect to infra-red technologies that would detect the number of persons per vehicle travelling in managed lanes.

Side friction along Onewa Road corridor is limited with the majority of adjoining lane use activities being residential and well spaced side road junctions. Minor access roads are uncontrolled compared with Lake Road, Birkenhead Road/Glenfield Road and Sylvan Ave which are signalised.

[12] Auckland Regional Council, Auckland City Council, Manukau City Council, North Shore City Council, Waitakere City Council were amalgamated in the establishment of Auckland Council in November 2010

A5.1.2 Dominion Road, existing and proposed bus lanes, Auckland[13]

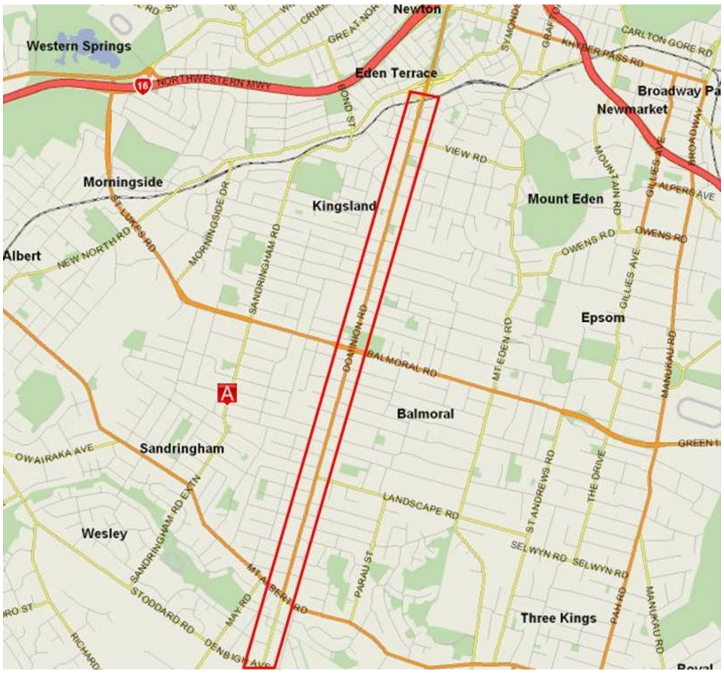
A5.1.2.1 Planning

Site selection

Dominion Road, situated in Auckland, is identifiable as an arterial corridor serving both public and private transport users from the city's southern suburbs to Auckland's CBD. Since 1976, Dominion Road has been under intense investigation and strategic and policy decisions over these last 30 years have cemented Dominion Road as a key public transport corridor on Auckland's isthmus. During this period, public transport has been an important element in the majority of investigations which have envisioned potential step changes from buses to light rail.

Key milestones for public transport on Dominion Road came in 1998 with the introduction of peak period bus lanes. Further ongoing investigations for Dominion Road are currently focused on the widening of the corridor to accommodate full-time bus lanes. Figure A5.3 highlights the study corridor of existing and current bus lane investigations by Auckland city.

Figure A5.3 Locality of Dominion Road bus land corridor, Auckland



Mandate

Evidence presented to the August 2000 Notice of Requirement for the Dominion Road Passenger Transport designation, outlined the historical development of Dominion Road as a key passenger transport corridor. This evidence stated that:

- it was preferred over other arterials such as Manukau Road for public transport
- Dominion Road was identified for intensification in the Auckland Regional Growth Strategy

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[13] This case study is based on SKM (2008) *Scheme assessment report*.

- Dominion Road was central to the isthmus
- staged enhancements had already taken place
- it was difficult to implement PT priority on Manukau Road with existing clearways in place.

Of interest is the evidence cited from the 1998 technical investigations into the introduction of bus lanes which had considered the possibility of clearways instead of bus priority improvements (SKM 2008). However, it was concluded that clearways would not increase the people-carrying capacity of the corridor. Further evidence identified that with the introduction of bus priority measures in 1998, bus patronage had increased by 40% and the then Auckland City Council and Auckland Regional Council were consistent in their plans for Dominion Road (SKM 2008).

In July 2004, the designation for Dominion Road was confirmed, but with a limit of 12 years which provided for incremental improvements to public transport, and potentially the possibility of light rail. The SKM (2008) report provides the realisation of the proposed future 24/7 passenger transport corridor on Dominion Road.

Supporting travel demand management measures

Since 1998, the Auckland City Council sought to upgrade bus shelters along the corridor and improve information for buses within the implementation of real-time information on Dominion Road in 2000.

The scheme assessment report by SKM (2008) outlines the proposed scheme corridor improvements which support the overall vision for Dominion Road – described as a great character street to be reclaimed as a pedestrian friendly environment. This will work well for public transport providing a reliable, quality transport choice regardless of traffic volumes. Corridor improvements will potentially foster and enhance business centres located on Dominion Road (SKM 2008).[14]

To achieve this, corridor enhancements which support passenger transport include:

- full-time shared bus and cycle lanes with priority 'B' phases at controlled intersections
- improved high-quality bus shelters and seating
- real-time information at stops
- widened footpaths
- street-scaping to support a boulevard and pedestrian environment
- pedestrian refuges along the length of the corridor to facilitate safe crossing and improved accessibility and mobility within the corridor.

In addition to the proposed corridor improvements, an opportunity to consider a park and ride facility with the extension of SH20 to the Richardson Road interchange, would also maximise the uptake of the proposed facilities on Dominion Road. ARTA's (2008) draft park and ride report identified a short time park and ride facility at Onehunga which could potentially support bus operations until the rail connection is upgraded.

[14] Dominion Road Upgrade is still an on-going project. In late 2010 AECOM was commissioned to investigate scheme improvements on Dominion Road. In October 2012 Auckland Transport confirmed at $47 million upgrade of the corridor which will include continuous bus lanes during peak periods. Subject to NZTA funding construction is expected to start in 2014. Further updates and details on the process of this project can be found at www.aucklandtransport.govt.nz/about-us/News/LatestNews/Pages/dominion-road-upgrade-approved.aspx

A5.1.2.2 Management

Monitoring

Monitoring of Dominion Road's existing peak period bus lane began in March 1998, the year of its implementation. Monitoring of the before and after effects of the bus lanes is undertaken annually and focuses on the following components:

- bus lane operations
- general purpose lanes
- patronage.

Monitoring records over this period illustrate a number of significant findings in bus priority benefits. The first is the reduction in bus travel times that have been as high as 25% on average with trip variability decreasing by as much as 33% on average. This has resulted in the peak period bus patronage increasing by over 80%.

Monitoring is also significant in demonstrating that there has been a minimum effect on the existing travel times of private vehicles in the adjacent general lane. This is partly due to the fact that in the existing bus lanes kerb-side parking is removed during peak periods. Evidence indicates that during peak times, growth in general traffic has led to increased travel times. It was interesting to see whether bus lanes on Dominion Road would lead to the reassignment of traffic to alternative routes such as Mt Eden Road or Sandringham Road. Investigations have suggested that bus lanes themselves have not caused extensive re-routing to either of these roads.

Based on historical records it is unlikely that the proposed scheme to introduce full-time bus lanes on Dominion Road will have an adverse effect on private vehicles.

Flexibility

The existing operation of part-time bus lanes on Dominion Road and the need to accommodate parking offers limited flexibility. The proposed scheme offers increased flexibility with the provision of a dedicated and full-time bus lane that will support the regional growth strategy and the future possibility of light rail replacing dedicated bus lanes.

Public education and promotion

Auckland City Council's communications department undertakes rigorous public education and promotion of bus lanes within the city, including joint publicity with Manukau City Council to promote the lane priority and fines. Bus operators have assisted in the provision of back of bus space, free of charge, for the promotion of priority lanes such as bus lanes. Advertising space on bus shelters has also been used to give advice on how to use managed lanes and the fines that are imposed for non-compliance.

A5.1.2.3 Design

Existing bus lanes operate kerb-side with the removal of kerb-side parking during peak periods of operation. The existing width of the lanes is 3.0m and they are used by buses, cyclists and motorcycles during their hours of operation.

During the earlier years of implementation the lanes were painted green, but due to the cost of maintaining this, some councils began to oppose lane colouring which reduced the effectiveness of the lane without the desired enforcement results. The BPISG standards set a minimum for surface colouring and pavement marking of lanes to reduce maintenance costs. This did not exclude those councils that wished to continue with full lane greening from doing so, but it ensured regional consistency with a minimum standard for special vehicle lanes (BPISG 2005).

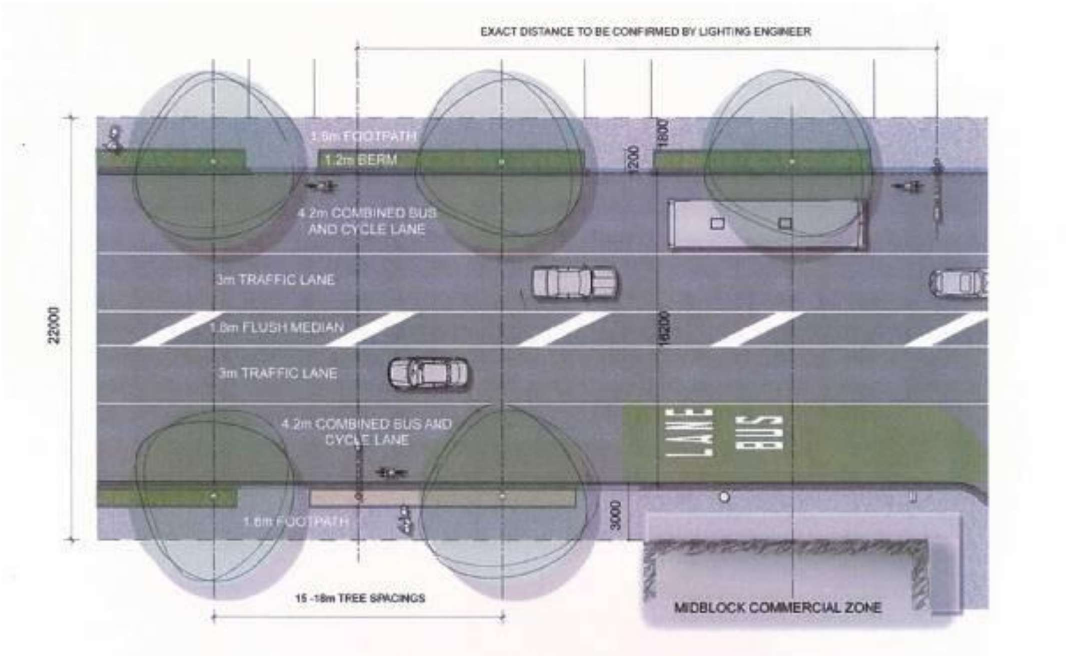
Figure A5.4 illustrates the road layout proposed from the widening of Dominion Road. The typical carriageway cross section would consist of:

- 3.0m traffic lane
- 1.8m central flush medium
- 4.2m shared bus/cycle lane
- 2.1m indented car parking (to support business zones)
- 1.0m tree planting berm (minimum)
- 1.5m wide footpath.

Pavement contrasting through the use of various shades of aggregate is included in the street design to distinguish between kerbs, bus stop locations and footpaths.

The design accommodates a 4.2m wide shared bus and cycle lane[15] the proposed width of the lane. The shared facility, with no cycle lane delineation along the mid-block of Dominion Road, was proposed because of Auckland City Council's policy considerations. The approach enables cyclists to make use of the entire shared facility, particularly adjacent to side roads and on-street parking.

Figure A5.4 Typical road layout for Dominion Road proposed bus lanes



Source: SKM 2008

A5.1.2.4 Operation

Permitted users of the bus lanes within Auckland city are buses, cyclists and motorcycles. The hours of operation are currently during peak AM and PM periods. Periodical enforcement of the lanes is manually

[15] It is unclear from the SAR if the council intends to ban motorcyclists from the proposed bus lane. Under the TDC (Traffic Control Devices Rule, 2004) motorcyclists and cyclists are permitted users of bus lanes unless otherwise signed.

undertaken by council parking wardens who follow similar procedures to those established elsewhere in New Zealand.

A5.1.3 Mana Esplanade transit lanes (T2), Wellington

Mana Esplanade T2 lanes became operational in November 2005 and have since been the subject of a high degree of public debate and discussion over their effectiveness and operation. Mana Esplanade forms part of SH1 and is managed by the NZTA. This case study highlights the political climate of a scheme implemented within a wider package of improvements which have not necessarily addressed or appeased localised community concerns.

The NZTA and Porirua City Council decided to replace the existing T2 lanes with a clearway during peak periods only.

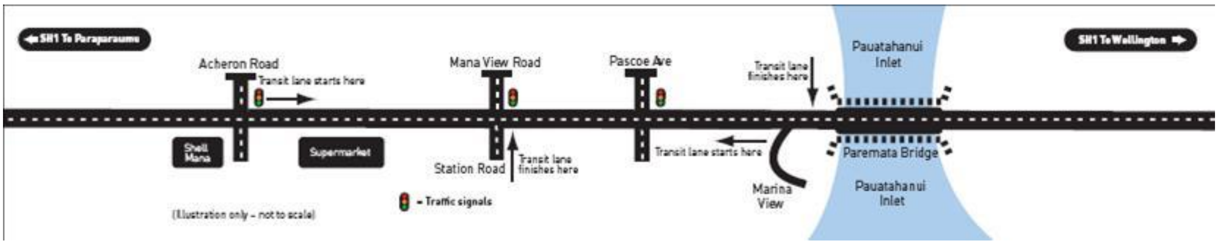
A5.1.3.1 Site location

Located within Porirua, Mana Esplanade T2 lanes operate between the northern end of Plimmerton roundabout, south along the route of the existing SH1 to Paremata roundabout (see figure A5.5). Two kerbside T2 lanes operate over 1.3km in the south and north-bound directions during weekday peak periods, public holidays and Sundays (see figure A5.6). The speed environment posted with this section of road is 50km/h, with higher speeds outside the study area.

Land use adjacent to the site is predominately residential with some commercial activities along the southern side of Mana Esplanade. Utilisation of on-street parking is predominant on the south-bound direction (maximum of 13 vehicles surveyed) with fewer vehicles utilising parking spaces on the northern side.

Figure A5.5 Locality of Mana Esplanade T2 lanes

Figure A5.6 Mana Esplanade T2 lanes



Source: NZTA promotion material

A5.1.3.2 Planning

Site selection

The selection of the T2 lanes implemented in 2005 originated from a series of studies undertaken between 1995 and 1998, which looked at options for improving SH1 between Paremata and Plimmerton, and followed on from an extensive process of review and refinement including an Environment Court Hearing (Hyder 2008).

The original scheme focused on upgrading the existing state highway, providing a two-lane and a four-lane bypass to the west of the existing highway. Refinements of the original scheme or 'reduced upgrade' include the provision of T2 lanes which reflect the current configuration of four lanes along Mana Esplanade including two general purpose lanes and two T2 lanes.

Mandate

The mandate comes from conditions arising from the Environmental Court Decision in relation to the Notice of Requirement to Designate Land to Upgrade a Section of State Highway One. The NZTA has to review the operation, environmental effects, safety and efficiency of the works for the purpose of determining whether or not to seek any alternative to the designation (SKM 2006). The most recently completed independent review of the facility (Hyder 2008) is a joint commission from the NZTA and Porirua City Council. Excerpts from both the 2006 and 2008 surveys have been incorporated into the following sub-heading sections:

Supporting TDM measures

No supporting TDM measures were implemented with this scheme. No bus stop facilities operate in this section of road.

A5.1.3.3 Management

The following sections identify a number of management areas associated with the operation of the lanes:

Monitoring

An analysis of lane use indicated that the utilisation rate of HOVs overall was higher during the week than in weekends. Reasons for this may be due to the difference in the operational periods of the lanes in weekends, particularly between 11.30am and 2.30pm. Motorists and passengers engaged in weekend employment, and/or sporting activities, travel outside the current weekend operational times of the lanes and therefore are not captured. Travel patterns may also differ between Saturday and Sunday and this will need to be considered in setting the operational times of weekend managed lanes.

As the reasons are unclear, it is worth considering the operation of a managed lane during weekends. The provision of the Mana T2 lanes for weekend use is a first within New Zealand and evidence has indicated that the greatest increase in HOV use of this lanes occurs on Sunday, with a jump in HOV users from 59.6% to 66.3% (SKM 2006; Hyder 2008).

Washington State undertook a study entitled *Weekend freeway performance and the use of HOV lanes on weekends* (Ishimaru et al 2000). The study examined HOV lanes in continuous operation and whether there was scope to open the facilities to other traffic at non-peak times. Interestingly the study *HOV facility development: a review of national trends* (Fuhs and Obenberger 2001) found that the average vehicle occupancy was higher than expected during non-peak periods and especially at weekends. This would suggest that HOV facilities should remain operational continuously to provide the benefits to HOVs and further encourage the modal transition to higher occupancy forms of transport (Maunsell AECOM 2008a).

Surveys concluded in 2006 that the Mana T2 lanes during their operational hours were successful in attracting vehicles with more than one occupant. However, the overall traffic volume in the adjacent non-managed lane (left lane) which carried all trucks and general traffic was 20% to 40% higher than the HOV volumes. This equates to lane utilisation of approximately 2.5 times that of the T2 lane, and that the number of HOVs on SH1 showed a slight increase from 15,500 (41%) in 2005 to 16,000 in 2006 (43%) (SKM 2006; Hyder 2008).

From the analysis it was concluded that the T2 lanes had little effect on the overall percentage of HOVs along SH1, particularly during weekday peak periods.

Flexibility

The Mana T2 lanes do not offer flexibility. Instead they provide fixed operational periods during the AM and PM weekday and weekend periods. Outside of these periods the lanes reverts to allowing/permitting kerbside parking.

Public education and promotion

When compared with similar schemes around New Zealand, promotion and publication of material for the operation of these lanes is of a high standard and widely published both in printed and web-based forums.[16] Unlike other managed lane sites within New Zealand, this facility has four different operational hours during weekday and weekend periods. Outside these periods the lanes revert to kerbside parking.

Parallel to this scheme, the NZTA also had to advise heavy commercial vehicles to use the off-side lane adjacent to the transit lane at all times.

Maintaining the ability to operate effectively

The NZTA has undertaken several measures to improve the operational effectiveness of the T2 lanes, including the implementation of electronic signs to provide on-site visual references to motorists on the use and operation of the T2 lanes.

The above-mentioned surveys undertaken by SKM (2006) and Hyder (2008) indicated that the ability to operate the T2 lanes effectively has been a major challenge for the NZTA.

Survey questions on operational effectiveness generated the largest responses from respondents, in particular, the T2 lanes, clearway times, and the management and understanding of these facilities. The responses received came from two distinct groups, those who regularly travel through this section of highway, and residents who live adjacent to the T2 lanes.

The majority of non-resident responses felt that the clearway hours should be extended or parking removed altogether, and that the current T2 system, which enables kerbside parking outside of its operational hours, was both confusing and ineffective.

[16] For an example, see www.nzta.govt.nz/projects/paremata-to-plimmerton/docs/project-update-201112.pdf

In contrast, the residents of the immediate areas held an expectation that the T2 lanes should be more strongly restricted, referring to Environmental Count evidence that promised this would be the case.

New Zealand Police commented that the T2/clearway lanes seemed to have alleviated the congestion problems, although some weekend congestion was still occurring. Compliance with the clearway T2 hours was generally good with few vehicles having been ticketed. Police did not consider that parking outside of the restricted hours was a significant safety hazard. They did, however, notice that signage was confusing for motorists unfamiliar with the lanes, due to the scale of writing on the signs.

A number of issues were raised at consultation meetings with the Paremata Residents Association. Of interest was the comment that, 'the problem is not with the T2 lanes during operational hours but when the lanes effectively operate as a four-lane road the rest of the time' (Hyder 2008).

Dealing with concerns

The NZTA and Porirua City Council have been very active in dealing with concerns arising from the implementation of managed lanes on Mana Esplanade. Extensive time has been committed to this facility with the NZTA Central Operational Manager estimating up to 10% of his time is spent dealing with concerns about the Mana Esplanade T2 lanes.

Since the lanes have been implemented there have been numerous improvements addressing feedback on the following concerns:

- safety
- operational
- parking.

Hyder's (2008) survey was designed to assess several core issue groups, and to provide the facility to identify any issues that users felt were relevant. The core headings of the survey were:

- access
- safety
- operational effectiveness
- environmental impacts
- other.

A summary of the findings is set out in table A5.3.

Table A5.3 Summary of findings of survey by Hyder Consulting (2008)

Survey heading	Survey results	Other survey comments
Access	Overall access to and through the area has been improved, particularly at peak times; including access to and from local facilities and local road network.	
Safety	Overall an improved level of perceived safety by 42% of respondents compared with 27% who either saw safety as having decreased while 20% indicated no change.	

Survey heading	Survey results	Other survey comments
Operational effectiveness	See above	There was a general lack of understanding of the T2 rules, and the status of the lanes outside of the T2/clearway hours. There was also the perception that no legal framework exists for the T2 lanes. The T2 lane was too short to encourage car pooling. Many respondents were against on-street parking.
Environmental impacts	While 29% indicated no specific view, 28% of survey respondents (mainly from local residents) did indicate some improvement in air quality while 18% indicated a negative impact on air quality and noise.	'One of the most significant issues raised by several residents was the dividing impact on the community resulting from parking activities and the underlying motives of residents' on-street parking; and the local residents' view on the level of restrictions placed on the clearway lanes outside of peak periods' (Hyder 2008) Perception that local residents only park on the road to make a point, and restricting the use of the left lane has created a bad feeling across the community.

From the surveys taken over the operation of the lanes from the November 2006, it appears there is little evidence to suggest that the crash rate in the T2 lanes, in particular involving parked cars, is in anyway unusual (SKM 2006). SKM (2006) and Hyder (2008) both indicated that parking at during the peak account for was 13 vehicles in the southbound direction with fewer vehicles parked in the northbound direction.

In conclusion, Mana Esplanade illustrates an example where a high degree of management has been required over a short section of road. This, together with strong local community opposition, has resulted in suggestions to remove the scheme.

A5.1.3.4 Design

The design of the T2 lanes resulted from the refinements of the original scheme or 'reduced upgrade', which included the relocation of the current configuration of four lanes along Mana Esplanade to include two general purpose lanes and two T2 lanes to operate during designated peak hours and revert back to kerbside parking during off-peak hours. The lane widths are 3.0m – 3.2m.

A5.1.3.5 Operation

Permitted users of the T2 lanes are HOV vehicles with two or more persons, with the exception of buses, taxis, motorcyclists and cyclists.

The operational hours of the lanes are similar to other managed lane operations around New Zealand that provide priority travel to permitted users during weekday AM and PM peak periods. However, unlike other locations within New Zealand, priority to users of these T2 lanes is extended to priority users on Sunday and public holidays.

Outside of the designated periods the kerbside (nearside) T2 lanes can be used for parking as well as travel.

The signage in figure A5.7 informs motorists of the lanes' operational hours. It has been supplemented by electronic signage as a means of clarifying the rules and time restrictions of the lanes.

Figure A5.7 An example of the information and enforcement signage for Mana Esplanade

Enforcement issues

Monitoring of compliance of lanes is undertaken by Tenix, the NZTA network management consultant, who carries out monitoring on an irregular basis covering 50% of the lanes' operational time. The estimated cost for this level of monitoring is in the order of $10,000 per month. For non-compliant users of the lanes, an infringement notice is sent by mail with a $150 fine/penalty. This practice is similar to the enforcement of managed lanes elsewhere in New Zealand (SKM 2008).

In December 2006, SKM monitoring of the lanes concluded there was a non-compliance rate of 4% (southbound direction) and 1% (northbound direction). However, based on the traffic count data on lane utilisation, it is suggested that the rate of non-compliance is much higher given that monitoring of the lanes only occurs 50% of the time.

Of interest is the cost associated with monitoring the Mana T2 lanes. It is estimated that weekday enforcement costs $290, compared with weekend day enforcement costs of $250. On top of this cost is a network management fee of $6000 and an enforcement charge of $1.50 per confirmed violation to cover the cost of postage associated with reminder letters (not the infringement notice). This roughly equates to $10,000 per month for monitoring/enforcement of these lanes.

A5.1.4 Hewletts Road bus lane, Tauranga

A5.1.4.1 Planning

Site selection

The completion of the Harbour Link project, was the last remaining section of the central corridor of the Smart Transport network to be built. It provides a continuous four-lane expressway from Takitimu Drive through to Mount Maunganui (SH2/SH29) (refer to figure A5.8).

Figure A5.8 Locality of Hewletts Road bus lane, Tauranga

A5.1.4.2 Design

During the design stage it became apparent there was enough space within the road corridor to provide an additional managed lane on either side of the expressway. This part of the project did not go to formal consultation as the managed lanes fitted within the existing road reserve and the NZTA was already providing an extra traffic lane and new footpaths in each direction.

The lanes are in a 70km/h zone so the lane width has been set at 4m which is expected to provide enough space for buses to pass bicycles. Where geometric conditions constrain the width it has been reduced to 3.3m and the cycle lane has been separated from the bus lane.

A5.1.4.3 Operation

Permitted users of the lanes are buses, motorcycles and bicycles. The NZTA chose what is essentially a bus priority lane, as the four-laning project was already providing an additional traffic lane. If the bus lanes were used too heavily, there would be a congestion problem where the traffic had to merge from three lanes into two.

A5.1.5 Main North Road bus lane, Christchurch

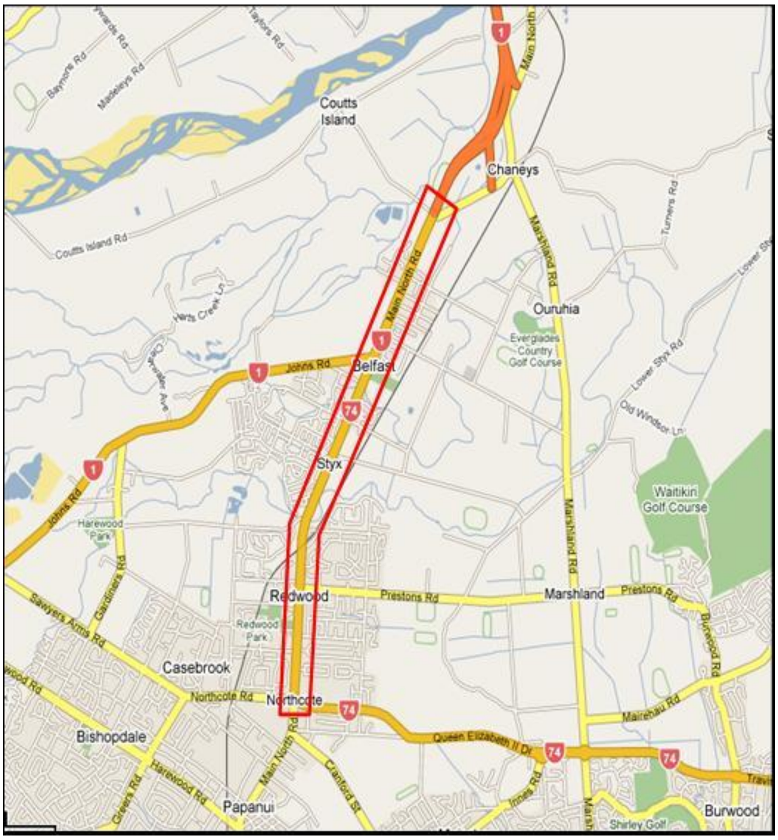
A5.1.5.1 Planning

Site selection

This route runs from Factory Road in Belfast, south along Main North Road to QEII Drive. The route is approximately 5.2km and connects with the Papanui/Main North Road scheme. Main North Road represents the northern gateway to the city for public transport services to and from the Waimakariri District. Belfast is the most northern urban centre in Christchurch city served by the urban network and public transport (refer to figure A5.9).

The public transport services along Main North Road vary as routes join and leave the corridor. The greatest hourly flow is 12 buses between QEII Drive and Daniels Road, with the lowest between Factory Road and Radcliffe Road at four buses per hour.

Figure A5.9 Locality of the Main North Road proposed bus lane



A5.1.5.2 Design

Following consultation and an assessment of the existing kerb and channel, it was considered that for the narrow bus lanes, a slightly wider lane (3.2m measured to kerb face) would minimise any damage to the existing kerb and channel and provide a more comfortable ride. Bus lane widths of 4.5m (rather than 4.2m), that allow buses and cyclists to pass in a 60km/h area, were adopted in accordance with the *New Zealand supplement to Austroads guide to traffic engineering practice - part 14: bicycles* (Transit NZ 2008).

The 3.2m lane is accepted as wide enough to accommodate both buses and cycles in areas where a 4.5m wide lane could not be reasonably achieved.

The bus lanes are painted at the beginning of each section, at a left-turn intersection and at 100m intervals to improve their visibility. The lane is also marked with a continuous white line and painted white text in the lane itself.

The standards used match those prepared by the Auckland BPISG.

Supporting infrastructure and tools

Various other mechanisms were proposed to help with the operation of the lane:

- Variable message signs: to help warn drivers of the change in use of the section.

- Bus borders: this is a built-out kerb which allows the bus to remain in the traffic flow when stationary, thus retaining its original position and avoiding any delays trying to rejoin the flow.
- Bus stop rationalisation: this involves a reduction in the number of bus stops and/or the relocation of bus stops to sites where they are deemed to be more convenient for passengers and the bus.
- Passenger transport information and priority system: this would detect a late running bus and pass the information to a central computer controlling the traffic signals. This in turn could adjust signal phasing to allow a bus to continue through an intersection.
- Signal pre-emption: if the traffic signal configuration at an intersection is suitable, this would involve allowing a bus to go straight ahead from a left-turn lane on a left-turn signal.
- Bus gate: a set of traffic signals would be installed at the end of a bus lane. As a bus approaches the signal, detectors trigger the red signal to stop the traffic flow enabling the bus to rejoin through the gap created by the red signal.

A5.1.5.3 Operation

Through consultation it was found that the majority of residents were in favour of peak period bus lanes only, where the bus priority lanes would return to either parking or additional traffic lanes outside the peak travel periods (7am to 9am inbound and 3pm to 6pm outbound). This lane became operational in 2010.

A5.1.6 The Esplanade bus and taxi lane, Lower Hutt

The establishment of a bus lane on The Esplanade in Petone, Lower Hutt was established in 1995. The bus lane became operational in August 2004.

A5.1.6.1 Site location

The Esplanade runs along the Petone foreshore from Seaview Road to the Petone interchange in Lower Hutt. It is the main link for commuters to SH2 travelling from Eastbourne and Wainuiomata to Wellington city and the site area can be seen in figure A5.10.

A number of side streets along the eastbound side of The Esplanade provide access to and from Jackson Street, which runs parallel to The Esplanade and is the main shopping street in Petone.

The Esplanade is defined as a major district distributor with a 50km/h posted speed limit and characterised as a medium divided road with one lane available for eastbound traffic, and several turning bays for left-turning traffic, interspersed with kerb-side parking. The westbound lane is a single traffic lane until just prior to the Victoria Street intersection, where a second lane (central lane) is utilised as a special vehicle lane.

A5.1.6.2 Planning

The establishment of a bus lane on The Esplanade arises out of work undertaken by Hutt City Council from as early as 1992 (Hutt City Council 1992). Investigations identified that significant queuing delays on Hutt Road and The Esplanade were due to insufficient capacity on SH2 to absorb entering traffic flows. Travel time delays can range as high as 20 minutes. Investigations indicated that the provision of a bus lane along The Esplanade would offer up to five minutes or greater travel time saving on average journey times along The Esplanade for buses bypassing queued vehicles.

Figure A5.10 Locality of The Esplanade bus and taxi lane, Lower Hutt

The implementation of The Esplanade bus lane would seek to address the following objectives:

1 Reduce the time for bus travel to Wellington

2 Meet the objectives of Wellington Regional Council and Hutt City Council to promote greater use of public transport

3 Help reduce CO_2 and other green house gas emissions.

The estimated cost of a two-stage approach to implementing this bus lane within the existing road reserve in 1993/4 was $15,000.

Stage 1 Introduction of a special vehicle lane for buses, taxis and right-turning vehicles on The Esplanade between Buick Street and Armidale Street.

Stage 2 Extension of the bus lane from Armidale Street to Hutt Road depending on the monitoring and operation of stage 1.

An assessment of the lane's benefits was identified as $10,000 per year to buses and passengers while the non-benefits to motorists were estimated at $1500 per year.

However, the initial implementation of the bus lane was deferred pending further detailed monitoring of delays to bus traffic over an eight-week period on The Esplanade. Further investigations by council officers identified that the average delay in peak hours was 7.2 minutes. The delays to buses, airport shuttle services and taxis were such that a separate bus lane was warranted during the morning peak period 7am to 9am with provision also made for vehicles turning right into side streets.

In August 1994, stage 1 of the bus lane was implemented followed by stage 2 in 1995.

As early as 1992, council officers acknowledged that enforcement of the lane was likely to be necessary to ensure compliance due to the relatively low number of buses.

Prior to 2005 this lane operated without pavement colouring or enforcement by council officers. This was in part due to difficulties experienced across the country in obtaining council officers' warrants for the enforcement of managed lanes. Hutt City Council relies on police to monitor compliance.

A5.1.6.3 Management

The lane has performed well over the last 13 years with improved travel times for buses and taxis. Periodical non-compliance issues arising from the illegal use of the lane varies. Surveys in 2005 (MWH 2005) arising from public complaints of illegal vehicle use, indicated that 13% of vehicles using The Esplanade lane were non-compliant, which is comparable with unpainted bus lanes in Auckland (average of 11% non-compliance).

Recommendations of the 2005 survey concluded that colouring The Esplanade bus and taxi lane would reduce the level of non-compliance. The council recommended that the application of green pavement colouring be installed on the lane along with the upgrading of signage identifying lane users and operational times of the lane. Pavement colouring, surfacing and signage follows the Auckland BPISG guidelines (2005).

With the exception of the possibility of bus advances at key intersections, there are currently no additional managed lane measures proposed within the Petone area. It is envisaged that a significant amount of traffic may now be redirected away from The Esplanade as a result of major roading projects within the vicinity of The Esplanade and SH2.

A5.1.6.4 Design

The carriageway width on The Esplanade between Victoria Street and Te Puni Street comprises 2.2m parking with one 4.3m wide lane in the eastbound direction separated by a 3.7m wide median from the two westbound lanes. In the westbound direction the right lane (special vehicle lane) is 2.9m, and the left lane is 3.6m with a 0.6m shoulder.

A5.1.6.5 Operation

The establishment of this westbound bus and taxi lane operates in the right lane between 7am and 9am Monday to Friday for use by buses, taxis and right-turning traffic only. The lane is approximately 700m in length, starting just prior to the signalised pedestrian crossing east of Victoria Street intersection, and ending 200m from the roundabout at the Petone interchange. Two side streets, Victoria Street and Te Puni Street can be accessed over this length by right-turning traffic only (see figure A5.11). Pavement colouring of the lane was implemented in 2005/06 to improve compliance within the lane.

Figure A5.11 Petone Esplanade special vehicle lane (Source: MWH 2005)

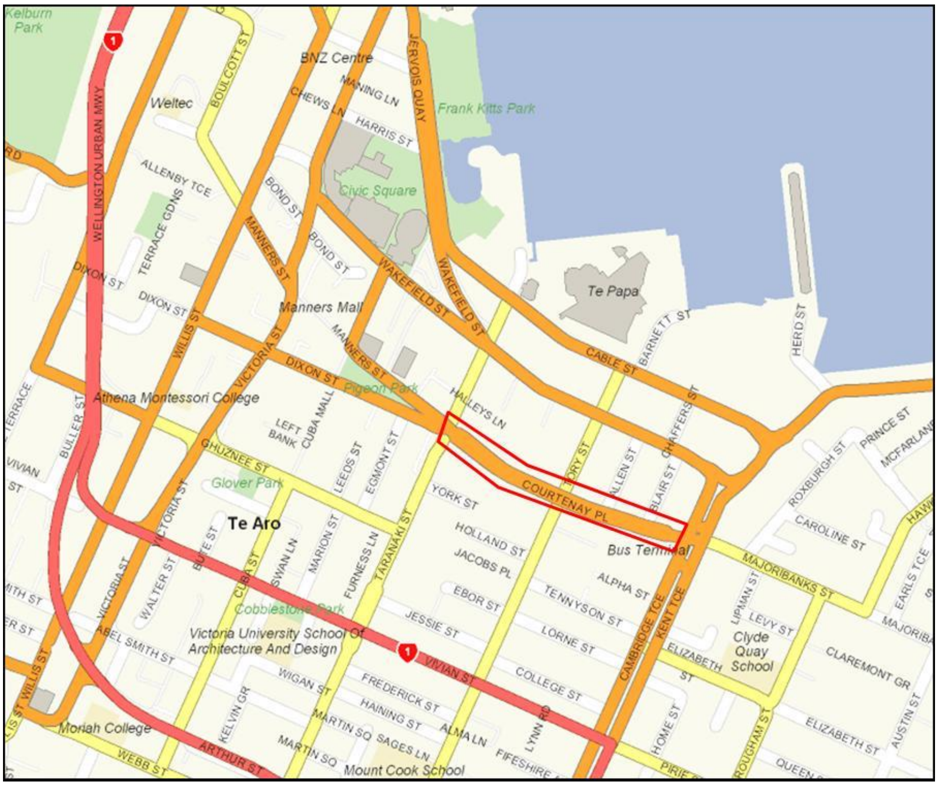
A5.1.7 Courtenay Place proposed bus lane, Wellington

A5.1.7.1 Planning

Site selection

WCC's (2007) bus priority plan *Choose to take the bus* identified a number of schemes within the city for implementation (refer to case study 3). Under measures for the central city, Courtenay Place was identified as the second busiest junction within the city's public transport network and a key part of the city's Golden Mile (see figure A5.12). Nearly 300 bus trips are made through Courtenay Place during the AM and PM peak periods, carrying around 40,000 passenger movements per day (WCC 2008).

Figure A5.12 Locality of Courtenay Place proposed bus lane, Wellington



As part of the Golden Mile, Courtenay Place supports the city's entertainment precinct and is an important retail and business location. For passenger transport, Courtenay Place is deemed a constraint which is weakening the city's public transport system. An evaluation by the council identified that the primary through movement of users within this area was as follows:

- buses
- pedestrians
- other vehicles and cyclists travelling through
- vehicles and cyclists accessing parking spaces
- taxis picking up and dropping off
- vehicles servicing local shops.

Buses are heavily constrained due to congestion resulting from delays in available corridor capacity (an estimated 6500 weekday trips are made through Courtenay Place), kerb-side parking friction and weekday vehicle trips.

The council advised that the average journey times for buses travelling through Courtenay Place were 1.5 minutes during the AM periods and 4.25 minutes during the PM periods. This time was recorded against a free-flow journey time of 40 seconds. Of relevance was the variability to bus passengers' journey travel times through Courtenay Place which could fluctuate between 40 seconds to in excess of 10 minutes.

Given these impediments to bus passengers and the critical nature of Courtenay Place to the city's passenger transport network, improvements to rationalise and prioritise the competing demands on limited road space, identified for Courtenay Place, were essential in the realisation of the city's bus network plan.

The proposed scheme had six key components which sought to 'unblock' Courtenay Place and strengthen its linkages to other priority schemes within the vicinity of this location through:

- directing cars, during peak hours, to use alternative routes such as Wakefield and Cable Street
- introducing bus lanes on Cambridge Terrace and Taranaki Street
- strongly encouraging bus companies to improve bus loading and offloading using new technology
- reducing the speed limit to 30km/h
- improving existing taxi loading and off loading
- investigating signalising the pedestrian crossing

These improvements would be retrofitted into the existing road space but would require the removal of kerbside parking during specific times of the day. During the hours of the lanes' operation, private vehicle users would be required to find an alternative car parking. Delivery and emergency vehicles would still have access.

The council had identified that there was no need to impose 24-hour restrictions on car access to Courtenay Place, as there was limited bus activity.

This scheme also sought to complement improvements to bus lanes on Cambridge Terrace. Additional provision on Kent Terrace would support the existing bus lane operating during the evening peaks, which currently carries in excess of 50 buses per hour. The council identified that these schemes would have minimal or zero impact on kerbside parking (WCC 2007). The council also said it would provide either bus or transit lanes on Taranaki Street should current bus volumes not exceed its threshold of 20 buses an hour.

Mandate

The mandate for the development of the Courtenay Place bus lanes stemmed from the approved bus priority plan *Choose to take the bus* (WCC 2007), which set out the development of the city's bus and HOV network over the next 10 years and was in accordance with the WCC (2006a) *Transport strategy*, including national and regional strategies and policies.

The plan placed Courtenay Place within proposed schemes for the central city. Each scheme identified, however, is subject to further detailed planning and consultation.

Consultation on the proposed Courtenay Place scheme was to be reported back to the council in late 2008.[17.] Parking provisions, while limited on Courtenay Place, were likely to be contested and could significantly affect the successful implementation of this scheme which was critical to the city's bus network.

Screening criteria

To assist the council in determining the proposed priority of the implementation of schemes identified within the bus priority plan, the following criteria were used:

- practical feasibility of introducing priority measures
- projects which give the greatest travel benefit to the most people according to a ranking system
- addressing known constraints and problems in the road network
- that the schemes' impact on the community is manageable.

Based on the above the plan would develop in the following order, according to the economic benefits arising from these areas:

- central city, followed by radial routes feeding the central city
- the growth spine, taking into account routes to Newtown and Kilbirnie in the south and Johnsonville in the north
- remaining key suburban routes.

Schemes for each of these areas would be developed based on each of the lines identified in figure A4.8 (refer to case study 3 in section A4.6 of this report) and approved by the council prior to implementation. Under the bus priority plan, Courtenay Place is included in central city priority routes for further consideration.

The primary measure of success identified by the WCC is the rate of schemes implemented within the plan. The pace and number of schemes implemented is based on the success of the previous schemes in relieving the following:

1. Congestion of buses
2. Known constraints in the road network
3. Predicated constraints as the result of development growth
4. Success in influencing mode shift, either to buses or ride-share for transit lanes.

Supporting travel demand management measures

The council, via the bus priority plan, would provide complementary infrastructure such as bus shelters and park and ride facilities.

While the council could provide managed lane provision, the success would also be dependent on support from the Greater Wellington Regional Council and bus operators in coverage and frequency of services and investment in bus infrastructure and real-time technologies.

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[17] This section relates to the Courtenay Place scheme prior to the 2012. The reader will note that in early 2012, bus lanes were installed on Courtenay Place to improve the reliability of services to and from the city and suburbs. Further details bus priority schemes implemented since this literature review can be found on the WCC website at: www.wellington.govt.nz/projects/ongoing/bus/prioritymeasures.html

A5.1.7.2 Design

Five proposed schemes were investigated. The preferred scheme, option two, consisted of a redesign of Courtenay Place to accommodate the movement of buses, relocation of on-street parking including the provision of taxi stands. The proposed scheme also sought to lower the existing speed to 30km/h from 50km/h to protect the vibrancy of the street's high pedestrian environment. Such a reduction in speed was consistent with the 30km/h limit on Lambton Quay and parts of Willis Street.

Signage and marking would reflect the proposed operational times of the lane option accepted by the council. Pavement markings, surface colouring and signage followed the BPISG standards.

A5.1.7.3 Operation

The investigation of the five schemes identified several options for buses to operate during peak hours, all of which required various restrictions to be imposed on access for cars. The level of restriction applied to cars was relative to the need to provide on-street parking to vehicles during the operational hours of bus lanes through Courtenay Place. Vehicle access for delivery and emergency vehicles would not be restricted. The bands of restrictive times imposed by the options were 7am to 9am and 4pm to 6pm.

A5.2 The United Kingdom experience

The UK has over 40 years experience in introducing bus priority projects into arterial and motorway corridors. The first bus lane was introduced in London in 1968. Since then bus priority has evolved from the simple introduction of bus lanes to improving all aspects of the bus passenger trip over an entire bus route.

In the UK, responsibility for the rules and regulations, and to an extent associated guidance, rests with the Department for Transport (DfT). Within Scotland, Wales and Northern Ireland the devolved governments have a range of powers but it is principally the DfT that leads, with minor variations on application, eg bilingual signs in Wales.

Implementation is split between the Highway Agency (or equivalent Transport Scotland/Welsh Assembly Government), for motorways and trunk roads, and local authorities/councils on local roads. Funding comes from a range of sources depending on location:

- DfT
- Welsh Assembly Government
- Scottish Government
- regional transport authorities (SPT/SESTRANS) (Scotland)
- passenger transport authorities/passenger transport executives
- Transport for London
- individual local authorities.

This means that the scope and scale of measures vary and the types of measures/improvements and approach can vary, even if the infrastructure design rules are similar.

The UK DfT, in recognition of the scope and scale of bus priority, has developed a resources pack: *Bus priority: the way ahead*, which has brought together a range of material in order to provide 'practical information and guidance on successful bus priority' (DfT 2004).

In terms of evolution of approach this can be tracked in two ways: in how improvements have been introduced and what is defined as bus priority.

A5.2.1 Treatment approach

There have been effectively three different approaches to introducing bus priority in the UK:

- site specific/hotspots
- bus corridors
- whole bus routes.

These can be described as:

- **Site specific/hotspots:** based on reviewing the bus network or feedback and developing bus priority measures to targeted specific problems/issues (often referred to as 'hotspots') within the site being investigated.
- **Corridors:** this approach identifies particular corridors, generally those with heavy bus usage and then applies a range of improvements along the corridor.
- **Whole bus routes:** similar to corridor approach, in that measures are applied along a pre-identified route travelled by a specific bus service.

The hotspot approach was applied initially and is still used, particularly by smaller local authorities. It does require an understanding of the bus network and conditions. Some local authorities keep a hotspot list developed with operators. Others may have a pool of funds that can be used for traffic management schemes that deliver specific bus benefits. A good example of the hotspot approach is the London Bus Priority Network (LBPN).

The LBPN was formed in 1994 by the 33 boroughs and London Transport who jointly developed, in liaison with the Government Office for London (GOL) and the then Traffic Director for London, a cross boundary bus network for the whole of London. Originally it was an 865km network of borough roads across London that complemented the priority (red) routes, although since 2003 it covers all borough roads that carry buses.

In the early years of LBPN, schemes were generally aimed at specific problem locations. An assessment would be undertaken of existing journey times, passengers, etc and a simple cost–benefit analysis produced against the journey time savings. The focus was on reducing journey time and improving reliability. In 1998 a new approach based on a whole route upgrade was piloted on London's route 43.

The intention was to address the problem caused by the hotspot approach, which tended to avoid tackling difficult problems, and just moved the bus delay to somewhere else along the route. The efficiency of a bus route is dictated by the weakest links in it. Thus the improvements were to be applied along the entire route ensuring continuity. The core principles applied to route 43, from GOL (1998) *Traffic management and parking guidance for London* and 'Integrated transport policy' from DETR (1998), were:

- *the management of traffic and road space should be based on the movement of people and goods;*
- *a more strategic approach to parking with the objective of securing a shift to more sustainable transport modes for travel to London's numerous "town centres*"
- *greater emphasis on measures to assist buses, cyclists, and pedestrians thereby opening up a wider set of transport choices for all and reducing dependency on the car*
- *a clearer recognition of the needs of all road users, especially people with disabilities or difficulties with walking; and*

- *better interchange between modes, particularly from bus and car to rail and underground, and from public transport to walking; this must be adequately reflected in the local management of traffic and parking.*

Thus a more holistic approach and range of improvements would be applied.

The perceived success of this approach led to the London Bus Initiative (LBI), a three-year fixed term initiative established in April 2000 covering 27 high-frequency routes. This has then moved on with LBI 2, and latterly 3rd Generation Bus Priority (3GBP) delivering whole-route bus priority measures. The scope and scale of bus priority will be discussed later in this section. However, the key feature of the route-based approach is that it tends to cover not just infrastructure on the ground, ie bus lanes to bus shelters, but also the buses, information and enforcement.

Similar programmes have been undertaken elsewhere in the UK such as the Showcase routes in the Midlands and in Merseyside with the SMART programme. Identifying a particular bus route for improvements means that, working with the operators, the vehicles can be upgraded and branded.

The corridor approach is similar to that for routes focusing on an identified corridor used by buses, although in practice many corridors follow a route served by a particular service. It is now the orthodox way of introducing bus priority improvements in the UK and there are various examples of bus corridors or quality bus corridor (QBC) type projects, such as:

- SEMMS and JETTS QBCs (Greater Manchester)
- Streamline (Glasgow)
- A65 QBC (Leeds)

The common theme throughout is the provision of continuity along a road/corridor and a wider definition of bus priority.

A5.2.2 What is bus priority in the UK?

Understanding what is meant by bus priority, and how this has changed, is important in understanding its context and evolution in the UK. In its simplest form, bus priority means measures that improve the journey time and reliability of buses in giving them priority, or an advantage over other traffic. In its most recognised form, bus priority is epitomised by bus lanes. Within this traditional understanding, a range of traffic engineering measures are applied in the UK including:

- with-flow bus lanes
- contra-flow bus lanes
- bus gates
- bus only links
- guided busways
- pre-signals and bus advance areas
- selective vehicle detection
- bus SCOOT (split, cycle and offset optimisation technique).

However, the general application of corridor/whole route treatments has expanded the scope of measures to a wider context that can include a range of less overt and other complementary measures. The main objectives of the QBCs in Greater Manchester illustrate this:

- Reduce bus journey time to make them more competitive with the car.
- Reduce variability of bus journey times and consequent reliability of services.
- Increase the comfort and convenience of bus travel for all users.
- Ensure that bus services provide a real alternative to car use.
- Improve pedestrian and cycle facilities along the corridors.

Bus stops, and all aspects of their design, from the bus cage to the flag and shelter, are seen as intrinsic to bus improvements on a QBC. Well designed bus stops have been shown to not only improve accessibility and passenger experience but also reduce journey time by improving boarding/alighting.

Parking and loading on-street is a major issue for buses. Kerbside parking and loading can reduce highway capacity by increasing congestion and delays. Where bus lanes are introduced, parking/loading is generally removed and this leads to consultation and implementation issues, with many schemes opposed because of the removal of parking, and perceived impact on businesses. Thus many corridors incorporate reviews of parking and loading, and the provision of loading bays and parking laybys, etc as part of the improvements. A proactive approach to parking and loading as undertaken on the Red Routes in London and Birmingham has, by organising and rationalising kerbside space, led to improved journey times for buses.

Pedestrians and cyclists are generally considered within corridor/whole route schemes. For pedestrians, or passengers, it is the issue of access to and from the bus stop and provision of crossings. Cyclists tend to benefit from measures such as bus lanes but also tend to gain additional specific improvements under corridor/route treatments.

Traffic signals play an important part in managing traffic in urban areas. Consequently they have an impact on bus journey times. This has been addressed with specific bus priority measures such as selective vehicle detection, and bus pre-signals that assist buses in bypassing queues or getting more green light opportunities. Other strategies and approaches have also been developed with traffic gating, holding non-bus traffic and the associated idea of virtual bus lanes.

A5.2.3 M4 bus lane, London

Possibly one of the most controversial and well publicised bus priority schemes in the UK is the M4 bus lane (see figure A5.13). On the M4 in-bound carriageway between Heathrow and central London, there is a 5.6km lane for buses, coaches, motor-cycles and taxis. Introduced in 1999, along with a 50mph (80km) speed limit, the scheme introduced the lane on a section where the road narrowed from three to two lanes, starting the narrowing point earlier for general traffic, therefore smoothing the merge.

Figure A5.13 M4 bus lane (picture from the BBC)

Highly controversial research undertaken by TRL indicated that despite a 10% increase in traffic in the months after the bus lane became operational, during the morning peak the following journey time decreases were noted:

- coaches and taxis using the dedicated lane saved up to nine minutes
- other vehicles saved up to six minutes.

An average of 3400 vehicles use the bus lane daily: 700 are coaches or minibuses and 2700 are taxis. Improved journey times were also documented during the evening rush hour and on Sunday evenings. In the off-peak hours the journey times increased by one minute for buses and 30 seconds for other vehicles. Arguments raged about the apparent limited usage of the bus lane and penalising of motorists. In October 2010 the new Conservative Transport Secretary, Mr Hammond, announced, 'Nothing is more symbolic of Labour's war on the motorist than the M4 bus lane.' The result was the scrapping of the bus lane in 2010.[18]

A5.2.4 Portwood roundabout, Stockport

The Portwood roundabout is at junction 27 of the M60. Various bus services passing through the large signal-controlled roundabout were subject to delays. A scheme to reduce the delays experienced by bus services without impacting on general traffic resulted in a new bus-only link across the existing roundabout. The short length of bus lane gives access to a 130m long bus-only road across the large, busy roundabout. The new bus-only link allows seven bus services, travelling from the centre of Stockport along Great Portwood Street, to reach Carrington Road without negotiating the roundabout (see figure A5.14).

The scheme has resulted in bus journey-time reductions with minimal impact on other traffic.

- 35% journey-time savings over all time periods (43 seconds)
- 47% journey-time saving in AM peak (69 seconds)
- 41% journey-time saving in PM peak (23 seconds)
- 41% journey-time saving in off-peak (50 seconds)

Figure A5.14 Portwood roundabout junction 27 – bus only road

[18] The M4 bus lane would be reopened as a 'Games Lane' for the 2012 Olympic Games to allow permitted vehicles, eg Olympic buses to travel congestion free. Further details are available at www.dailymail.co.uk/news/article-2173301/Hated-M4-bus-lane-springs-life-Monday--exclusive-use-Olympic-VIPs-coaches.htm

Pre-signals and bus advance areas

These measures use traffic signals to provide bus priority by holding general traffic at a set of lights a short distance from the main junction, allowing buses to get to the head of, and bypass the queue.

The measure is designed to overcome the issue with traditional bus lane setbacks of buses merging back into the traffic stream. It provides particular benefits where there are buses performing right-turn movements, or where it supports a gating strategy.

The disadvantage is that it can cause unnecessary delays to buses, and other traffic, in low-flow situations and can in some situations provide little benefit over a normal bus lane setback. Consequently some of the schemes implemented in previous years have gradually been removed.

There are a number of variations of layout and method of control.

> *The University of Southampton's Transport Research Group has identified three main categories of pre-signals that can be used to provide priority for buses at busy junctions:*
>
> - *Category A*
> - *These are described as pre-signals where buses are not controlled by a pre signal pre-signal, whereas general traffic is. This means that while traffic is held at the pre signals pre-signals, buses can proceed straight to the main junction uncontrolled. However when the general traffic has a green signal, buses will have to give way to the main traffic flow [see figure A5.16].*
> - *Category B*
>
>   *At these pre-signals buses are controlled in the same way as general traffic, so buses have priority when general traffic is held at a red pre-signal and vice versa [see figure A5.15].*
> - *Category C*
>
>   *These pre signals are defined as those that use vehicle detection to activate the pre signals pre-signals and give priority to approaching buses. This would mean that delays to general traffic may be minimised as they are only stopped if an approaching bus is detected. Once a bus is detected and the general traffic has been stopped at the pre signals pre-signals the bus can then proceed to the main junction without delay.*
>
> From *Bus priority: the way ahead* (DfT 2004)

Figure A5.15 Category B pre-signal – Bristol

A5.2.5 North Road, Cardiff, Wales

A5.2.5.1 Background

The Boulevard de Nantes/Kingsway/North Road junction is a key gateway to Cardiff city centre. Much of the traffic arriving at the junction originates from north of the city centre, including commuters, shoppers, freight, taxis, buses and cyclists.

In the morning peak, buses would experience delays on the southbound approach to the junction, due to the queuing of general traffic.

The operation of the junction was reviewed and options developed to provide bus priority measures over general traffic enabling buses to bypass the queues and get a ‘head start’ on their entry to the city centre.

Assessment and design

The operation of the junction was reviewed and a number of objectives identified. It was important to allow buses to bypass queues, and to assist bus movements to and from the southbound bus stop. There were also other issues in terms of lane usage on the other approaches.

The junction was modelled in both LINSIG and VISSIM and a phased approach developed. The first phase was the introduction of a bus gate on the North Road (southbound) approach. A length of bus lane was provided to allow buses to bypass the queues. Modelling indicated that the bus lane length, while restricted by land issues, would be sufficient for bypassing the queuing general traffic.

The second phase of work looked at the lane usage on the North Road (southbound) and Boulevard de Nantes approaches. The design was developed to allow for changes in what turning movements were permitted from each lane in future phases, when additional bus priority measures were introduced elsewhere on the network.

Implementation

The bus pre-signals and bus lane were installed in November 2009. The measures have improved bus journey times to the junction without having a significant impact on general traffic.

Selective vehicle detection (SVD), bus SCOOT and automatic vehicle locating (AVL)

Traffic signals are an important tool in controlling traffic. The technology provides the opportunity to prioritise vehicles through changes to the method of control and signal timings. This can be achieved by extending phases, skipping stages or reducing phase time on non-bus approaches. The application of this type of bus priority technology through SVD, Bus SCOOT or AVL is common throughout the UK. While the older systems use a mix of detectors, beacons and transponders, the latest systems such as iBUS in London utilise GPS-based location systems.

Figure A5.16 Changes to bus journey times (AM peaks)

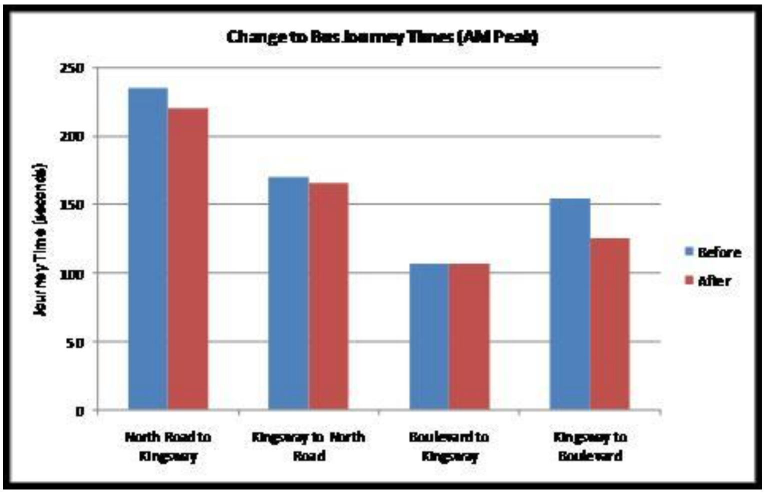


Figure A5.17 Before and after bus advance SVD treatments

a) Before treatment

b) After (category A pre-signal) treatment

A5.2.6 iBUS, London

As discussed above, the London iBUS system utilises GPS technology and other on-bus systems such as odometer output and door sensors to communicate with the bus's on-board computer. The computer, known as the iBIS plus unit, is programmed with bus priority and other relevant information such as bus location details.

When a virtual detection point, as programmed into the iBIS plus software, is reached, a signal is sent to the transceiver in the signal controller, requesting bus priority, and to a central location for performance monitoring. The new bus location system provides a far greater degree of information about the bus and its journey than previous systems, and will be used for other purposes such as the provision of real-time passenger information displayed in bus shelters. Additional benefits for SVD utilising iBUS technology include:

- reduced cost of roll-out per SVD junction
- more SVD junctions can be delivered for the same money
- increased speed of roll-out
- decreased maintenance costs

- less requirement for roadside furniture
- increased performance information for SVD system.

Table A5.4 Bus priority at traffic signals

Bus priority systems	Test sites	Average journey time savings/ bus/junction (secs)	Average delay savings	System payback period
SVD at isolated junctions	Widespread rollout	9	32%	15 months
SVD at MOVA junctions	Hanworth	4-6	x	x
SPRINT	Uxbridge Road	2	x	x
Bus SCOOT	Edgware Road	3	33%	15 months
	Camden Road	5	22%	15 months
	Uxbridge Road	4	19%	5 months
	Twickenham town centre	2-5	6%	18 months
	Bromley	3-5	19%	10 months
	Kennington	3-5	16%	10 months
Metering in Bus SCOOT with bus lanes (AM peak)	Twickenham town centre	5	13%	7 months

Note:
X = not available
MOVA – allows more flexible control of isolated junctions
SPRINT – allows active bus priority within a fixed-time urban traffic control network
Bus SCOOT – allows active bus priority within SCOOT (a traffic-responsive urban traffic control system)

Source: TfL (2006)

A5.3 The Australia experience

In Western Australia, the Public Transport Authority (PTA 2004) lists transport objectives and measurable performance criteria to justify any bus priority measures. The transport objectives are listed below. It is noted that this document has also been referred to in the *Bus priority guidelines* prepared by VicRoads (2003) in Victoria.

- Increase the people-moving capacity of the existing and planned road system.
- Increase the utilisation and efficiency of road-based public transport.
- Reduce vehicle emissions per person-trip (improve air quality).
- Reduce use of non-renewable fuels per person trip (conserve non-renewable fuels).

While the objectives of implementing bus priority measures may vary slightly in different parts of Australia, the ultimate goal of this implementation is to achieve greater people-moving capacity by better allocation of road space. The conventional increase in road capacity by road widening does not provide enduring benefits for all road users as the congestion problem may arise with increasing traffic growth.

In terms of road space allocation, VicRoads (2003) stated that carriageway widening for an additional bus lane should not be recognised as a sound bus priority measure. It is expected that benefits for buses would not be sustained as congestion increases. The most useful bus priority measure should be able to be implemented within the existing carriageway.

A5.3.1 Gold Coast Highway – bus lane

A5.3.1.1 Planning

The Gold Coast Highway is approximately 33km long, connecting the coastal suburbs of the Gold Coast and providing access to popular tourist attractions.

The case study discussed here is a 6.4km section of the Gold Coast Highway. This section of the highway is a four-lane arterial road, containing 12 signalised intersections and three signalised pedestrian crossings. There are a total of 40 buses travelling at an average speed of 29km/h in both directions for the AM peak hour (Jepson et al 1999). Note that the average speed will increase during peak tourist periods due to higher traffic volumes on the highway.

During off-peak tourist periods, the highway carries between 1000vph and 2000vph in the peak periods travelling at an average speed of 40km/h; this increases to up to 30% during peak tourist periods.

A5.3.1.2 Investigation

Jepson et al (1998) evaluated a range of bus priority treatments and criteria for justification using quantitative analysis of various traffic conditions. Comparing with the average bus journey time of 782 seconds, table A5.5 tabulates the estimated bus travel time saving for various bus priority treatments along the study section.

Jepson et al (1999) recommended the implementation of a kerbside bus lane with selective active signal priorities and improved ticketing systems. This would potentially result in up to 20% of travel time savings for the four-lane Gold Coast Highway. It is further noted that with no adverse impacts on cars and the general purpose traffic on the highway, the improved ticketing system may itself promote a seven seconds/passenger bus travel time savings.

Table A5.5 Impact of various bus priority treatments on Gold Coast Highway

Type of priority	Saving to bus travel time (seconds)	Impact on the existing conditions for general purpose lanes
Bus lanes (with no signal priority)		
• Extended through intersection	60	Nil
• Set back from intersection stop line	48	Nil
Active bus priority[a]		
• Dedicated bus phase[a]	147	Extra delays of 7s major approach and 5–120s for minor approach.
• Queue jump bus phase[a]	48	Extra delays of 7s major approach and 5–120s for minor approach.
• Absolute bus priority[a]	147	Extra delays of up to 150s on minor approaches
• Selected bus priority[a]	75	Extra delays up to 22s on minor approaches
Passive bus priority		
• Design of traffic signals to suit bus journey speed	36	Extra delays of 7s major approach and 5–120s for minor approach
Transit lane	24	Nil
Busway	147	Nil
Improved ticketing system	88	Nil
Review of bus stop locations	n/a	Nil
Note: [a] indicates that it is assumed that bus lanes are provided in addition to active signal priority.		

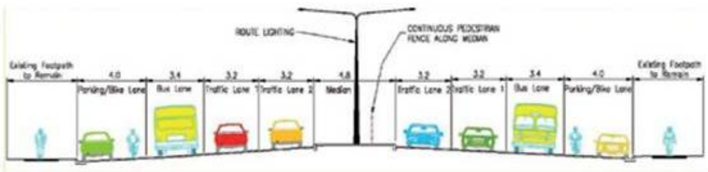
(Source: Jepson et al 1999)

A5.3.1.3 Design

The bus priority upgrades consisted of widening the corridor from four lanes to a six-lane corridor as shown in figure A5.18 with buses having their own lane to reduce travel time and improve reliability of public transport services. In addition there are new traffic signals, new line marking and street lighting. Each intersection will have their own turn or u-turn lane to eliminate hold ups caused by motorist wanting to turn.

Improving safety was also a focus of this project implementing a central median that has been fenced for safety, to bring all pedestrian and vehicle crossings under the control of traffic signals. With six traffic lanes, two parking lanes and one turning lane at each intersection, statistics indicate that of 13 fatalities on this road (1992–2006), 11 were pedestrians.

Figure A5.18 Typical cross section of the Gold Coast Highway upgrade incorporating 24-hour bus lanes



Source: Queensland Main Roads (2007)

Figure A5.19 illustrates a section of the Gold Coast Highway incorporating the six lanes with the intersection upgrade.

Figure A5.19 Layout of additional bus lanes and upgrade to traffic signals

Source: Queensland Main Roads (2007)

The following list indicates specific design features that have been incorporated into the design of the corridor.

Traffic signals:

- Signals are upgraded at eight intersections, providing for u-turns at all.
- Pedestrian signals are upgraded at Miami State High School opposite Paradise Avenue.

Safety features:

- All highway crossings by both vehicles and pedestrians are controlled by traffic signals.
- Central medians include a pedestrian barrier or fence.

- Angle parking has been changed to parallel to fit bus lanes within the road reserve and eliminate vehicles reversing into traffic.

Bicycles:

- Cyclists use a shared 4m parking/bike lane.
- Line markings at intersections identify where cyclists should cross.
- Hedges Avenue and Albatross Avenue remain the council-designated bikeway.

Buses:

- Bus stops are located at 400m intervals. Most are existing bus stops. They will be upgraded with TransLink bus information and infrastructure.
- Transport and Main Roads and TransLink are liaising with Miami State High School to improve its bus facilities.

Traffic flow:

- Speed limit is 60km/h.
- Signal adjustments and provision for u-turns improve traffic management and traffic flow.
- All streets are open to the highway (left-in and left-out).

A5.3.1.4 Operation

Jepson et al (1999) estimated that the bus priority treatments for the Gold Coast Highway would result in reductions of bus delays from improved ticketing and passenger information systems, which would substantially reduce the average overall bus journey time. The average loading time was observed at 12 seconds per passenger and reduced to around 5 seconds per passenger; a total of 88 seconds would be saved for an average loading of 12 passengers.

A5.3.1.5 Cost

This project involved the major reconstruction of the Gold Coast Highway to modernise and support the expansion of public transport with a continuous 24-hour bus lane. This project was funded by the Queensland state government at a cost of AUD$29 million and completed in 2009.

A5.3.2 South East Busway bus rapid transit (BRT) system, Brisbane

A5.3.2.1 Planning

The Brisbane BRT system shown in figure A5.20 is recognised as Australia’s most successful BRT system. The BRT system discussed in this case study is the Brisbane South East Busway (BSEB), completed in 2001.

Figure A5.20 TransLink busway network map

Source: www.translink.com.au/maps.php

A5.3.2.2 Design

The BSEB is a 16.5km unguided dedicated busway facility, connecting Eight Mile Plains to the CBD (figures A5.21 and A5.22 refer). Average bus travel speed on the busway is between 55km/h and 58km/h, equating to an average travel time of 18 minutes. There are currently 10 high-quality bus stations on the BSEB, providing level boarding platforms and grade-separated pedestrian access between platforms (Currie 2006).

Figure A5.21 Brisbane South East Busway – typical bypass lanes at station

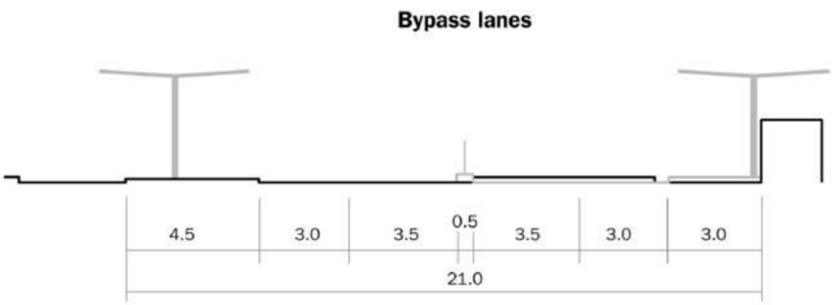
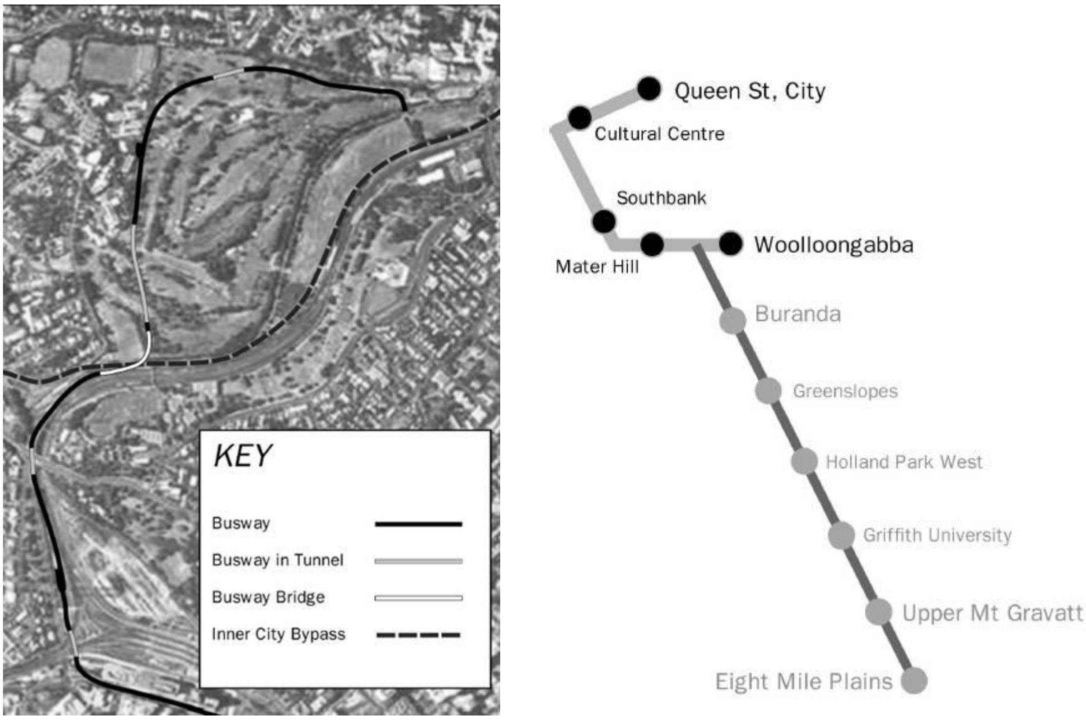


Figure A5.22 Brisbane South East Busway development and proposed station locations



The BSEB is located along one side of a six-lane freeway through much of the corridor. The cross section between stations consists of two 3.5m travel lanes.

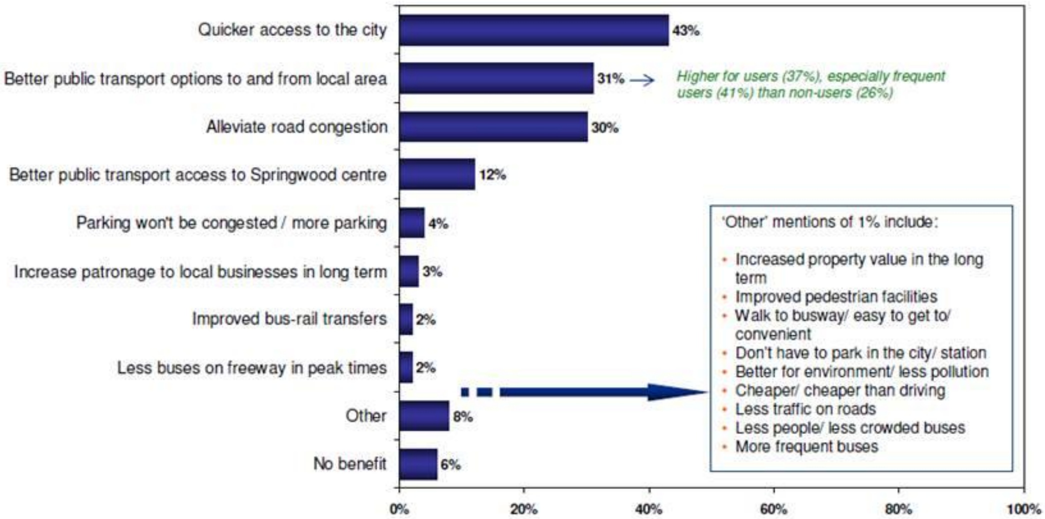
Bypass lanes are provided at stations to enable express buses to pass buses making stops (see figure A5.21). A 0.5m barrier with a fence separates two 3.5m travel lanes. These lanes are flanked by two 3.5m lanes for stopped buses. The entire busway envelope, including station platforms, occupies a 21m right-of-way.

A5.3.2.3 Operation

Since the implementation of the BSEB, buses gain 42 minutes travel time savings compared with a 60-minute motorway trip from Eight Mile Plains to the CBD (Deutscher and Pasieczny 2003). With over 140 buses per hour using the busiest section of the busway carrying 9500 people each way, the BSEB is operating at near or full cost recovery with little or no public subsidy (Golotta and Hensher 2008).

In 2007 Translink commissioned a public survey of BSEB community users. Of the benefits perceived by the public, the two top responses were faster travel times and better public transport options. This is shown in figure A5.23. Residents highlighted that the busway was important to the community, regardless of whether they used public transport or not.

Figure A5.23 TSN Social Research – benefits of the Brisbane South East Busway



Source: TransLink 2007

The TransLink research revealed a high use of the existing BSEB among residents in the catchment corridor:

- As expected, 'users' are more likely to have used the South East Busway (95%), however four out of five 'non-users' (82%) have also used the busway in the past.
- Those who have used the BSEB have been satisfied with the facilities (mean score of 8.0 out of 10) and services (mean score of 7.9 out of 10).

A5.3.2.4 Cost

The construction cost of the BSEB was AUD$24 – $40 million per kilometre due to the high-quality station design

A5.3.3 Lutwyche Road bus lane and T3 lane, Brisbane

A5.3.3.1 Design

Lutwyche Road has both bus lane and T3 lane facilities. In the inbound direction, a T3 lane operates between Annie Street and Horace Street from 7am to 9am, before Lutwyche Road continues as a 24-hour bus lane to Water Street. In the outbound direction, a 24-hour bus lane is currently operating between Gilchrest Avenue and Horace Street.

A5.3.3.2 Operation

Maunsell (2005) indicated that approximately 4% of the traffic used the inbound T3 lane and 83% of the vehicles had less than three passengers which did not justify the implementation of the T3 lane.

Bauer et al (2005) summarised the operations of the Lutwyche Road T3 lane in table A5.6 below. It is noted from Bauer's research that:

- There was a six minutes travel time savings for HOVs (excluding buses) travelling on the T3 lane in comparison with the total travel time of 20 minutes in the adjacent traffic lanes. However, it is also noted that buses did not experience any travel time savings because of time spent at bus stops. The average travel time for buses was 23 minutes, which is longer than the 20 minutes travel time on the adjacent lane.

- Both buses (on the HOV lane) and the general traffic experienced a level of service (LOS) F. Only HOVs (excluding buses) that travelled on the T3 lane experienced a reasonable LOS C.

Table A5.6 Lutwyche Road T3 lane summary

Lutwyche Road	T3 (HOV 3+) lane			2 general purpose (GP) lanes	Overall corridor
	HOV	Bus	Total		
Per-lane efficiency (person km/h per h)	33,900	16,300	50,300	33,000	122,800 (HOV+2xGP)
Vehicle volume (veh/h)	334	35	369	1,241	2,851 (HOV +2xGP)
AVO	1.95	41.6	5.37	1.24	1.89
Market share (% based on vehicle freq)	9.7	1.4	15.8 (4.7 illegal)	84.2	100
Market share (% based on persons)	11.3	30.0	44.9 (3.5 illegal)	55.1	100
Average travel time (min:sec)	14:02	23:57	-	20:02	-
Travel time difference to GP (min:sec)	-6.00 (-30%)	+3.55 (+20%)	-	-	-
Average travel speed (km/h)	31.6	19.2	-	22.4	-
Travel speed difference to GP (km/h)	+9.2 (+29%)	-3.2 (-14%)	-	-	-
Travel speed deviation	2.5	3.1	-	2.7	-
Travel speed standard deviation compared to GP	-0.2 (-7%)	+0.4 (15%)	-	-	-
HCM corridor level of service	C	F	-	F	-
Violation rate	-	-	32.8%	-	-

(Source: Bauer et al 2005)

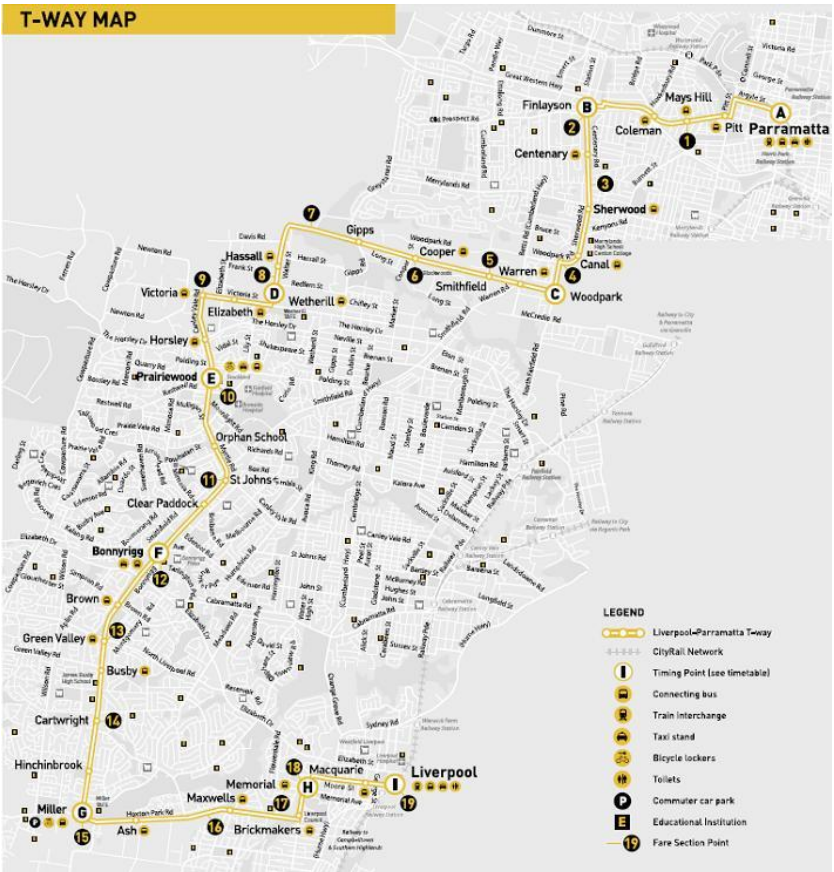
A5.3.4 Liverpool to Parramatta Transitway, Sydney

A5.3.4.1 Planning

The Liverpool to Parramatta Rapid Bus Transitway (LPT) is a public infrastructure, built in 2003 and owned by the state government. It is the first of seven rapid bus corridors planned for western Sydney. The purpose of the infrastructure is to provide quality public transport, initially by buses. The newly built sections of dedicated roadway are future proofed and built to a standard that could be used by light rail (trams) if the demand increased enough in the future.

The 31km LPT provides north-south public transport services, connecting the centres of Liverpool, Parramatta and suburbs along the route to major employment, education and recreation centres. It provides an alternative public transport connection to the Prairiewood and Bonnyrigg interchanges. These two interchanges were traditionally served by rail and east-west bus services until the operation of LPT provided the first effective public transport link across the region. Refer to figure A5.24 for the LPT route map.

Figure A5.24 LPT route map



Source: www.sydneybuses.info/western-sydney-buses.htm

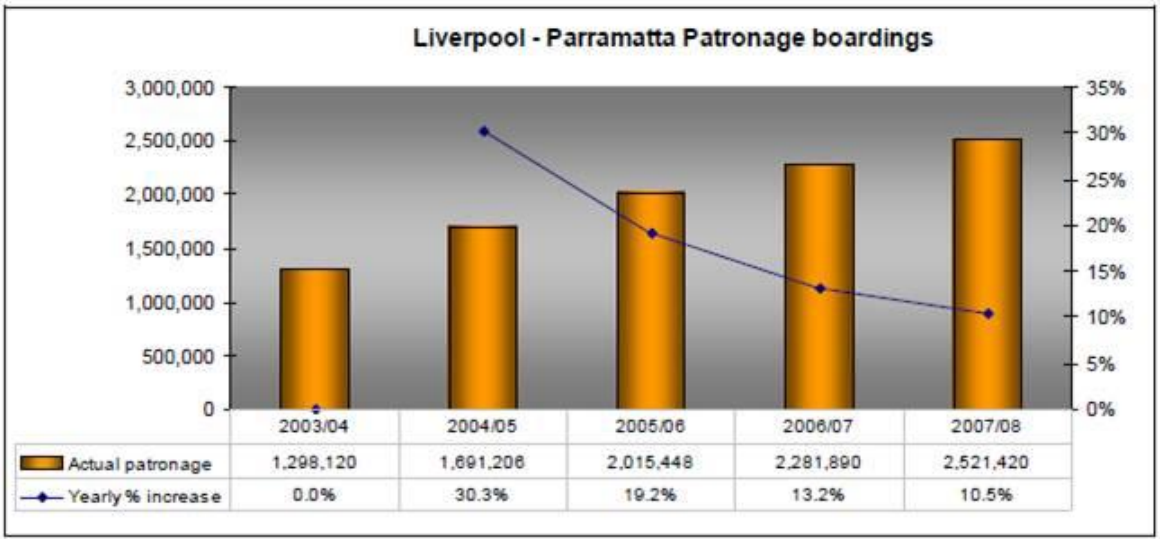
A5.3.4.2 Design

The LPT includes 20km of new bus-only roadway (dedicated busway) with one lane in each direction, and 11km of priority lanes for buses along existing or widened streets. There are 35 purpose-built stations and two major interchanges on each end. The route contains 59 signalised intersections, of which 28 intersections have bus-priority signals.

A5.3.4.3 Operation of the advance detectors at signalised intersections

The travel time from Liverpool to Parramatta (southbound) using the LPT is about 60 to 65 minutes. However, the travel time between these two centres by train ranges between 25 minutes (peak periods) to 50 minutes (off-peak service requiring interchange at Granville Station). The longer travel time by bus is due to the lack of directness of the bus service corridor; hence the LPT is less favourable for passengers wanting to travel the full length of the route. In fact, the Cumberland heavy rail line is often the preferred choice for the full length travel. This statement concurs with the field survey data determined by Vandebona and Rossi (2006) showing that the average travel distance of passengers using the LPT is about half the total route length. Despite the lack of directness of the LPT, the patronage counts have steadily increased (Australian Transport Council 2009). This is shown in figure A5.25.

Figure A5.25 Growth of patronage since opening of LPT



Source: Australian Transport Council (2009)

Quantification benefits due to advance detectors

There are three types of advance detectors installed on the LPT (Vandebona and Rossi 2006). In the southbound direction, these include:

1 12 non-stopping intersections. This means that buses get a clear passage through intersections without stopping.

2 10 intersections where stopping time is less than six seconds.

3 Six intersections where stopping time is greater than six seconds.

The benefits as a result of these 28 intersections are:

- About 3% – 4% gain in terms of percentage bus travel time (Vandebona and Rossi 2006), compared with another international example at San Juan of 1% – 2% gain (Janos and Furth 2002).
- Passenger savings are 16.2 passenger minutes per bus run in the southbound direction which takes a total of 60 to 65 minutes travel time, passing 28 priority intersections (Vandebona and Rossi 2006), compared with the Auckland example of approximately 11 passenger seconds per intersection (Gardner et al 2009)
- The reduction in stops will lead to savings in vehicle operating costs. RTA (2003) recommended an operating cost of AUD$0.6150 for each brief stop made by heavy vehicles.

A5.3.4.4 Cost

The LPT construction cost was approximately AUD$350 million, of which about AUD$25 million was spent on the construction of interchanges and stops (NSW Audit Office 2005).

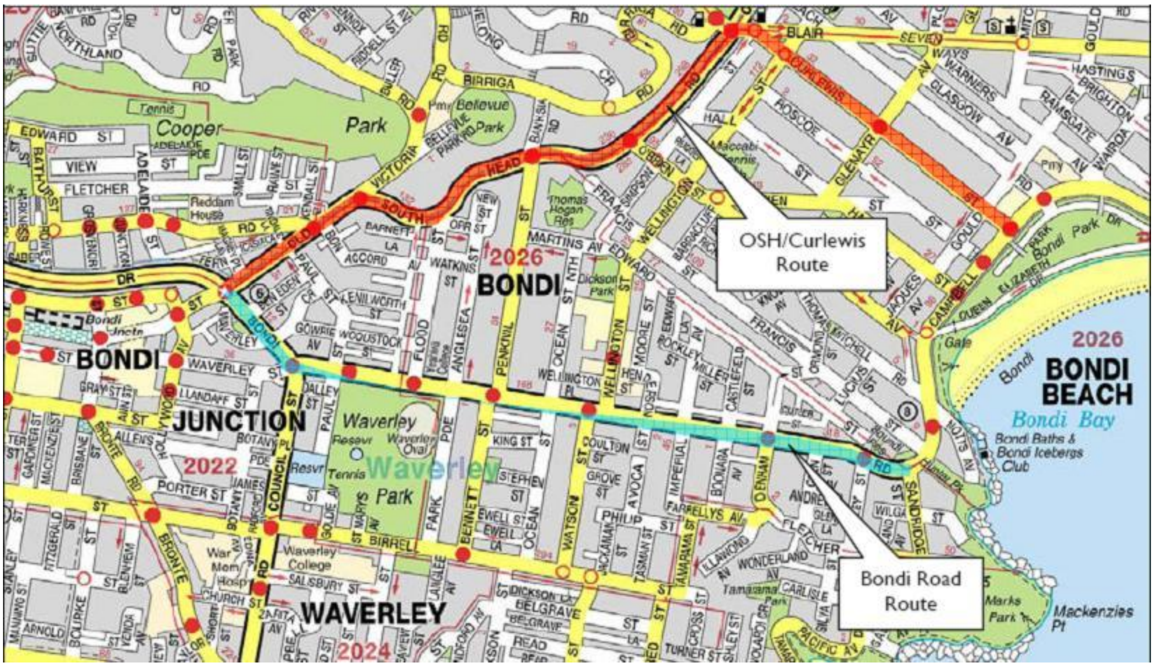
A5.3.5 Bondi Road clearway, Sydney

A5.3.5.1 Planning

Bondi Road is a four-lane road, with a posted operating speed of 50km/h. Prior to the implementation of the clearway, there were approximately 1400 vehicles in the peak hour utilising the inner lane, as the kerbside lane was quite often occupied by parked vehicles. This situation resulted in traffic queuing and congestion.

Figure A5.26 shows that Bondi Road connects the suburbs of Bondi Beach, Bondi and Bondi Junction within the Waverley Council local government area in Sydney. Bondi Beach is a popular tourist destination while Bondi Junction is an important transport hub where the eastern suburbs and Illawarra rail line terminate. Bondi Junction is also a major commercial/retail hub for the eastern suburbs. Sitting between Bondi Beach and Bondi Junction is the suburb of Bondi which contains a wide range of businesses directly fronting Bondi Road.

Figure A5.26 Location map



Source: RTA 2009

Due to the land use in these three suburbs, there are high traffic volumes during business hours and also on weekends along Bondi Road and at Bondi Beach, particularly in summer. RTA (2009) traffic flow analysis details that the increase in traffic causes significant delays during weekends, and in the afternoon peak (3pm – 7pm) in the westbound direction as people leave Bondi Beach.

Aiming to improve bus travel times and reduce delays for passengers, the State Transit Authority (STA) requested the RTA to implement a trial weekend clearway along Bondi Road westbound in the summer 2008/2009.

A5.3.5.2 Design

The trial 1.6km Bondi Road clearway operated between Sandridge Street and Council Street on Bondi Road westbound between 3pm and 7pm on Saturdays, Sundays and public holidays.

The length of the clearway resulted in 135 parking spaces being removed from the kerbside lane. Among the 135 parking spaces were 51 parking spaces located outside the shops fronting Bondi Road. To compensate for the loss of parking, RTA provided 54 restricted parking spaces, in the side streets, in close proximity to the commercial areas on Bondi Road.

A5.3.5.3 Operation

Network inspections carried out by RTA (2009) show there was a reduction in congestion during the clearway operational hours.

The quantified benefits due to the Bondi Road Clearway were:

- kerbside lane utilisation increased from 10% – 15% to 30% – 40%
- bus travel time improved from 20 to 30 minutes to an average of seven minutes
- over 95% of the bus services were on time with no cancellation of services
- higher parking turnover due to the parking restrictions in place in the commercial areas – this has not, however, been further investigated.

A5.4 Development of bus priority interventions in the USA

The USA has been at the forefront of building and operating HOV lanes for many years, with California and Texas, in particular, making widespread use of these lanes. The development of HOV lanes occurs within the freeway environment, resulting in many large-scale projects. For instance, a typical freeway improvement for a 2.6 mile (4km) section of the IH-10 in Texas required the widening of the existing dual three-lane freeway with one HOV lane and frontage roads, to dual five lanes with two HOV lanes and frontage roads. The planning and design of such facilities is based on the AASHTO standards which have been developed by various states (KBR 2004).

Other frequently used solutions are HOV queue bypasses on freeway on-ramps, which often require the construction of flyovers (Turnbull and DeJohn 2000). The I-287 HOV lane feasibility study recommended line haul HOV treatments, HOV ramps at the interchanges and access improvements at the I-78/I-287 interchange. The plan elements reflected design limitations, physical constraints and travel characteristics in different parts of the corridor (Turnbull and DeJohn 2000). Flyovers and T-bone ramps were provided to reduce the amount of weaving required by HOVs to access HOV lanes and to link HOV lanes directly with park and ride sites and bus stations.

Off-side HOV lanes (in the median) are preferred to near-side (kerb) lanes. An advantage of the off-side lane is that once the HOV gets there it avoids continuous weaving through the entering and exiting traffic. A disadvantage, however, is that the HOV has to weave through main traffic stream to get to or exit the HOV lane. A distance of approximately 500m has been considered as desirable between slip road tapers and the start or end of HOV lanes. On the other hand, in the USA direct access to and from HOV lanes is generally preferred over designs that require manoeuvres across several motorway lanes (KBR 2004).

It is worth noting that the development of HOV lanes on the near-side means that HOVs have to negotiate with merging and weaving lanes (if on a freeway) and vehicles wishing to turn left to enter or exiting properties and driveways (if transit lanes are located on arterial roads).

A5.4.1 USA case studies

The implementation of HOV and HOT lanes can be used to enhance public transport services. When HOV lanes are supplemented by bus services, HOV infrastructure can deliver measurable improvements in public transport usage and service provision. HOV lanes improve public transport provision by delivering:

- travel time savings for public transport services
- increased on-time reliability of public transport services
- reduced stop-start driving and in turn decreasing operating costs
- improvements in bus turn-around times and in turn improving bus utilisation.

This section drew on previous work by Maunsell AECOM (2008b). Where information on public transport services within HOV lanes was readily available, a brief commentary on the influence on public transport brought about by the introduction of HOV infrastructure is shown highlighted in the following case studies.

A5.4.2 I-80 & I-287 – New Jersey, USA

HOV lanes on the I-80 were installed in 1994. No buffer separated the completed HOV lanes from the adjacent travel lanes and HOV traffic was able to enter and exit the lane at any point. The HOV lane pavement was marked with the diamond symbol. Overhead and ground-mounted signs provided information of the HOV designation, operating hours, and occupancy requirements (Turnbull and DeJohn, 2000). A number of reversible lanes operate in the USA, with a section of the I-80 HOV designated to operate southbound from 6am to 9am and in the reverse direction, ie northbound, from 3pm to 7pm (Turnbull and DeJohn 2000).

Bus services within the I-80 corridor are provided by two private bus companies and primarily operate directly between New York City and communities surrounding the corridor. No services are operated by government authorities along the corridor, which is not usually the case in the USA. No fixed bus services operate within the I-287 corridor.

Following the implementation of HOV lanes on the I-80, the number of bus services provided within the corridor was found to increase slightly. Prior to opening, morning peak-period volumes ranged from 17 buses at the western end of the corridor to 26 buses on the east end of the corridor. Corresponding evening peak-period bus volumes were 40 buses at the eastern end of the corridor and 19 buses at the western end. Typically, these buses carried 600 to 900 passengers during each peak period. The number of route and school buses operating on the freeway in the morning peak period increased from 33 before the HOV lanes were open to 57 after the lanes were completed. In the afternoon peak period, bus volumes increased from 42 to 66 (FHWA 2000). These increases can be directly attributed by the operating efficiencies derived from the provision of dedicated HOV infrastructure.

Despite the ramp-up in bus service provision, Martin et al (2002) suggest that the limited number of bus services provided (no bus services in the case of the I-287 HOV lanes) may have contributed in limiting the extent to which vehicle occupancies could be increased and hence reducing public acceptability of the I-80 and I-287 HOV lanes.

A5.4.3 Houston HOV lanes, Houston, Texas, USA

The impetus behind the development of the Houston HOV network can be pinpointed to initial attempts by the Metropolitan Transit Authority (METRO) to improve bus service provision in the 1980s. The Houston HOV network now consists of over 160km of HOV lanes operating in six freeway corridors. The HOV network is complemented by supporting public transport infrastructures including:

- transport interchanges at each of the 28 park and ride sites providing connectivity with local bus services and in some cases, future light rail services
- direct access ramps between the HOV network and park and ride sites
- express buses and luxury coaches servicing each park and ride site
- ancillary support programmes, eg guaranteed ride home schemes.

Nearly 100 commuter express buses operate on Houston's extensive HOV network. METRO buses and coaches are allowed to use any HOV lane with no restrictions, including the I-10 and US-290 Quickride HOT lanes.

In 2003, the HOV lanes carried some 120,000 passengers in buses (local and express services), vanpools, and carpools on a daily basis (Turnbull 2003). The HOV infrastructure has also been designed to allow for a light rail transit system to be retrofitted if the need arises in the future.

The Houston regional rapid bus network has generated tangible benefits for its users. The Houston system caters for approximately 50,000 boardings per day and generates sizeable travel time savings for bus commuters of up to 15–20 minutes for I-10 and US-290 commuters (FHWA 2005). The resultant increases in bus operating speeds have led to significant reductions in bus schedule time and operating subsidy requirements. For instance, a 2.5km eastern extension of the I-10 HOV lane opened in the early 1990s is reported to have reduced revenue bus hours by 31,000 service hours per annum, saving METRO some NZ$9.1 million per annum (BTS 1992)[19].

Almost all commuters using the Houston rapid bus network have a choice to do so indicating that the Houston system has reduced car use. Approximately 90% of all rapid bus network users are estimated to have an alternative available with between 38% and 46% of commuters having driven alone to work prior to the development of the regional bus network (MTC 2000).

In the USA, facilities such as park and ride and direct access ramps (slip roads) are provided with HOV lanes (KBR 2004). For instance, some 100 miles (160km) of HOV lanes in Houston, Texas, in operation in six freeway corridors, are supported by 28 park and ride and four park and pool lots, transit centres and express bus services. In 2003, the lanes carried some 120,000 passengers in buses, vanpools and carpools on a daily basis (Turnbull 2003).

A5.4.4 I-80 HOV lanes, San Francisco, California, USA

The HOV network surrounding San Francisco plays an important role in providing bus priority in the Bay Area. For instance, of all people carried along the I-80 HOV lanes into San Francisco, approximately 29% are bus users (FHWA 2005).[20] Bus services are also permitted to use any HOV lane on any one of the Bay's toll bridges at no charge.

San Francisco is currently looking to develop a comprehensive rapid bus network system across the Bay Area to augment and increase the visibility of current bus operations. In 2000, a review was undertaken of bus service provision on the Bay Area's HOV lanes. The following works were considered to be required:

- infrastructure such as interchange stations with local bus and rail services including stations within the freeway carriageway
- new park and ride sites
- dedicated on and off ramps for HOV and bus traffic to access interchange stations and park and ride sites
- streamlining and expansion of the rapid bus network, particularly in areas not served by rail.

If implemented, the system would double existing peak-period regional express bus frequencies and generate an additional 26,600 daily patrons by 2020 (MTC 2000).

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[19] Expressed in 2006 prices. Converted based on an exchange rate of US$1 = NZ$1.32 and increases in US CPI between 1992 and 2006.

[20] In interpreting HOV user statistics in San Francisco, it should be noted that the morning and evening peak HOV statistics in San Francisco are somewhat distorted by a phenomenon known as 'slugging'. Typically, commuters will queue at various locations across the area, waiting for single occupant vehicles willing to share their vehicle, to utilise HOV lanes, on an informal basis during the morning peak. However, in the evening peak, commuters would catch public transport on their return trip.

A5.4.5 Twin Cities I-394 and I-35W HOV lanes, Minneapolis, Minnesota, USA

The Minnesota Department of Transportation (MnDOT) has been exploring public transport and HOT lane options for the better part of the last decade to assist in alleviating congestion on the strategic road network in the Twin Cities.

HOV lanes within the Twin Cities are established along two key corridors: the I-394 and the I-35W. A number of park and ride sites are provided in various locations adjacent to each corridor. Bus services typically commence their runs from residential areas surrounding the corridors where they then feed into park and ride sites located along each corridor.[21] Typically, a number of bus routes combine at each park and ride site to form a trunk route into downtown Minneapolis.

Bus users account for a relatively high proportion of all HOV users in Minneapolis. For instance, according to a study prepared for the FHWA, approximately 39% of I-394 HOV lane demand is attributable to bus users (FHWA 2005).

Due to the under-utilisation of HOV lanes, bus services during the peak period have generally been quicker than car travel. Bus commuters on the I-394 and the I-35W reported travel time savings of approximately 15 minutes relative to the use of the general lanes (Cambridge Systematics 2002).

Studies indicate that bus users are attracted by the travel time savings. Modelling and market research undertaken estimates that between 13% and 25% of car poolers and bus users in the two corridors will shift to driving alone if the HOV lanes are opened to all traffic (Cambridge Systematics 2002).

Further enhancements to support public transport initiatives have been proposed, including the conversion of a proportion of the I-35W HOV lanes to support bus rapid transit and HOT lane operations (URS 2005). The conversion of the I-394 HOV lanes to HOT lanes in 2005 has ensured bus travel time savings and on-time reliability along that corridor have been maintained and perhaps enhanced over time as traffic conditions in the general lanes deteriorated.

A6 Lessons learnt from case studies

Provision of a managed lane with bus priority interventions (eg bus lanes, bus gates and HOV lanes) can offer a number of potential benefits to communities and RCAs, which may include:

- providing travel time savings and more reliable trip times
- helping to reduce overall vehicular congestion and motorist delay by encouraging greater HOV use through car pooling and bus usage
- increasing overall efficiency of the system by allowing specific types of users to bypass congestion on lanes designed for their use
- improving air quality by decreasing emissions
- reducing vehicle trips
- maintaining mobility

[21] One of the two I-35W bridges spanning the Mississippi River collapsed in August 2007. A new bridge was opened in September 2008. During the intervening period a section of the I-35W was closed, and park and ride sites were established across the western parts of the city away from the I-35W corridor.

- promoting public transport and ridesharing
- providing travel options to meet user needs
- minimising impacts on other traffic in the corridor and on parallel facilities.

The rest of this section brings together the findings of New Zealand, Australian, UK and USA experiences to date in the planning and implementation of bus priority interventions (eg bus lanes, bus gates and HOV lanes) under the following headings where information has been made available:

Planning (sub-section A6.1.1 refers)

- site selection
- mandate
- screening criteria
- supporting travel demand management measures.

Management (sub-section A6.1.2 refers)

- monitoring
- flexibility
- public education and promotion
- maintaining the ability to operate effectively
- dealing with concerns.

Design (sub-section A6.1.3 refers)

- infrastructure
- lane configuration and signage
- supporting infrastructure.

Costs (sub-section A6.1.4 refers)

Operation (sub-section A6.1.5 refers)

- permitted users
- hours of operation
- priority for low emission vehicles (if any consideration given)
- enforcement issues.

In addition to bringing together review findings of existing and proposed managed lane facilities, the following sections draw on parallel lessons learnt from the previous technical working paper by Maunsell AECOM (2008b) on international experience in managed lanes.

A6.1 Summary of review findings

The review of selective managed lane experiences in Australia, New Zealand, the UK and the USA has highlighted that the decision to implement managed lanes is very much site specific and depends on policy objectives, stakeholder interest and funds. There are merits of various types of bus priority interventions incorporated into managed lanes which need to be considered in the context of each site, and how such sites potentially interact and complement other managed lanes across a city or region.

A6.1.1 Planning

This paper has concluded from the review of existing and proposed case studies identified in section A5 and discussions with RCAs, that the impetus for priority lane development (within the context of special vehicle lanes as opposed to toll roads) has not originated from a long-term vision of a managed lanes network.

Instead, many existing managed lanes have been implemented under one or two of the following scenarios:

- as an alternative and viable form of travel to address constrained corridor congestion
- pre-empted alternative transport solutions implemented in advance of future corridor congestion
- an after-thought – this form of implementation is often the most detrimental to the success of a managed lane as later sections of the paper will highlight.

While these scenarios apply to many of the existing or proposed schemes identified in sections A4 and A5 of this appendix, RCAs have realised that due to the number of lanes being implemented within their city, there has been a need for wider consideration of the form and function of managed lanes to be implemented and an understanding of the key transport corridors where such benefits would be realised.

Sections A4 and A5 illustrate that the focus in the development and implementation of managed lanes has primarily been focused on major metropolitan centres, eg London, Bristol, Auckland, Brisbane and Wellington where significant reductions in travel journey times for buses have been severely affected by increasing travel congestion associated with increased traffic volumes of single occupancy vehicles on key transport corridors.

The implementation of bus and transit lanes, since the 1990s has increased in response to the demand for improved travel journey times for buses and alternative choices for travel (bus or HOV) on congested sections of networks as identified in the case studies from the UK, Australia and New Zealand.

The review of case studies indicates that the majority of sites selected are those exhibiting high levels of peak-hour congestion with relatively high levels of bus numbers. These corridors tend to be serving primary ‘gateway’ access to and from key places of interest within a city. The proposed future upgrade of bus lanes on Dominion Road will also support improved passenger transport access between Auckland’s isthmus and the CBD, as a corridor supported by future intensification and identified in the Auckland regional growth strategy (ARC 1995).

However, a number of the implemented managed lanes have not been the result of a planned initiative to provide an alternative travel choice. Instead, managed lanes have been introduced into a road design, as a means to an end, in order to resolve design issues within a corridor. This approach can have a detrimental effect on the success of managed lanes, which under normal situations may not have been a justifiable solution, eg Mana Esplanade T2 lanes illustrate an example where strong external political influences opposed the original four-lane widening on Mana Esplanade.

A6.1.1.1 Site selection

Site selection for all cases is focused on key strategic routes (arterials, highways) which are subjected to heavy congestion during peak times of travel. The treatment may result in either a corridor or selective site improvement. The introduction of managed lanes with bus priority interventions can alleviate the number of single occupancy vehicles and improve travel time reliability for all road users. Underlying the selection of a managed lane implemented within cities and regions is dependent on a number of factors with the key influencing factor being the political mandate. In New Zealand and the UK, bus priority interventions eg bus lanes and bus advances have been widely implemented while fewer transit (HOV) lanes have been considered on arterials. The USA experience has largely been in the implementation of

HOV and HOT lanes as the preferred managed lane treatment, which provides priorities for buses. In the case of HOT lanes, buses and HOVs travel free over single occupancy vehicles, which pay a fee. This reflects the political climate and policy direction of regional and local transport strategies at the time of planning and implementing existing types of managed lanes.

More recently wider consideration has been given to the types of managed lanes being established in New Zealand which support buses. For example, figure A6.1 highlights a combined HOV and freight bypass lane on a motorway on-ramp in Auckland. This lane provides a priority bypass lane to trucks, buses and HOVs entering the motorway network from the neighbouring employment areas.

Figure A6.1 Ramp metering at Mt Wellington on-ramp SH1, with T2 (HOV2 +/bus) and truck bypass jump lane

Source: NZTA website

A6.1.1.2 Mandate[22]

The mandate for managed lanes extends from national, regional and local objectives and targets which require RCAs to seek alternatives to single occupancy vehicles. Australian governments recognise the importance in investing in public transport with each state managing a portfolio investing in infrastructure and technology solutions to improve the performance of bus travel. In New Zealand, the *Government policy statement on land transport funding* (MoT 2009), New Zealand Transport Strategy (MoT 2008), regional land transport strategies and Auckland Regional Freight Strategy (ARC 2006) require RCAs to consider a wider application of various forms and functions of managed lane, in addition to those currently implemented across New Zealand. As a result, RCAs will have to continue revisiting existing managed lane plans, to identify where alternative forms of managed lanes or improvements in existing provisions are required in order to offer greater benefits to specific user groups.

The size of multi-agency working groups will be dependent on the scale and location of a proposed scheme. Where such groups are formed there is a need for this on-going multi-agency working group to continue beyond the project's implementation to ensure that the operation and performance criteria identified at the outset of the project continue to serve priority users. It is not clear from all case studies reviewed in section

[22] Since the completion of this literature review, there have been a number of changes in the governance of Auckland. This has resulted in the amalgamation of all RCA functions into Auckland Council and Auckland Transport.

A5, who is involved in the multi-agency groups. International research (Maunsell AECOM 2008b) highlights that multi-agency working groups can often involve representation from the state transport department (ie New Zealand's Ministry of Transport); RCAs (ie ARTA – now Auckland Transport, territorial authorities), bus operators, enforcement agencies (eg NZ Police, RCA parking wardens and other interest groups identified by the project sponsor. The advantage of such teams is to ensure that the outcomes of implemented projects are successful and flexible in meeting the desired project objectives and outcomes set.

It is evident that the achievement of the national and regional transport strategies will require on-going collaboration between RCAs in managed lane initiatives. For example, the BPISG which operated from 1990s to c2003 provided a forum for the NZTA (then Transit NZ) and various RCAs to report on the progress, learned experience and development of managed lane initiatives across the Auckland region. The members of this forum also included bus operators and NZ Police. Members of the BPISG provided the impetus for the planning and implementation of Auckland's real-time information system, which forms a critical element of the TDM measures, introduced to support growth in passenger transport and managed lane initiatives.

A6.1.1.3 Screening criteria

Screening criteria for the majority of case studies identified in section A5, demonstrates specific project criteria and project objectives for the implementation of a managed lane. The following highlights a number of common criteria cited for implementing a managed lane with bus priority interventions:

- increase bus patronage
- induce people to carpool
- alleviate existing or future levels of congestion on a specific corridor
- increase people throughput vs volume
- support national, regional and local transport objectives and targets
- improve travel time savings to specific user groups, eg heavy commercial vehicles (HCVs), HOVs and bus users.

In addition to the above, a number of specific project objectives were also identified from the case studies. These include:

- streetscape enhancement, eg strengthening business/entertainment zones
- revitalisation of corridors, eg creating great character streets that support multi-modal activities, ie walking, cycling
- enhancing the connectively of managed lanes on existing/adjoining corridors, eg supporting a managed lane network
- rationalisation of kerbside parking and taxi stands
- support of specific passenger transport network plans, eg rapid (RTN) and quality (QTN) transit network identified by ARTA (Auckland) and quality bus corridors (QBC) identified in Leeds and Greater Manchester in the UK
- projects which give the greatest travel benefit to the most people according to a ranking system, eg bus lanes vs transit lanes
- addressing known constraints and problems in the road network.

New Zealand's approach to screening criteria reflects the current form and function of existing managed lanes (bus and HOV lanes) implemented. The US government screening criteria sets specific targets which include for example:

- peak-hour speeds <48km/h; work trips to densely developed activity centres
- high volumes of buses and car pools
- potential travel time savings at least 40s/km or five minutes overall
- availability of support facilities and services (Maunsell AECOM 2008b)

In comparing screening criteria used within New Zealand and the USA, New Zealand RCAs may seek to further refine current screening criteria to reflect specific performance thresholds similar to those used by USA government agencies. The identification of specific requirements will assist RCAs in monitoring various types of managed lane performance, ie the ability to operate and effectively respond to changes on the network. This becomes necessary the more complex a managed lane may be, for example, HOT lanes with dynamic or variable pricing require specific screening criteria to be employed in order to ensure the LOS in the lane is not unduly compromised by SOVs (URS 2005).

A6.1.1.4 Supporting travel demand management measures

Development of TDM measures to complement various types of managed lanes is still in its infancy. This is likely to change once more managed lane corridors are implemented to provide greater coverage across the transport network. Elements commonly associated with HOV lanes include:

- marketing and public information programmes
- park and ride/kiss and ride parks
- bus services
- rideshare and TDM programmes
- employee transportation activities
- enforcement efforts and other initiatives.

Within the UK and New Zealand, the supporting TDM measures used for managed lanes have primarily focused on improving passenger transport facilities within the corridor. Such improvements included within a scheme design are:

- upgrades to bus shelters
- real-time information
- bus borders
- signal pre-emption for buses
- bus gates.

For New Zealand, with the exception of the Northern Busway, there are no park and ride facilities currently supporting existing managed lane schemes in the case studies.

A6.1.2 Management

A6.1.2.1 Monitoring

New Zealand has been active in the monitoring of bus priority interventions compared with Australia, the UK and the USA. A review of Australian literature revealed that the RTA (2003) stated that in the five years of delivering Sydney's Strategic Bus Corridors very little information was collected initially on bus performance to assess before and after treatments.

Monitoring of a lane's performance, before and after implementation, has been undertaken by a number of New Zealand RCAs, either as a requirement for a Notice of Requirement, eg Mana Esplanade, or simply as a performance criteria by RCAs wanting to demonstrate the benefits of introducing a managed lane on specific corridors. Monitoring of a lane's performance can focus on the following elements:

- non-compliance within the lane by non-permitted users
- travel time savings for specific users
- recording occupancy levels within HOV and HOT lanes
- bus operations
- bus patronage
- understanding users within the corridor, eg HCV, HOV
- LOS provided to specific users
- effects of managed lanes on general traffic within the corridor or wider network.

Onewa Road Transit Lane (HOV3+) demonstrates that effective monitoring of a managed lane can provide significant benefits to users through improved travel times of up to 30 – 40 minutes over the general traffic lane (Murray 2003). Monitoring is an essential component of maintaining and refining a managed lane's ability to operate efficiently. It includes:

- the ability to establish an optimum design length of lane in order to achieve greater benefits
- responding to changes in occupancies of HOVs, eg knowing when to shift from HOV2+ to HOV3+
- identifying where potential opportunities exist to extend the operational periods of managed lanes in response to the demand for managed lane usage
- identifying potential issues within the lane, ie downstream issues where a lane extension could be a great benefit
- the ability to respond to issues within a lane before they become public concerns
- the ability to provide information to media on the success of managed lanes
- flexibility.

The UK experience also stressed the importance of being clear about the benefits and impacts of measures implemented. For example, successful bus priority schemes do not necessarily provide an improved journey time but deliver reliability, which proves to be a better indicator of success. An illustration of this is, increased patronage, encouraged by bus priority improvements, leads to greater time spent in boarding and alighting, which can result in new journey time delays. This highlights the need for monitoring of all elements within the corridor, that is, road and bus infrastructure, ticketing, information and enforcement to ensure that bus priority intervention systems work as a whole.

A6.1.2.2 Public education and promotion

The most common forms of public education and promotion of managed lanes in New Zealand are via the following mediums, all of which seek to inform motorists and residents on the type of lanes, their usage and enforcement for non- compliance:

- radio and media coverage
- advertising on bus shelters and buses

- website providing details on proposed and existing schemes, operational periods and enforcement of lanes
- direct flyers to residents and businesses within the vicinity of the lane
- information boards on corridors informing motorists of managed lanes ahead.

It is evident that many managed lane projects do not include a budget for on-going media coverage with many lanes simply lumped into general road maintenance programmes and not viewed as a priority lane facility. Implementation of a managed lane project is an on-going commitment to provide a facility of optimal performance, eg LOS often set higher than for the adjacent general traffic lane. A specific budget for marketing and promotion of lanes implemented by RCAs is necessary. International literature as well as local experience can demonstrate that on-going public education and promotion is necessary throughout the whole life of a facility. The degree of input required will vary according to the form and function of the managed lanes implemented.

A6.1.3 Design

Sections A4 and A5 have identified that bus priority interventions can be incorporated into any managed lane with varying successes. In New Zealand most bus priority interventions operate within the kerbside (nearside) lane and operate predominantly during peak periods utilising road space often reserved for kerbside parking during the off peaks.

A number of factors affect the design and success of managed lanes with bus priority interventions. Factors affecting the design can be either site specific or posed as common issues across a number of sites. Major impediments to all managed lanes located on key arterial routes, are the provision of kerbside parking and limited opportunities to widen corridors to increase a lane's width in order to accommodate additional road space for cyclists/motorcyclists. This has been the case for a number of first generation bus lanes as discussed in section A5 of this review.

As USA and UK experience shows there is also the need to consider the user of the lane and how each priority user interacts with others, in order to maintain the operational efficiency of the lane. For example, the Australian Institute of Traffic Planning and Management (Bauer et al 2005) identifies the key design principles of HOV facilities as follows:

- Identification of bus bays on arterial HOV lanes is necessary to avoid traffic being stopped by the boarding and alighting of passengers.
- Bus stops should be located on the far side of junctions or at mid-block locations to prevent traffic blocking back through signal controlled junctions.
- Nearside running arterial HOV lanes allow for left-turning general purpose traffic without impeding the flow of HOVs.
- HOV lane signage should be free of confusion for road users.
- Consultation with the necessary authorities should be undertaken to provide sufficient enforcement facilities.
- The needs of cyclists should be accommodated.

As authorities identify potential corridors for managed lane treatments, it is evident from the review that some RCAs will need to revisit current objectives which set out to install for example, managed lanes, where there is no disadvantage to motorists, if wider benefits and national/regional targets are to be achieved. In many cities reviewed, the first generation of managed lanes (predominantly bus lanes) have been easily implemented through the utilisation of parking clearways or surplus capacity in the road, without adversely affecting other road users. Many cities have now moved into the third generation bus priority interventions as shown in the UK case studies in section A5 of this review.

One of the key aspects of many managed lanes (for example bus lanes) currently implemented in cities, is that a number of measures have been implemented on the basis of 'pre-emption', well in advance of any forecast demand. This has been in part the drive to meet political directives to increase passenger transport modes and the ability to recommend and implement schemes on key transport corridors where future demand is expected.

Currently, there is no obligation for RCAs to build supporting infrastructure for managed lanes. Many of the projects reviewed in section A5 seek to upgrade existing infrastructure as part of attempts to encourage new patronage to facilities but this is currently limited to bus shelters and real-time information upgrades. The USA experience includes the provision of park and ride facilities to support HOV lanes which operate in freeway (state highway) environments.

A6.1.4 Cost

There is considerable variation in costs associated with the implementation of managed lanes in Australia, New Zealand, the UK and the USA. This is due to a number of reasons which include:

- site-specific requirements
- land acquisition
- project objectives
- engineering standards – degree of grade separation, safety issues
- identified users' requirements
- design complexity of the form and function of the lane which may require either reallocation of road space for and/or a new lane and/or use of an existing hard shoulder
- converting a general purpose lane to a managed lane
- converting a managed lane, eg bus lane to HOV and/or HOT lane
- enforcement technology

Such factors will govern the cost associated with each managed lane scheme. For example, the typical range of implementing bus and transit lanes schemes in Auckland can be in the order of $100,000 to $300 million with higher costs associated with barrier separation of busway and/or HOT lanes.

Unlike the USA and the UK, managed lane schemes implemented in New Zealand are often only funded for planning feasibility assessments, scheme assessments and the construction of preferred schemes. Funds to deliver a total corridor package of improvements (ie public education, promotion, monitoring and TDM initiatives) associated with a managed lane scheme are rare. The importance of multi-agency working groups is essential, given the various delivery arms and responsibilities of RCAs in supporting managed lane projects.

The future funding of managed lane schemes in Australia and New Zealand for example, could potentially mirror the cost of schemes put forward internationally. Costs associated with implemented international managed lanes schemes include:

- the managed lane facility
- enforcement technology

- supporting TDM initiatives, ie park and ride facilities, multi-modal stations
- real-time information
- supporting shelters for buses and/or HOV users
- effective enforcement
- public education and promotion of managed lanes.

Costs associated with enforcement, public education and promotion of managed lanes is an important consideration by RCAs in their ability to effectively operate various forms of managed lanes. Often only limited funds are available for the on-going management of managed lanes which require higher levels of management than general purpose lanes. Costs which need to be taken into consideration in RCAs' asset management programmes include:

- marketing public education and promotion
- enforcement technologies (to reduce manual ticketing over time)
- parking warden training in enforcement
- annual monitoring surveys (including occupancy counts).

A6.1.5 Operation

A6.1.5.1 Permitted users

Across all case studies, RCAs manage and give priority to one or more classes of vehicle within managed lanes. The priority order given for most is:

1. Buses (no fee imposed)
2. HOVs (no fee imposed)
3. SOVs (fee paying in HOT lanes).

Depending on the site conditions of the corridor taxis and freight vehicles, cyclists and motorcyclists may also be permitted to use managed lanes free of charge (no fee). RCAs have the ability to include or exclude, by way of signage, users they feel are not permitted to use the lane; this is established by an RCA's project objectives or directive. For example, table A4.1 in section A4 illustrates the permitted users of lanes currently established in New Zealand. A number of these projects are examined in the case studies.

Taxis are usually banned from using bus and HOV lanes in New Zealand. Exceptions are in the Hutt Valley where taxis are permitted users of the Petone Esplanade bus and taxi lane, and in the North Shore where taxis can use transit lanes. Wellington City Council is running some taxi trials in existing bus lanes on Adelaide Road, Chaytor Street, Glenmore Street and Kaiwharawhara Road in Wellington. Further details on this can be found on the council's website.[23]

In the UK some bus priority lanes allow freight vehicles to use the lanes based on either light commercial goods (<3.5 tonnes) or heavy commercial vehicles (7.5 tonnes or more) classifications (refer to figure A6.2).

[23] Further details regarding taxis trials in Wellington can be found at www.wellington.govt.nz/projects/ongoing/bus/buslanes.html

Figure A6.2 UK example (Nune Elms) illustrates permitted users of a priority lane during the lane's operational hours

A6.1.5.2 Hours of operation

In New Zealand the hours of operation are predominantly restricted to weekday peak hours. Mana Esplanade was the only site reviewed that provided weekend peak-hour operations. Evidence from Mana Lane indicated that the greatest increase in HOV use of this lane occurred on Sunday, with a jump in HOV users from 59.6% to 66.3% (SKM 2006 and Hyder 2008).

Washington State undertook a study 'Weekend freeway performance and the use of HOV lanes on weekends' (Ishimaru et al 1998). This examined HOV lanes in continuous operation and whether there was scope to open the facilities to other traffic at non-peak times. Interestingly the study, 'HOV facility development: a review of national trends'(Fuhs and Obenberger 2001) found that the average vehicle occupancy was higher than expected during non-peak periods and especially at weekends. This would suggest that HOV facilities should remain operational continuously to provide the benefits to HOVs and further encourage the modal transition to higher occupancy forms of transport.

For RCAs to extend the operation of existing bus and HOV lanes they will require longer restrictions to be placed on kerbside parking (weekday and weekend periods) which may prove difficult to implement if the impact on business is proven to be significant.

A6.1.5.3 Enforcement issues

New Zealand's approach to enforcement is similar to international research findings for various types of managed lanes currently operating. At present most enforcement is heavily reliant on RCA parking wardens, supported by video imaging of a non-compliant user of the lane. The use of ITS technologies employed on more sophisticated HOV and HOT lane operations in the USA are still reliant on manual checking to ensure that a violation has been committed. Advancements in enforcement technologies are seeking to reduce manual tasks both onsite and behind the scenes. The investment in such ITS technologies will need to be measured against each potential scheme to determine if current practices are less cost effective.

As indicated in section A6.1.4, RCAs need to be able to seek sufficient funding for enforcement of managed lanes as an on-going cost. It is via effective enforcement that the full benefits of a managed lane for priority users will be realised. Long term it may be more effective for a regional transport authority or private operators to provide enforcement of managed lanes on a regular basis, thus alleviating costs currently placed on RCAs.

A7 Conclusion

It is evident from the success of a number of managed lanes implemented in Australia, New Zealand, the UK and USA, that an ongoing mandate and enhancement of managed lanes is essential. From the review of New Zealand practices, there has been, until recently, limited consideration of forms of managed lanes other than the existing bus and HOV facilities. The review of case studies in section A5 and discussion of lessons learnt about managed lanes in section A6 identifies that New Zealand's approach to bus priority interventions has not been dissimilar to international experiences in the provision of managed lanes.

The completion of this literature review has revealed there is limited documentation publicly available on quantifiable and comparable benefits resulting from bus priority interventions. This lack of before and after data on managed lanes implemented (eg bus lanes, HOV), makes it difficult to determine and provide conclusive evidence on actual travel time savings over X years of operation; concise annual growth rates, modal trends in the usage of managed and general traffic lanes, as well as an examination of the costs associated with the lane construction and its on-going management, eg education and enforcement.

However, anecdotal evidence from the studies described in this review clearly indicates that a range of bus priority interventions do provide benefits to permitted road users within a managed lane, including the potential to improve travel conditions within adjacent general traffic lanes. We offer caution in terms of applying managed lanes, with due consideration to be given to site-specific conditions, political mandate, planning, design and operational frameworks[24].

The researchers found that many authorities approached were not able to provide information on various aspects of bus priority interventions; reasons included the historical nature of the project and the lack of records. The evidence found through this literature review[25], assisted the team in the development of a series of algorithms in the development of an analytical modelling framework (see appendix B).

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[24] Table A5.1 in section A5 of this literature review provides an assessment guide to managed lane provisions.

[25] As well as through additional research to be carried out during the next phase of developing the analytical modelling framework which will seek to address outstanding identifiable gaps in both quantifiable and comparable benefits of managed lanes with bus priority interventions.

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Appendix B: Development of the analytical model

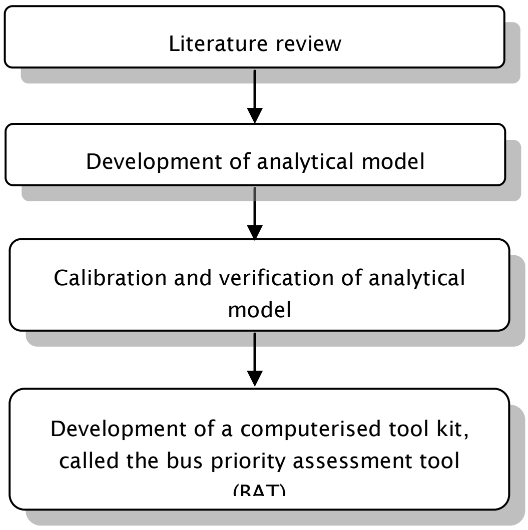
B1 Introduction

B1.1 Background – research work

The work reported here describes a component of the research work on bus priority treatments commissioned by the NZ Transport Agency (NZTA). The purpose of this research was to develop a practical decision-assisting tool for identifying appropriate bus priority treatments for any given location, based upon route and intersection characteristics. The appropriate treatments aim at reducing congestion and improving trip time reliability in New Zealand cities.

The four components of the research work are shown in figure B1.1 and described in the following paragraphs.

Figure B1.1 Research work components



The literature review in appendix A describes managed lanes and other bus priority interventions in New Zealand, Australia, the UK and USA. The review identifies the planning, implementation, operation and evaluation of bus priority interventions to assess their quantifiable and comparable benefits.

The intention of the literature review in appendix A was to advise the research team on a range of bus priority interventions that could be analysed.

Appendix B describes the development of an analytical model for testing the effectiveness of several bus priority treatments at intersections and on road segments. The analytical model is an engine of this research work. It is a set of algorithms, which enable estimation of the benefits of potential bus priority treatments in the context of the existing on-site situation. The development of the model is a theoretical work based on real-life inputs obtained from the literature, surveys and calculations using probabilities and the values of delays, saturation flows, traffic signal splits, etc observed on surveyed major arterials. This appendix describes the thinking behind the algorithms, the assumptions on which they are based, and the developed set of algorithms.

The calibration and verification of the analytical model converts the theoretical work into a practical tool. This is achieved by testing the model on case studies and addressing the comments received from the peer reviewer and the research steering group.

The calibrated analytical model is used as the basis of the computerised procedure (the tool kit called the bus priority assessment tool (BAT)), thus turning the process into a simple computer operation. BAT uses Microsoft Excel software and is accompanied by the *BAT user manual* guiding the user through the process. A user with a good understanding of their traffic system will be able to identify the most appropriate bus priority interventions for their potential sites.

BAT is capable of providing broad indications of appropriate bus priority treatments based on average values and situations. The default values adopted in the model are averages and are expected to represent most of the situations with adequate accuracy. However, there may be situations falling outside the acceptable range. It is therefore necessary to subject the treatments identified by the model to a project feasibility report (PFR) or scheme assessment report (SAR) analysis as required by the NZTA, before the decision on implementation is reached.

B1.2 Model description

B1.2.1 Model structure

The model structure is based on a simple three-stage concept: *input*, *process* and *output*. The model is developed for two types of urban sites – an intersection and a transport corridor. The transport corridor comprises a number of intersections and road segments.

The model has been calibrated against the results of implemented and monitored bus priority treatments and by comparison with the results of case studies from Auckland, Wellington and Christchurch. It has to be noted that the Christchurch case studies predate the 2010 and 2011 earthquakes and therefore the data has not been affected. The model has been reviewed by an independent peer reviewer and verified by a panel of bus transport specialists representing local RCAs in Auckland, Wellington and Christchurch.

B1.2.2 Model input

The input to the model describes the characteristics of the existing location where the installation of a bus priority treatment is being considered. There are two sets of inputs: mandatory data and optional data. The mandatory inputs have to be provided by the user, since the model does not provide substitutes for the mandatory input data. However, where optional inputs are required, the user has an option of accepting the default values built into the model. Table B1.1 lists the mandatory and optional input data.

The input consists of general data (such as the available budget or annual traffic growth rate), and the site-specific data (such as the type of traffic control, traffic volumes, the road cross-section, lane configuration). Depending on the project requirements the user will input data for either 1) the intersection, or 2) the road segment, or 3) both.

Table B1.1 Input data

Mandatory input data		Optional input data
Intersection	**Road segment**	
Available project budget	Available project budget	Number of signal cycles per hour
Weighting of KPIs	Weighting of KPIs	Existing signal cycle phase split
Type of intersection	Number of through lanes	Car occupancy
Traffic flow on main approach for each movement	Section length	Bus occupancy
Number of buses going through and turning right on the main approach	Number of through traffic volume per hour	Traffic growth rate
Number of lanes for each movement on the main approach	Number of through buses per hour	Proportion of traffic on other approaches
Number of lanes on the opposite and side approaches	Estimated cost of analysed treatments	T2 percentage
Estimated cost of analysed treatments		T3 percentage

B1.2.3 Model process

The process is an analytical algorithm. The algorithm is designed to:

- screen the input data
- identify the alternative treatments
- calculate the values of key performance indicators (KPI) for each alternative
- select the most appropriate alternative.

The two critical elements of the process are the KPIs and the default values. The selected KPIs are consistent with the stated purpose of this research work – to develop a tool kit to assist authorities in reducing congestion and improving bus transport trip time reliability. They are:

KPI 1 – overall bus and car traveller delay

KPI 2 – reduced car growth rate over 10 years

KPI 3 – lane person throughput in 10 years

KPI 4 – cost of vehicle emission.

For KPI 2 and KPI 3, it is not plausible to assess the immediate impact on car growth and lane person throughput after the installation of bus priority treatments. Therefore, a 10-year horizon is set.

Recognising the difficulty facing the user when asked to supply and input a wide range of the data to run the model, the research team developed a set of default values within the model. The default values are based on the values reported from relevant monitored treatments elsewhere (eg Ussher (2010); Boorer (2010); Gardner et al (2009); Newcombe (2009); and other publications), the values given in the *Economic evaluation manual* (NZTA 2010), and the calculations using probabilities and the values of delays, saturation flows, traffic signal splits, etc, observed on surveyed major arterials. The independent variables where the default values were built into the model are shown in table B1.2:

Table B1.2 The independent variables where the default values in the analytical model have been provided

Independent variable
Bus delay reduction due to the various bus priority treatments
Delay to non-bus traffic due to the various bus priority treatments
Green time allocated to the traffic stream as a proportion of the cycle time
Opposite approach traffic flow as a proportion of the main (with bus) approach flow
Side road traffic flows as a proportion of the main (with bus) approach flow
Demand for bus service in response to the travel time reduction
Bus, car and high occupancy vehicle occupancy rates
Annual traffic growth rate
Growth rate of demand for passenger transport

In some cases the user has a choice of using either the default values or substituting them with the data collected from the site. However some inputs are site specific and mandatory – the user will have to provide them as the default option does not exist. The model will not proceed to next stage if any of the mandatory values have not been provided. See table B1.1 for a list of mandatory and optional input data.

B1.2.4 Model output

The model identifies two bus priority treatments deemed to be most appropriate for a given situation. Both treatments are accompanied by a rough benefit-cost ratio (BCR). It has to be noted that the BCR does not play a role in the selection process, so the preferred treatment might have a lower BCR than the alternative treatment. The BCR is only a rough indication of economic efficiency. The input data required for selection of the appropriate bus priority treatments is not detailed enough to carry out a comprehensive economic analysis. The full economic analysis is outside the scope of this research.

The output is selected from the five intersection bus priority treatments represented diagrammatically in figure B1.2 and six road segment treatments shown in figure B1.3. The first diagram in figure B1.4 (with-flow bus lane/transit lane) represents three potential treatments: the bus lane, T2 lane and T3 lane.

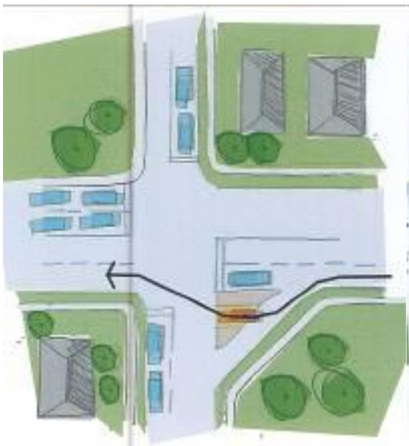
These treatments were selected through discussion with the external peer reviewer out of a wider range of the possible treatments (see section B8).

B1.2.4.1 Intersection treatments

- **Bus advance** with the bus phase, where by utilising the existing traffic island it is feasible for the bus to reach the stop line bypassing the traffic queue. The bus phase allows the bus to enter the intersection before the general traffic is released.
- **Transit active signal** for the bus detected on the approach to the intersection. The detected bus triggers the signal phase change. By the time the bus arrives at the intersection the traffic signal changes. If the bus arrives on red the red phase is terminated. If it arrives at the end of green the green phase is extended.
- **Queue jump lane** is an additional short lane constructed on the approach to an intersection for buses to bypass queues of waiting cars. Therefore buses have free access to the stop line from where they continue with the traffic stream into the bus lane on the far side of the intersection.
- **Bus right turn only**, where buses have a dedicated right turn signal phase.

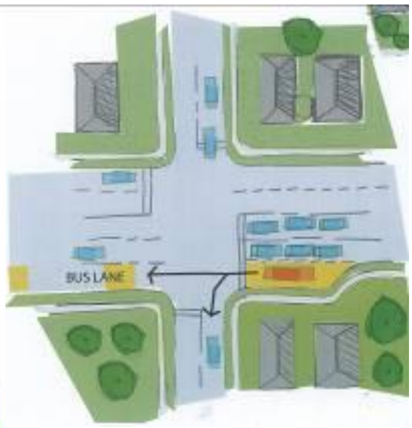
- **Bus gate for bus right turn** from the bus lane at kerb. With the bus gate the bus avoids weaving at low speed through the general traffic ahead of the intersection and travels without reducing speed.

Figure B1.1 Analysed bus priority treatments – intersection

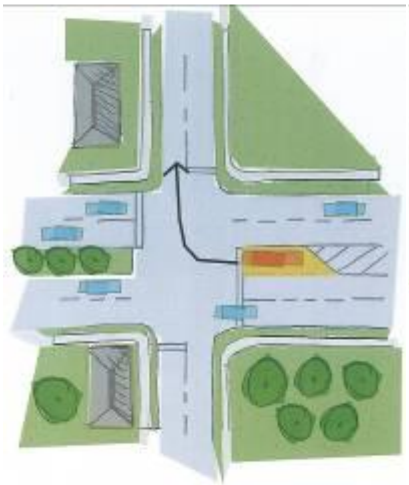


a) Bus advance

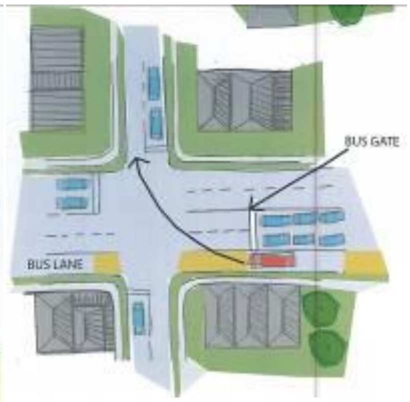
b) Transit active signal



c) Queue jump lane



d) Bus right turn only



e) Bus gate for bus right turn

Transport corridor

A transport corridor is a combination of intersections and road segments whereby the user selects:

- the individual treatment for each intersection
- suitable treatments for groups of road segments between the intersections.

The model is limited to five road segments and six intersections, which make up the transport corridor. Figure B1.2 highlights a diagrammatic representation of the transport corridor.

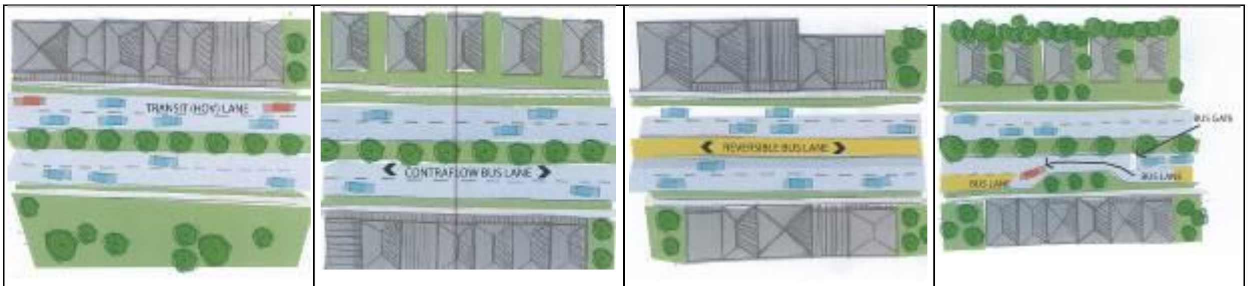
Figure B1.2 Transport corridor with five segments and six intersections

The six road segment treatments analysed by the model are:

- **With-flow bus lane** – a traffic lane intended for the use of buses in the direction of the neighbouring general purpose traffic lanes. Some bus lanes allow cyclists and motorcyclists.
- **Contra-flow bus lane** – a traffic lane intended for the use of buses, where buses travel in the opposing direction of the neighbouring general purpose traffic lanes.
- **Reversible bus lane** – a traffic lane intended for the use of buses, where buses travel in one direction during morning peak and in the opposite direction during afternoon peak.
- **Bus gate** (or virtual bus lane) – a useful bus priority device in the situations where a bus lane has to be discontinued in the middle of the road segment. The approaching bus in the bus lane triggers the red signal phase for general traffic and bypasses the bottleneck travelling without reducing speed.
- **T2 transit lane** – transit lanes are with-flow bus lanes, which allow multi-occupant vehicles sharing the lane with buses. T2 transit lane allows vehicles with two or more occupants to share the lane with buses.

B1.2.5 T3 transit lane – similar to the T2 transit lane but allowing three or more occupants to share the lane with buses.

Figure B1.3 Analysed bus priority treatments – road segment



a) With-flow bus lane/transit lane (see note 1)	**b) Contra-flow bus lane**	**c) Reversible bus lane**	**d) Bus gate**

Note 1: This configuration represents three potential treatments: with-flow bus lane, T2 transit lane and T3 transit lane. The only difference among these three treatments is the difference in vehicle type restricted in the bus lane.

B2 Data collection

B2.1 Introduction

The analytical model relies on a large number of inputs. The accuracy of these inputs is essential to the veracity of the model and the quality of the output. The two key sources of input come from:

1 The user providing site-specific data

2 The default values based on the research work.

The default values are derived from the literature review, the surveys and the calculations using probabilities and the values of delays, saturation flows, traffic signals, etc, observed on surveyed major arterials.

The user will be able to supply some of the inputs, which will be well known to the user and understood by the user. However, there will be other inputs critical to the model, which might not be familiar or readily available to the user. Addressing the issue of the data, which the user might not be able to provide, the model developers identified the most representative values of such inputs and inserted them as default values in the model.

The search for the representative default values used three methods – the literature review, the surveys and the calculations using probabilities and the values of delays, saturation flows, traffic signals etc observed on surveyed major arterials. When a default value was derived by more than one method, the results were reconciled to produce a single robust value.

The default values of interest are the reduction of delay to buses and increased delay to other vehicles relevant to each of the studied bus priority treatments. This section discusses the data collected, reviewed and used as the default values in the analytical model.

B2.2 Literature review

The literature review for the analytical model attempted to identify the values of delay to buses and other vehicles measured on site during the local and international case studies as well as those reported from the computer simulations. In spite of a large number of reviewed publications, only limited amount of information consistent with the purpose of this review was found.

The findings of the literature review are presented in sections B6 and B7. Section B10 is a bibliography of material consulted in the course of the literature review. The extracted data, which could be used for validation of the values used in the analytical model, is summarised in table B2.1.

Table B2.1 Data retrieved from the literature used to validate the default values

Bus priority treatment	Indicator	Unit	Sample size	Range
Transit active signal	Reduction of bus delay	s/bus	15	-7.5 to -9.0
Transit active signal	Average main road vehicle delay	s/veh	3	-1.5
Transit active signal	Side road vehicle delay	s/veh	6	+3.0 to +3.6
With-flow bus lane	Reduction of bus delay	s/bus/km	15	-48.9 to -65.2
With-flow bus lane	Additional traffic delay	s/veh/km	5	+28.2 to +33.8
T2 and T3 transit lane	Reduction of bus delay	s/veh/km	18	-29.0 to -69.3

Table B2.1 summarises the data retrieved from the following publications: Barton (2003); Bauer et al (2005); Berry (2010); Bodé (2010); Boorer (2010); Davol (2001); Gardner et al (2009); Gravitas Research (2010); Jepson et al (1999); Kwon and Varaiya (2007); Leeds City Council (2007); Liao (2006); Martin et al (2004); Maunsell Australia (2006; Mirabdal and Yee (undated); Nee et al (2002); Newcombe (2009); Ova and Smadi (2001); Paling and Brown (2010); Smith et al (2005);Traffic Design Group (2008); Transport for London (2006); Ussher (2010); and Wei and Chong (2002).

B2.3 Surveys

Several surveys were conducted in Auckland to collect the data required for the development of the analytical model. The surveys were conducted during the morning peak period in the following four locations:

- Dominion Road, city fringe – to survey the operation of the bus lane in a major arterial and to compare the survey data with previous monitoring data along Dominion Road.
- Onewa Road, North Shore – to survey the operation of the bus lane in a major arterial and to compare the survey data with previous monitoring data along Onewa Road.
- Custom Street East, Auckland CBD – to understand the operation of an exclusive bus right-turn signal in the city centre.
- Parnell Road, city fringe – to understand the businesses of retail outlets on a major arterial.

The collected data is shown in table B2.2. The data obtained from the surveys was considered to be representative of average values for the morning peak and is used as default values in the model. Some of these default values could be overridden by the user if the user has more reliable site-specific data.

Table B2.2 Surveyed data

Indicator	Unit	Average value	Standard deviation
Bus occupancy	Number of passengers/bus	32	8
Bus volume	bus/h	23	
HOV in transit lane	%	7	
Bus speed	km/h	24.5	5.1
Bus travel time	s/km	147	
Car speed	km/h	16.6	11.0
Car travel time	s/km	217	
Queue dissipation rate	s/veh	2.1	
Traffic signal split	% main green	70	
Traffic on side roads	% of main flow	50	
Opposite traffic	% of main flow	60	

B2.4 Calculations

As noted in section B2.2 the data retrieved from overseas publications and local reports did not cover all the bus priority treatments investigated for the purpose of this research. Therefore it was necessary to develop algorithms for estimation of the delays to buses and other affected vehicles from the first principles. Refer to sections B6 and B7 for the derivation of numerous algorithms for the analytical model.

The algorithms, built into the model, offer the user two choices – to accept the default values or to input the site-specific data into the algorithms and thus derive the outcomes more appropriate for the site under study.

B3 Analysis of intersections and transport corridor

B3.1 Introduction

A large number of algorithms were developed in order to estimate the effects of each of the analysed bus priority treatments on the performance of buses and other vehicles. The algorithms take into consideration reduced delay or travel time to buses and potentially adverse effects on other traffic, especially in side roads. Some of the intersection treatments favour vehicles travelling in the same direction as the buses and therefore reduce the adverse impact on all non-bus traffic. Other treatments, however, introduce additional delays to non-car traffic on all approaches.

B3.2 Intersection

B3.2.1 Concept

Each of the approaches at the intersection is analysed separately and the total effect on the intersection is obtained by adding the individual impacts.

B3.2.2 Analysis

The algorithms for estimation of the bus and other vehicle delays at the intersection are presented in section B6. The table below shows the representative values. These values were derived on the basis of the typical Auckland road traffic environment and operations. The observed characteristics of a typical traffic situation were: traffic volume of 1000veh/h in two lanes on the main (‘with bus’) approach, 20 buses per hour, average bus occupancy of 30 passengers per bus and a 120 seconds signal cycle length.

Table B3.1 Intersection default values derived analytically

Bus priority treatment	Indicator	Unit	Average value
Bus advance	Reduction of bus delay	s/bus	-5.0
Bus advance	Other vehicle delay	s/veh	+0.3
Transit active signal	Reduction of bus delay	s/bus	-7.2
Transit active signal	Other vehicle delay	s/veh	+0.3
Queue jump lane	Reduction of bus delay	s/bus	-5.0
Queue jump lane	Other vehicle delay	s/veh	0
Bus right turn only	Reduction of bus delay	s/bus	0
Bus right turn only	Other vehicle delay	s/veh	+0.2
Bus gate for bus right turn	Reduction of bus delay	s/bus	-1.4
Bus gate for bus right turn	Other vehicle delay	s/veh	+0.5

It is evident that the individual delay reduction for buses (per bus) is much greater than the individual increase in delay for other vehicles (per vehicle). The economic efficiency of the user’s project, however, depends on several factors, the most important of which are the number of buses, bus occupancy, traffic volume and car occupancy.

B3.3 Transport corridor

B3.3.1 Concept

Transport corridor in the analytical model has two components:

1. the intersection
2. the road segment.

Each intersection can have a different bus priority treatment, therefore the intersections will be analysed individually. However, it would not be practical to treat the road segments individually, so a uniform bus priority treatment has to be adopted for the full length of the transport corridor or at least its major portion.

The user has to input the salient features for each of the road segments. The analytical model will identify a maximum of three governing segments along the route. The bus priority treatment will be applied to the governing and upstream segments. The model of the transport corridor is restricted to five segments and six intersections as previously illustrated in figure B1.2.

The effectiveness of the transport corridor is assessed by the weighted KPIs as discussed in section B1.2.3. The KPIs reflect the overall person travel time rather than the vehicle travel time and are aiming at a future horizon year. An important aspect of the analysis is therefore the attractiveness of the bus priority treatment to encourage modal shift from single-occupant cars to buses and multi-occupant cars where transit lanes exist.

B3.3.2 Analysis

The algorithms for estimation of the bus and other vehicle travel time on the road segments are presented in section B7. The default values in the road segment model that can be replaced by the user are the annual traffic growth rate and the occupancy rates for car, bus and multi-occupant vehicles. All remaining inputs are mandatory. The user has to input the required data and the model will identify the governing road segments. The user will carry out the analysis of each of the governing segments separately. The adopted treatment of the governing sector will apply to the upstream segments up to the next governing segment.

One of the elements of the economic analysis of the road segment is the removal of kerbside parking in front of small retail businesses. Removal of parking might be necessary for the installation of a bus or transit lane, but it usually has an adverse impact on the affected retailers. The research team were unable to find any material in the literature on the value of the potential loss to the affected retailers.

B4 Limitations of the analytical model

The quality of the output depends on a number of factors. These factors are:

- Site-specific inputs. For many of the inputs the user has an option of accepting the default values built into the model or substituting them with site-specific values. The output will benefit substantially if the user has a good understanding of the site and is able to provide a sound set of input data.
- The default values accessible to the user. If the user relies on the default values, the output will tend to represent a generalised situation rather than the specific site. Much attention was paid by the research team to identify the most representative situations, which would cover the majority of the locations. However the onus is on the user to identify any large discrepancies between the representative values adopted for the model and the site values, and supply the data, where the large discrepancies occur.

- The default values inaccessible to the user. Although much attention was paid by the research team to identify the most appropriate operational characteristics as shown in tables B1.1, B1.2 and B2.1, it needs to be realised that there would be sites and conditions where the operational situations could materially differ, leading to sub-optimum outputs of the model.
- Representative traffic and operating conditions. The representative conditions were defined on the basis of Auckland traffic. Although not likely to affect the output substantially, one has to be aware that there might be regional differences affecting the relevance of the output.

The BAT tool kit, developed as the product of this research work is capable of providing broad indications of appropriate bus priority treatments based on average values and situations.

The researchers openly acknowledge that BAT is only a first generation application tool developed on existing data available, and that any solution which BAT recommends will entail a multi-faceted suite of influences and decisions which will determine the actual treatment provided on site.

The default values adopted in the model are averages and are expected to represent most of the situations with adequate accuracy. However, there may be situations falling outside the acceptable range. It is therefore necessary to subject the treatments identified by the model to a PFR or SAR analysis as required by the NZTA, before a decision on the implementation is reached.

B5 Initially investigated range of bus priority treatments

B5.1 Introduction

An extensive literature review of local and overseas publications identified a range of appropriate bus priority treatments aimed at improving the quality of the bus service. The description of the treatment, reason for its selection or rejection, and source of references are shown below.

Figure B5.1 B-phase at signalised intersection

Figure B5.2 Bus advance in Manukau, New Zealand

Source: Auckland Council GIS viewer

1 Bus advance with the bus early release at traffic signal

a Operation: Bus has free access to the stop line and gets the B-phase before the traffic stream is released later.

b Decision: Accept for the analysis – the treatment has successfully been used on various locations in New Zealand.

2 Transit active signal for the bus detected on the approach to the intersection

a Operation: Approaching the intersection the bus triggers the signal phase change. By the time the bus arrives at the intersection the traffic signal changes. If the bus arrives on red the red phase is terminated. If it arrives at the end of green the green phase is extended.

b Decision: Accept for the analysis – the treatment (usually referred to in New Zealand as signal pre-emption) has successfully been used internationally. There are numerous installations in New Zealand.

3 Queue jump lane to allow the bus to bypass the queue

a Operation: Bus is able to bypass the queue of the waiting cars, because a short bus lane is installed on the approach to the intersection. Therefore buses have free access to the stop line from where they continue with the traffic stream into the bus lane on the far side of the intersection. The delay to bus is reduced by bypassing the queue. There is no adverse impact on the other vehicles, as the signal cycle is not affected.

b Decision: Accept for the analysis – the treatment has successfully been used internationally.

4 Bus right-turn only signal

a Operation: Bus turns right from a dedicated right-turn bay.

b Decision: Accept for the analysis – the treatment has successfully been used internationally and there are some installations in New Zealand.

Figure B5.3 Queue jump lane

Figure B5.4 Bus right turn only

5 Bus gate at the intersection allowing buses to cross all traffic lanes to access right turn lane

a Operation: Bus in the bus lane has to turn right at the intersection. In order to cross the general purpose traffic lanes a bus gate is installed in advance of the stop line. Without the bus gate the bus would have to weave through the general traffic ahead of the intersection and travel at low speed. With the bus gate the bus travels through the intersection without reducing speed.

b Decision: Accept for the analysis – the treatment has been successful internationally.

6 Bus priority at the roundabout closing access of the conflicting traffic stream

a Operation: Bus approaching the roundabout triggers a traffic signal for the circulating flow, which stops the conflicting vehicles in the roundabout. As soon as the bus enters the roundabout the signal turns green and the usual priority controlled operation of the roundabout returns.

b Decision: Do not analyse – the peer reviewer considered it to be less appropriate for New Zealand traffic situation than other treatments.

7 Bus priority at the roundabout with full traffic signal control

a Operation: Bus approaching the roundabout triggers traffic signals on the roundabout, allowing the bus to enter the roundabout unopposed. As soon as the bus enters the roundabout the signal turns green and the usual priority controlled operation of the roundabout is restored.

b Decision: Do not analyse – the treatment is inappropriate for New Zealand as there are no signalised roundabouts here.

8 With-flow kerbside bus lane

a Operation: A dedicated bus lane running at kerb parallel to the general purpose traffic lanes. Sometimes the kerbside bus lane may accept cycles, motorcycles or/and taxis.

b Decision: Accept for the analysis – it is one of the most common bus priority treatments internationally. There are numerous applications of kerbside bus lanes in New Zealand cities.

The BAT model is unable to distinguish between the with-flow kerbside bus lane and the with-flow offside bus lane. Therefore the BAT model will analyse both treatments as a generic 'with-flow' bus lane. The lane performance analysis for both treatments is the same in the BAT model. However, the user can distinguish between both by inserting a different construction cost.

9 With-flow kerbside bus and cycle lane

a Operation: A dedicated bus lane running at kerb parallel to the general purpose traffic lanes. In comparison with the 'with-flow kerbside bus lane', this treatment requires wider traffic lane width to allow safe bus-cyclist interaction.

b Decision: The BAT model is unable to analyse the impact of cyclists in the bus lane. Therefore this treatment is analysed as the 'with-flow kerbside bus lane' treatment in the BAT model. There are numerous applications of the 'with-flow kerbside bus and cycle' lanes in New Zealand cities.

Figure B5.5 With-flow kerbside bus lane in London

Figure B5.6 With-flow kerbside bus and cycle lane

10 With-flow offside bus lane

a Operation: A dedicated offside bus lane running at the lane next to the median parallel to the general purpose traffic lanes. Sometimes the with-flow offside bus lane may accept motorcycles or/and taxis.

b Decision: The offside bus lane has a lot of associated issues, such as access and egress, location of bus stops etc, which have to be resolved separately. There are no applications of such treatment in New Zealand cities.

As noted before, the BAT model is unable to distinguish between the with-flow kerbside bus lane and the with-flow offside bus lane. Therefore the BAT model will analyse both treatments as a generic 'with-flow' bus lane. The lane performance analysis for both treatments is the same in the BAT model. However, the user can distinguish between both by inserting a different construction cost.

11 Busway

a Operation: An exclusive bus right of way where buses can travel at high speeds, because the intersections are grade separated. The bus stops are bus stations located at suitable locations along the route. The busway operates on a principle similar to the railway, and therefore is an excellent facility for a high-frequency high-capacity bus service. The only existing busway in New Zealand is a very successful public transport operation.

b Decision: Do not analyse – due to high capital and operating costs of the busways the decisions concerning them have to be based on comprehensive studies.

Figure B5.7 With-flow offside bus lane at M32 in Bristol, UK

Figure B5.8 Northern Busway, New Zealand

12 With-flow combined bus/freight lane

a Operation: A shared bus and freight lane. It can be potentially advantageous on the freeways, where express buses travel without stopping at bus stops, but its functionality in urban areas seems to be dubious.

b Decision: Do not analyse – its practical application in New Zealand seems to be limited.

13 Reversible bus lane

a Operation: A dedicated bus lane running in a wide median of a dual-carriageway road. A major advantage of the reversible lane is that it operates in one direction in the morning peak and in the opposite direction in the afternoon peak. No other vehicle classes can be allowed in the reversible bus lane. The reversible lane on the Auckland Harbour Bridge is an example of a successful operation, although it is a special case – it is a general purpose lane (not a bus lane) and it is separated from opposing traffic by a movable barrier.

b Decision: Accept for the analysis – it is one of the bus priority treatments used internationally.

14 No-car lane

a Operation: The lane accessible to vehicles that are not a car, eg buses, trucks, vans, motorcycles. Its functionality in New Zealand urban areas seems to be dubious.

b Decision: Do not analyse – its practical application in New Zealand seems to be limited.

Figure B5.9 No-car lane in Newcastle, UK

Figure B5.10 Transit lane at Constellation Drive, Auckland

Source: AECOM 2008

15 Transit lane T2 (all vehicles with at least two occupants)

a Operation: A 'with-flow kerbside bus lane' shared with all other vehicles that have at least two occupants. The T2 lane usually allows use by cyclists and motorcyclists.

b Decision: Accept for the analysis – there are numerous applications of T2 lanes in New Zealand cities.

16 Transit lane T3 (all vehicles with at least three occupants)

a Operation: A 'with-flow kerbside bus lane' at kerb bus lane shared with all other vehicles that have at least three occupants. The T3 lane usually allows use by cyclists and motorcyclists.

b Decision: Accept for the analysis – there are numerous applications of the T3 lanes in New Zealand cities.

17 Contra-flow bus lane

a Operation: A dedicated bus lane running on the opposite carriageway or in a one-way street against the traffic stream. Issues concerning the passenger boarding and alighting, and access to bus stops have to be resolved.

b Decision: Accept for the analysis – it is one of the bus priority treatments used internationally, although there are no New Zealand applications.

Figure B5.11 Contra-flow bus lane, UK

18 Motorway bus lane

a Operation:A dedicated bus lane on the motorway. The lane can be located at kerb, at median, or can be a shoulder lane. Some shoulder bus lanes exist in New Zealand.

b Decision: Do not analyse –peer reviewer considered it to be superfluous to the brief of this project.

19 Bus gate at the mid-block allowing buses to negotiate the bus lane discontinuity created by the 'on-street' parking or bulbous kerb extensions for pedestrian crossing

a Operation: Bus gate is a traffic signal, which by stopping non-bus traffic creates a virtual bus lane. When there is a discontinuity of the bus lane in mid-block, the bus approaching in the bus lane triggers the signal, and traffic in the adjacent lane stops, allowing the bus to negotiate the discontinuity and return to the bus lane.

b Decision: Accept for the analysis – the treatment has successfully been used internationally.

Figure B5.12 Bus gate at A1, London

Figure B5.13 Reversible bus lane, Spain

Source: AECOM 2008

20 Motorway high occupancy vehicle (HOV) lane

a Operation: A shared bus and multi-occupant vehicle lane on the motorway. The lane can be located at kerb or at median. This is a common priority treatment on the USA freeways.

b Decision: Do not analyse –peer reviewer considered it to be superfluous to the brief of this project.

21 High occupancy toll (HOT) lane

a Operation: A shared bus and multi-occupant vehicle lane on the motorway, where the access by multi-occupant vehicles is limited to vehicles paying toll. The lane can be located at kerb or at median, and needs to have its own toll gates. It is a common priority treatment on USA freeways.

b Decision: Do not analyse – New Zealand legislation does not allow tolling vehicles for this purpose.

22 Transit mall

a Operation: Bus has access to the pedestrian mall, where access is prohibited to all other vehicle classes.

b Decision: Do not analyse – this treatment is not practical for New Zealand, as there are no pedestrian malls here.

Figure B5.14 Motorway HOT lane, USA

Figure B5.15 Transit mall

Source: http://transitmy.org/2011/01/01/transit-to-dbkl-pedestrian-bridges-do-not-solve-jaywalking-deaths/

B6 Literature review – intersection data

B6.1 Introduction

The purpose of this literature review was to gather evidence to back up the default values used in the analytical model developed for the intersections according to the selected bus priority treatment. The original number of potential treatments was reduced to five on the advice of the peer reviewer. The selected treatments for the intersection are:

1. Bus advance with bus phase
2. Transit active signal for the bus detected on the approach to the intersection
3. Queue jump lane (an additional short lane for bus to bypass queue)
4. Bus right turn only
5. Bus gate for bus right turn.

The default values of interest are the reduction of delay to buses and increased delay to other vehicles relevant to each of the studied bus priority treatments. This literature review attempted to identify the values measured on site during the actual case studies as well as those reported from the computer simulations.

B6.2 Findings

In spite of a large number of reviewed publications (see section B10), only a limited amount of information was identified and consistent with the purpose of this review. The data that could be used for validation of the values used in our analytical model is summarised below.

Alexander Skabardonis of the University of California Berkeley, quoted in Barton (2003), reported on a study of an arterial road with signalised intersections, where as a result of the signal bus pre-emption the delay to buses was reduced by 2.0s per bus per intersection. The sensitivity analysis showed these results were insensitive to the number of buses in the range of up to 30 buses per hour. Chada and Newland found that cross street traffic was not significantly affected, while Kloos reported an improvement in bus travel time variability of 8% to 10% (Barton 2003).

Davol (2001) of MIT conducted a review of transit signal priority (TSP) micro-simulation modelling studies. A study of the TSP in Los Angeles revealed there was a minimal adverse impact on cross street traffic. A study of PRIBUSS[26] strategy in Stockholm investigated three active signal priority functions – green extension, phase shortening (early green), and insertion of an additional phase. The study found there were no significant adverse effects on side street vehicles when green extension or insertion were applied, but phase shortening had an adverse impact.

Another important finding of the Stockholm study was the impact of TSP on travel time variability – the standard deviation of bus travel time was reduced by 50% if all three priority functions were implemented, but the side street vehicles' travel time variability was not affected.

An international review of bus priority treatments by Gardner et al (2009) summarises the benefits and impacts on travel time for a number of cities. It notes the reduction of delay for buses in Auckland of 11s per bus per intersection. A similar magnitude of delay reduction was reported from Southampton – 9.5s per intersection for buses and a 3.8s delay increase for general traffic. In Aalborg the delay reduction for buses was 5.8s per bus per intersection, but the impact of signal priority on general traffic was not recorded. In London, the delay reduction for buses was 9s per bus for isolated intersections and 3s to 5s for SCOOT controlled intersections.

Jepson et al (1999) reported on the study of the Gold Coast Highway in Australia. The studied section was a 6.4km long four-lane arterial road with 12 signalised intersections and three signalised pedestrian crossings. The benefits of the bus priority treatments and the associated impacts on the general purpose traffic were assessed using computer simulation (TRANSYT 8 and SIDRA 4.1 models).

The reduction of bus delay with active bus priority treatments were 12.3s per bus per intersection for the dedicated bus phase, 4s for queue jump bus phase, 12.3s for absolute bus priority and 6.3s for selected bus priority. Passive bus priority (signal coordination favouring buses) showed a 3s delay reduction. The reported impact on the general traffic is inconclusive, producing the results in the range of 5s to 12s per vehicle.

A review of TSP implementation experiences in the USA was presented by Liao (2006). The most common signal priority functions were early green and extension of green phase for buses. The results showed a range of 2s to 13s per bus per intersection delay reduction, 1.5s/vehicle delay reduction for cars on the 'with-bus' approach, and 1s to 8.2s/vehicle delay increase for cross streets.

One of the studies reported by Liao was traffic simulation using the AIMSUN micro-simulation package of operation along the Franklin Corridor in Minneapolis from DuPont to 27th Avenue. This corridor is 4.8km long with a total of 22 signalised intersections. Buses received a dedicated bus phase before the release of general traffic.

The findings show that:

- In the morning peak there was an average delay reduction of 7s per bus per intersection. It was accompanied by an average delay increase of 0.6s per vehicle for general traffic in the main road and 2.6s per vehicle in the side roads.

[26] PRIBUSS is an active signal priority strategy four buses that was developed for use in the city of Stockholm, Sweden. PRIBUSS is the acronym for 'prioritisation of buses in a coordinated signal system'. The objective of PRIBUSS is to provide priority to buses without significant disruption of signal operations, especially under coordinated control (Davol 2001).

- In the evening peak the average travel time delay reduction for buses was 5.4s per intersection, accompanied by an average delay increase of 3.5s per vehicle for general traffic in the main road and 6.3s per vehicle in the side roads.

A report by Maunsell Australia (2006) discussed various management tools to enhance the operation of arterial roads. Applying the signal coordination with Bus SCOOT the bus delay can be reduced by 4s per bus per intersection if the priority is given to all buses or by 3s per bus per intersection if the priority is given only to buses that are behind schedule.

Ova and Smadi (2001) from Upper Great Plains Transportation Institute reported on the efficiency of TSP strategies for small and medium cities in the USA. They found that the most common active signal priority functions were early green and extension of green phase for buses. The results of field studies revealed a range of 1s to 4s per vehicle delay increase on side streets. However the simulations were more conservative showing an average increase in stopped delay on cross street of 8.2s per vehicle. One of their conclusions was that bus headways would have to be less than 15 minutes to justify the implementation of TSP.

Smith et al (2005) reported on TSP for the US Department of Transportation. Several of their findings are relevant to our work. They found that TransLink in Vancouver, British Columbia, showed the delay reduction of 16.3s per bus per intersection (although this might include some travel time savings on the links, resulting in an overestimate). Studies in other cities showed the priority for all buses resulted in 35% to 40% reduction in bus trip travel time variability, while the priority for late buses only resulted in 19% reduction in bus trip travel time variability and, more importantly, in the modal shift from cars to buses ranging from 23% to 30%.

The extent of the modal shift has been corroborated by Vuchic (2007, p242), who quoted the modal shift range of 10% to 30% based on the studies in several North American cities. He also stated that such a modal shift was not a one-off phenomenon but continued annually for several years.

The iBUS system (Transport for London 2006) utilises GPS technology and other on-bus systems such as odometer output and door sensors to communicate with the computer on-board the bus. The computer, known as the iBIS plus unit, is programmed with bus priority and other relevant information such as bus location details. When a virtual detection point is reached as programmed into the iBIS plus software, a signal is sent to the transceiver in the signal controller requesting bus priority, and to a central location for performance monitoring. The new bus location system provides a far greater degree of information about the bus and its journey than previous systems, and will be used for other purposes such as the provision of real-time passenger information displayed in bus shelters.

The trials of various bus priority treatments resulted in the following findings – 9s per bus per intersection when SVD strategy is used at isolated intersections, 4s to 6s with SVD at MOVA intersections, 2s with SPRINT intersections and 3.9s per bus per intersection with Bus SCOOT.

Bus SCOOT allows active bus priority within the SCOOT system, SPRINT allows active bus priority within fixed-time traffic control system, and MOVA allows more flexible control of isolated intersections. In New Zealand we do not use any of these three traffic control systems. However, the results of the general SVD, which can easily be implemented within the SCATS system, appear to be consistent with the reported elsewhere results of the early green and extension of green phase for buses.

Bodé (2010) reported on the performance of the short bus lane bypassing the traffic queue on the approach to Portwood Roundabout in Stockport, UK. Various bus services passing through the large signal controlled roundabout were subject to delays. A short length of bus lane sought to reduce the delays experienced by bus services without impacting on general traffic. The short lane gives access to a 130m long bus-only road across the large, busy roundabout. The scheme has resulted in bus journey-time reductions with minimal impact on other traffic – the delay was reduced by 43s per bus for all periods, with a maximum reduction of 69s achieved in the AM peak.

B6.3 Conclusions

In spite of a large number of reviewed publications there was very little information pertinent to our research work. The retrieved relevant data is presented in tables B6.1 to B6.3 below.

Table B6.1 Transit active signal – indicator: reduction of bus delay

Unit	Value	Comments	Source
s/bus	2.0	Arterial road in California	Barton 2003
s/bus	11.0	Auckland	Gardner et al 2009
s/bus	9.5	Southampton	Gardner et al 2009
s/bus	5.8	Aalborg	Gardner et al 2009
s/bus	9.0	London isolated intersections	Gardner et al 2009
s/bus	3.0–5.0	London SCOOT intersections	Gardner et al 2009
s/bus	12.3	Gold Coast Highway – bus phase	Jepson et al 1999
s/bus	12.3	Gold Coast Highway – absolute bus priority	Jepson et al 1999
s/bus	4.0	Gold Coast Highway – queue jump bus phase	Jepson et al 1999
s/bus	6.3	Gold Coast Highway – selected bus priority	Jepson et al 1999
s/bus	2.0–13.0	USA – average, various locations	Liao 2006
s/bus	7.0	Franklin Corridor, AM peak	Liao 2006
s/bus	5.4	Franklin Corridor, PM peak	Liao 2006
s/bus	4.0	Simulation with Bus SCOOT, priority to all buses	Maunsell 2006
s/bus	3.0	Simulation with Bus SCOOT, priority to late buses	Maunsell 2006
s/bus	16.3	Vancouver, likely overestimated	Smith et al 2005
s/bus	9.0	London, selective veh detection	TfL 2006

The range of the reported delay reduction values is wide, from 2s to 16.3s per bus per intersection. However if the lowest and highest values are eliminated as outliers, a plausible conclusion can be drawn: the averages of the data, the mode and the median are very close – ranging from 7.5s (average) to 9.0s (mode). It seems plausible to use this range for verification of the default value of the bus delay reduction, which we will incorporate in the analytical model of the transit signal priority.

Table B6.2 Transit active signal – indicator: general traffic delay

Unit	Value	Comments	Source
s/veh	-1.5	Reduction for 'with bus' traffic	Liao 2006
s/veh	0.6	Franklin Corridor, Minneapolis main road traffic, AM peak	Liao 2006
s/veh	3.5	Franklin Corridor, Minneapolis main road traffic, PM peak	Liao 2006
s/veh	3.8	Southampton, all approaches	Gardner et al 2009

Unit	Value	Comments	Source
s/veh	1.0–8.2	Cross streets – range, USA	Liao 2006
s/veh	2.6	Franklin Corridor, Minneapolis cross streets, AM peak	Liao 2006
s/veh	6.3	Franklin Corridor, Minneapolis cross streets, PM peak	Liao 2006
s/veh	1.0–4.0	USA range, cross street survey	Ova & Smadi 2001
s/veh	8.2	USA, cross street simulation	Ova & Smadi 2001
	NA	USA review – no significant impact on cross street traffic	Barton 2003
	NA	Los Angeles – minimal impact on cross street traffic	Davol 2001
	NA	Stockholm – no adverse effect on cross street traffic	Davol 2001

The range of the reported general traffic delay values is also relatively wide. The data can be divided into two groups i) the delay to the main road traffic, which is less affected, and ii) the more affected side road traffic.

A small sample of the main road traffic delays ranges from a 1.5s reduction of delay per vehicle per intersection to a 3.5s increase of delay. The first value applies to the situation where buses and general traffic get the green phase together. The latter value applies to the situation where the exclusive bus phase appears before the release of general traffic. Therefore the first value, an average reduction of car delay of 1.5s per vehicle, is suitable for verification of the default value adopted for our analytical model. The other value applies to a different situation, in a way similar to the 'bus advance with bus phase' treatment used in our analysis.

The sample of side road traffic is slightly larger and contains three qualitative statements to the effect that the delays in the side roads are minimal. Two values of 8.2s delay per vehicle were derived by simulation and not validated by the site measurements. They seem to be well outside the range and were rejected as outliers. As a result the range set by the average and the median values is narrow, between 3.0s and 3.6s, and seems to be acceptable for verification of the value adopted for the analytical model.

Table B6.3 Short bus lane – indicator: reduction of bus delay

Unit	Value	Comments	Source
s/bus	43	Portwood Roundabout, all periods	Bodé 2010
s/bus	69	Portwood Roundabout, AM peak	Bodé 2010

Only one study reported on the effect of the installation of a short lane for buses to bypass the traffic queues. Buses overtake the queue of some 20 vehicles. An average for all periods of 43s saved by the bus could be used to verify our default value of the bus delay reduction for this type of strategy. The Portwood Roundabout study confirms that the short lane constructed in addition to the existing carriageway does not reduce the existing capacity and thus has no detrimental effect on the general traffic.

B6.4 Additional comments

In addition to the quantified values discussed above, the literature review provided some insights to other aspects of bus priority treatments, especially the impact on trip time variability, modal shift from cars to buses, the minimum number of buses needed to achieve the benefits of the scheme, and a general impact of the number of buses on the delay to other traffic.

Installation of bus priority treatments in Stockholm resulted in the reduction in bus travel time variability by 50%. A review of the US bus priorities showed a 35% to 40% reduction when priority applies to all buses and a 19% reduction when priority is given only to those buses that run behind the schedule. Another US study reported an 8% to 10% improvement.

A review of the bus priority treatments in the USA showed that the shift from cars to public transport ranged between 10% and 30% and could be sustained annually for several years. Another US study concluded that the reduction of delay to buses as a result of the bus signal priority was insensitive to the number of buses up to 30 buses per hour. And yet another US study established that the minimum number of buses for any bus priority treatment to return benefits was four per hour.

B7 Literature review – road segment data

B7.1 Introduction

The purpose of this literature review was to gather data to back up the default values used in the analytical models developed for the selected bus priority treatments on road segments. The treatments appropriate for New Zealand conditions were selected for this research project in discussion with the peer reviewer, Professor Graham Currie of Monash University:

1. With-flow bus lane
2. Contra-flow bus lane
3. HOV/transit lanes (T2 and T3)
4. Removal of kerbside parking in front of small retail businesses.

The default values of interest are the reduction of delay to buses and increased delay to other vehicles relevant to each of the studied bus priority treatments. This literature review has identified relevant values measured on site during the actual local and international case studies as well as those reported from the computer simulations.

B7.2 Findings

B7.2.1 With-flow bus lanes

A fair amount of data on the operation of with-flow bus lanes has been collected in New Zealand and overseas. The discussion below is presented in sections describing Auckland, Wellington and Christchurch monitoring reports and overseas sources.

B7.2.1.1 Auckland

The bus lane monitoring report (Gravitas 2010) shows the differences in travel time for buses and general traffic across a number of CBD and urban arterial locations in Auckland. The following bus lanes have similar characteristics to the ones represented by the analytical model being developed by AECOM:

- Bus lanes 4.5km long were introduced on Great North Road between Ponsonby Road/Newton Road and Point Chevalier/Carrington Road in September 2000. Bus travel time was reduced by 220s per bus (49s/bus-km) with a corresponding 152s increase per vehicle (34s/veh-km) to general traffic.
- Bus travel time surveys on the 2.9km bus lanes in Mt Eden Road installed between New North Road/Symonds Street and Balmoral Road in March 1998 and later extended south of Balmoral Road,

showed the bus travel time reduction of 136s (47s/bus-km) for the city bound bus lane and a 129s reduction (45s/bus-km) for the outbound lane.

- Surveys in the 1.7km bus lanes in Sandringham Road in both directions between Farrelly Avenue and Aurora Avenue installed in April 1999 showed the reduction of bus travel time of 162s (95s/bus-km) and an increase of 48s (28s/veh-km) for general traffic.
- The 3.3km bus lanes were introduced on Dominion Road in both directions between Valley Road and Mt Albert Road in March 1998. The travel time was reduced by 211s (64s/bus-km) for the city bound bus lane and by 37s (11s/bus-km) for the outbound lane. The general traffic travel time increased by 35s (11s/veh-km).

The Newcombe (2009) report quoted bus operators of the Remuera Road bus lane who estimated a journey time saving of approximately 300s (190s/bus-km) in the 1.6km bus lane. They also concurred that travel time reliability had improved substantially.

B7.2.1.2 Wellington

The Wellington city bus lane monitoring survey by Traffic Design Group (2008) investigated the effects of a number of bus lanes operating around Wellington city. The purpose of the surveys was to determine whether the introduction of the bus lanes had any effect on cars, cyclists, pedestrians or adjacent land use. The results of this survey are summarised below:

- The Chaytor Street bus lane extends for 500m south of Old Karori Road and operates all day. The bus lane has resulted in 31s reduction (62s/bus-km) in the average bus travel time and 11s (22s/veh-km) reduction in average car travel time.
- The bus lane on Kaiwharawhara Road extends from Old Porirua Road to the stop line at the Hutt Road intersection for a length of 350m.The bus lane operates between 7am and 9am Monday to Friday and is available for parking outside these hours. The bus lane has resulted in 42s reduction in the average bus travel time (120s/bus-km) and 21s (60s/veh-km) reduction in average car travel time.
- The Glenmore Street bus lane extends in a northbound direction from The Rigi up until the stop line at the intersection with Upland Road for a length of 550m. The bus lane operates between 4pm and 6pm and has resulted in 16s (29s/bus-km) increase in the average bus travel time and 65s increase (118s/veh-km) in average car travel time.

B7.2.1.3 Christchurch

Ussher (2010) summarised the impact on bus travel time of the 3.1km bus lane along Papanui Road between Northlands Mall and Bealey Avenue. For the inbound bus lane the bus travel time was reduced by 120s (39s/bus-km) in the morning peak. For the outbound bus lane, the bus travel time was reduced by 180s (58s/bus-km) in the evening peak.

Another bus lane monitoring report (Boorer 2010) presented the impact on bus travel time of the 7.5km bus lane along New Brighton Road/Shirley Road/Hill Road/Fitzgerald Avenue between Gloucester Street and Bower Avenue. For the inbound bus lane the bus travel time was reduced by 60s (8s/bus-km) in the morning peak. For the outbound bus lane the bus travel time was reduced by 54s (7s/bus-km) in the evening peak.

B7.2.1.4 International sources

Wei and Chong (2002) reported on the performance of Kunming's 5km bus lane in Yunnan, China. The lane runs along the city's most important south-to-north artery network. Monitoring revealed a 691s (138s/bus-km) travel time saving over the length of the lane. The report, however, does not present any data on the effect of the bus lane on general traffic travel time.

Berry (2010) looked at the applicability of integrating a bus only shoulder into the intermittently congested segment of US 101 in southern San Luis Obispo County. A simulation was built to model the travel time savings against the potential general traffic speeds. The summary of the simulation results is presented in table B7.1 below. A situation resembling New Zealand conditions (bus speed in the lane 56km/h and general traffic speed 32km/h) resulted in a 48s/bus-km travel time saving.

Table B7.1 Vehicle time savings as a proportion of overall travel time

Mainline Speed	Shoulder Transit Lane Speed	Maximum Speed Difference	Car Driving Time	Bus Driving Time	Time Savings	Proportional Time Savings
7.5 Mile Corridor			(length of corridor/speed) * 60 minutes		car driving time - bus driving time	(car driving time-bus driving time)/car driving time
> 35 mph	Not on shoulder	0				
35	35	0	12.9	12.9	No savings	0
30	35	5	15.0	12.9	2.1 minutes	0.14
25	35	10	18.0	12.9	5.1 minutes	0.29
20	35	15	22.5	12.9	9.6 minutes	0.43
15	30	15	30.0	15.0	15 minutes	0.50
10	25	15	45.0	18.0	27 minutes	0.60
5	20	15	90.0	22.5	67.5 minutes	0.75
0	15	15	n/a	30.0	(unrealistic)	n/a

Source: Berry 2010

B7.2.2 Contra-flow bus lane

Mirabdal and Yee (City of San Francisco) reported on the benefits of San Francisco's first downtown transit contra-flow bus lane. The bus lane runs a length of 500m from Washington Street to Bush Street. The impacts of travel time on a number of bus lines were recorded. These buses were travelling on different routes prior to the implementation of the bus lane. For bus line #15, there was a 351s (702s/bus-km) reduction in bus travel time during peak hours. For bus line #12 and #42, there was a 472s (944s/bus-km) reduction in bus travel time during peak hours.

The large bus travel time savings presented above achieved over relatively short distances indicate that the benefits of the contra-flow bus lanes could be substantial. In congested conditions traffic speed might not be higher than 10km/h, while the bus in the contra-flow lane is unobstructed and travels at the speed close to the legal speed limit.

B7.2.3 High occupancy vehicle/transit lanes (T2 and T3)

Paling and Brown (2010) reported the HOV travel time savings for the Onewa Road 2.3km T3 lane. The recorded travel time saving was 20 minutes (520s/veh-km). Other cities noted in the study were Trondheim in Norway, where the reported travel time saving in the T2 lane was 90s, and Snohomish in Washington State, USA, where the T2 lanes produced travel time saving of 60 seconds.

Bauer et al (2005) reported on the effectiveness of HOV facilities in Brisbane Australia. The Waterworks Road 2+ HOV lane is an 'add-a-lane' facility extending for approximately 8km. The Waterworks Road inbound travel time saving in the HOV lane was 339s (42s/veh-km). Outbound direction had a travel time reduction of 148s (18s/veh-km). The Lutwyche Road 3+ HOV lane is 1.9km long and showed the monitored travel time reduction of 360s (190s/veh-km).

Kwon and Varaiya (2007) reported a study conducted on the effectiveness of California's 1171 mile HOV system during peak-hour traffic. The study reached the conclusion that HOV lanes offer small travel time savings. The reported HOV lane mean saving over a random 10-mile route vs the adjacent general purpose lane was only 102s (6s/veh-km); however, HOV travel times were more reliable.

The 2+ HOV lane on A647 opened in 1998 (Leeds City Council 2007) showed in August 1998 the morning peak HOV journey time savings of 150s (30s/veh-km) for a 5km trip from the Leeds Outer Ring Road to the Inner Ring Road. In September 1998 this saving had increased to 210s (42s/veh-km) and by June 1999 the time saving was 240s (48s/veh-km).

Turnbull (2003) reported the travel time impacts of the HOV lane system in Houston, Texas. By 2003 some 100 miles of HOV lanes were in operation in six freeway corridors. The elements of the HOV system were the HOV lanes, park-and-ride lots, transit centres, direct access ramps and express bus service. The HOV lanes provided travel time savings for buses, vanpools and carpools. Morning peak-hour travel time savings ranged from approximately 2 to 22 minutes on the different HOV lanes. The Northwest Freeway HOV lane generally achieved the largest travel time savings of about 22 minutes. The Katy HOV lane averaged between 17 and 20 minutes, the North 14 minutes, and the Gulf and Southwest between 2 and 4 minutes. In addition, the HOV lanes provided more reliable trip times to carpoolers, vanpoolers and bus riders.

Nee et al (2002) monitored the performances of a number of HOV lanes in the Puget Sound area in Washington State, USA. All these HOV lanes are concurrent (with-flow) lanes and operate for 24 hours a day. They reported the following travel time savings:

- I-5 north of the Seattle CBD. Northbound carriageway (15.1 miles of 2+ HOV lanes) - 16s per mile (10s/veh-km). Southbound carriageway (15.6 miles of 2+ HOV lanes) - 27s per mile (17s/veh-km).
- I-5 south of the Seattle CBD. Northbound (10.3 miles) – 23s per mile (14s/veh-km). Southbound (10.2 miles) – 6s per mile (4s/veh-km).
- I-405 north of I-90. Northbound (14.5 miles) – 33s per mile (21s/veh-km). Southbound (14.8 miles) – 45s per mile (28s/veh-km).
- I-405 south of I-90. Northbound (10.3 miles) – 70s per mile (44s/veh-km). Southbound (10.5 miles) – 34s per mile (21s/veh-km).
- I-90 eastbound (11.1 miles) – 11s per mile (7s/veh-km). Westbound (11.1 miles) – 11 seconds per mile (7s/veh-km).
- SR 520 westbound (1.4 miles) – 171 seconds per mile (107s/veh-km).
- SR 167 northbound (8.2 miles) – 29 seconds per mile (18s/veh-km). Southbound (8.2 miles) – 44 seconds per mile (28s/veh-km).

Martin et al (2004) reported on the effectiveness of HOV lanes on Interstate 15, Seattle US. 16 miles of 2+ HOV lanes opened on the re-constructed I-15. The HOV lanes operate 24 hours. Their findings showed 108 seconds (4s/veh-km) travel time savings in the AM Peak, 36 seconds (2s/veh-km) travel time savings in the off peak and 1,272 seconds (50s/veh-km) travel time savings in the PM peak.

B7.2.4 Removal of kerbside parking/clearway

The RTA (NSW) (2009) reviewed the performance of Bondi Road clearway in Sydney. The clearway was 1.6km in length and induced a bus travel time saving of 1380 seconds (863s/bus-km).

B7.3 Analysis

From a large number of reviewed publications, a relatively large number of results was found for the impact of the with-flow bus lane on the travel time of buses and cars, and for the travel time reduction for multi-occupant vehicles travelling in HOV lanes. Only one report dealt with the contra-flow bus lane and reversible bus lane. No information was found on the effectiveness of the bus gate. There was also no information on the impact of the removal of kerbside parking in front of small retail shops.

The retrieved relevant data is presented in the tables B7.2 to B7.4.

Table B7.2 Bus lane – indicator: reduction of bus delay

Value (s/bus-km)	Location	Source
-49	Great North Rd outbound, Auckland	Gravitas 2010
-47	Mt Eden Rd inbound, Auckland	Gravitas 2010
-44	Mt Eden Rd outbound, Auckland	Gravitas 2010
-95	Sandringham Rd inbound, Auckland	Gravitas 2010
-64	Dominion Rd inbound, Auckland	Gravitas 2010
-11	Dominion Rd outbound, Auckland	Gravitas 2010
-188	Remuera Rd, Auckland	Newcombe 2009
-62	Chaytor St, Wellington	Traffic Design Group 2008
-120	Kaiwharawhara Rd, Wellington	Traffic Design Group 2008
-39	Papanui Rd inbound, Christchurch	Ussher 2010
-58	Papanui Rd outbound, Christchurch	Ussher 2010
-8	Queenspark inbound, Christchurch	Boorer 2010
-7	Queenspark outbound, Christchurch	Boorer 2010
-138	Kunming, China	Wei and Chong 2002
-48	San Luis Obispo, California	Berry 2010

The range of the reported delay reduction values is wide, ranging from 7s to 188s per km per bus. However since the values on both extremes are not single values, none were rejected as outliers.

The analysis of this sample (sample size 15) shows the mean value of 65.2s saved for bus km, and the median value of 48.9s/bus-km. This range appears appropriate for the verification of the default values in the analytical model.

Table B7.3 Bus lane – indicator: general traffic delay

Value (s/veh-km)	Comments	Source
+34	Great North Rd inbound, Auckland	Gravitas 2010
+28	Sandringham Rd outbound, Auckland	Gravitas 2010
+11	Dominion Rd outbound, Auckland	Gravitas 2010
-22	Chaytor St, Wellington	Traffic Design Group 2008
-60	Kaiwharawhara Rd, Wellington	Traffic Design Group 2008
+118	Glenmore St, Wellington	Traffic Design Group 2008

The range of the reported general traffic delay values is also wide, from 60s/bus-km travel time reduction to 118 s/bus-km travel time increase. The extreme value of travel time reduction has been considered as an outlier because the lane was only 350m long. The lower value of travel time reduction might be plausible in the situation where a large number of buses withdrawn from the general purpose lane release additional capacity for the vehicles in that lane.

The analysis of this small sample (sample size 5) shows the mean value of 33.8s of additional delay for vehicle km, and the median value of 28.2s/veh-km. It seems plausible to use this range for the verification of the default values used in the analytical model.

Table B7.4 Contra-flow bus lane – indicator: reduction of bus delay

Value (s/bus-km)	Comments	Source
-702	San Francisco bus line #15	Mirabdal and Yee
-944	San Francisco bus line #12 & #42	Mirabdal and Yee

The sample size is too small to get a plausible assessment of the travel time saving. However, the large travel time savings achieved in this short, 500m long, contra-flow lane indicate that the contra-flow bus lanes can bring substantial travel time savings.

Table B7.5 T2 and T3 transit lane – indicator: travel time savings in HOV lane

Value (s/veh-km)	Comments	Source
-522	Onewa Road, Auckland	Paling and Brown 2010
-42	Waterworks Road, Brisbane	Bauer et al 2005
-18	Waterworks Road, Brisbane	Bauer et al 2005
-180	Lutwyche Road, Brisbane	Bauer et al 2005
-5.5	California	Kwon and Varaiya 2007
-30	A647, Leeds	Leeds City Council
-42	A647, Leeds	Leeds City Council
-48	A647, Leeds	Leeds City Council
-10	I-5 north of Seattle CBD northbound	Nee et al 2002
-17	I-5 north of Seattle CBD southbound	Nee et al 2002
-14	I-5 south of Seattle CBD northbound	Nee et al 2002
-4	I-5 south of Seattle CBD southbound	Nee et al 2002
-21	I-405 north of I-90 northbound	Nee et al 2002
-28	I-405 north of I-90 southbound	Nee et al 2002
-44	I-405 south of I-90 northbound	Nee et al 2002
-21	I-405 south of I-90 southbound	Nee et al 2002
-7	I-90 eastbound	Nee et al 2002
-7	I-90 westbound	Nee et al 2002

Value (s/veh-km)	Comments	Source
-107	SR 520 northbound	Nee et al 2002
-18	SR 167 northbound	Nee et al 2002
-28	SR 167 southbound	Nee et al 2002
-4	I-15 AM peak	Martin et al 2004
-2	I-15 off peak	Martin et al 2004
-50	I-15 PM peak	Martin et al 2004

The range of the reported delay reduction values is wide, ranging from 2s to 522s per km per bus. The values on one extreme (from -2s to -7s) were considered to be outliers, as they are inconsistent with the main body of the sample, and come from the US freeway system. Although the travel time saving of 522s/bus-km on the other extreme appears to be an outlier, it is not, because our travel time surveys in Onewa Road have confirmed its validity.

The analysis of this sample (sample size 18 after the outliers were rejected) shows the mean value of 69.3s saved for bus kilometre, and the median value of 29.0s/bus-km. This range can plausibly be used for the verification of the default values used in the analytical model.

B7.4 Conclusions

The reviewed publications yielded the following data suitable for the verification of the analytical model, which has been developed by AECOM research team.

Table B7.5 Data obtained from the literature review

Bus priority treatment	Indicator	Unit	Sample Size	Range
With-flow bus lane	Reduction of bus delay	s/bus-km	15	48.9 – 65.2
With-flow bus lane	Additional delay to traffic	s/veh-km	5	28.2 – 33.8
T2 and T3 transit lane	Travel time saving	s/veh-km	18	29.0 – 69.3

This literature review has not found a sufficient amount of data to draw valid conclusions with regards to other bus priority treatments, which are the subject of this study: contra-flow bus lanes, mid-block bus gates, reversible bus lanes and the impact on the retail shops of removal of the parking spaces to make room for a bus or transit lane.

B8 Algorithms to estimate default values – intersection

B8.1 Introduction

Due to the limited amount of useful information from the literature review, the research team developed algorithms to estimate default values for each of the five intersection treatments. The operations, implications, assumptions adopted and equations developed to calculate the delays to buses and other vehicles at the intersection for the each of the five intersection treatments are detailed in this section. The adopted assumptions are based on traffic surveys and the calculations using probabilities. These algorithms and adopted assumptions have been discussed with the research steering group.

B8.2 Bus advance (with the bus early release at traffic signal)

B8.2.1 Operation

Buses have free access to the stop line and receive priority (B-phase) before the general traffic stream is released.

B8.2.2 Implications

Bus delay is reduced by bypassing the queue. The delay to cars is increased on three approaches – the main (with bus) approach and the cross roads. The opposite approach is not affected, because it gets the green phase together with the B-phase. There might be a slight benefit there, but this was ignored in the analysis.

B8.2.3 Assumptions

- Bus has free access to the stop line.
- Bus early release 3s.
- Queue dissipation rate 2s/veh.
- Traffic signal split is 70% green/30% red favouring the major approach.
- Main approach has two lanes.
- Vehicles arrive in the middle of the phase, whether red or green.
- Traffic volumes on side roads are equal ($\alpha_2 = \alpha_4$).
- Number of buses arriving on red 30%.

B8.2.4 Notation

D_B – reduction of bus delay (s/bus)

D_C – additional car delay (s/veh)

D_{Ci} – car delay on approach ***i*** (s/veh)

Q_{TO} – volume of through traffic (veh/h)

Q_{BO} – number of buses (bus/h)

NC – number of signal cycles per hour

KL – queue length (veh/lane)

α_i – proportion of approach *i* traffic to main traffic flow Q_{TO}

B8.2.5 Analysis

The analysis is broken down into individual components:

1 Queue length

Arrivals on red phase	$0.3 \times Q_{TO}$	(veh/h/approach)

Arrivals on red phase	$0.3 \times Q_{TO}/2$	(veh/h/lane)
Arrivals on red phase	$0.15 \times Q_{TO}/NC$	(veh/h/lane/cycle)
Queue length	$KL = 0.15 \times Q_{TO}/NC$	(veh/h/lane/cycle)

2 Average reduction of the bus delay

Bus arrives at the middle of red phase and bypasses the queue, thus saving 2.0s per overtaken vehicle.

Half queue length	$0.5 \times 0.15 \times Q_{TO}/NC$	(veh/h/lane/cycle)
Time for queue to dissipate	$2.0 \times 0.5 \times 0.15 \times Q_{TO}/NC$	(s)
Reduction of bus delay	$D_B = 0.15 \times Q_{TO}/NC$	(s/bus)

3 Cars arriving on red phase on the main 'with bus' approach

General traffic is delayed by 3.0s, because of the late release; the affected vehicles are only those arriving on the 'bus cycles'.

Number of cycles with bus	$0.3 \times Q_{BO}$	
Queue length	$KL = 0.15 \times Q_{TO}/NC$	(veh/h/lane/cycle)
Number of affected vehicles	$2 \times KL \times 0.3 \times Q_{BO}$	(veh/h)
Increased delay to the affected vehicles	$0.6 \times KL \times Q_{BO} \times 3.0$	(s/h)
	$D_{C1} = 0.27 \times Q_{BO} \times Q_{TO}/NC$	(s/h)

4 Increased car delay on the side road (i = 2)

All vehicles queuing on 'bus cycles' will be delayed by 3.0s.

Red phase	$0.7 \times 3600/NC = 2520/NC$	(s/cycle)
Number of cycles with bus	$0.3 \times Q_{BO}$	
Vehicle arrival rate	$3600/(\alpha_2 Q_{TO})$	
Number of affected vehicles	$(2520/NC) \times (0.3 \times Q_{BO})/(3{,}600/(\alpha_2 Q_{TO}))$	(veh/h)
	$= 0.21 \times \alpha_2\, Q_{BO}\, Q_{TO}/NC$	
Delay to cars on both side approaches:	$D_{C2} + D_{C4} = 2 \times 3.0 \times 0.21 \times \alpha_2\, Q_{BO}\, Q_{TO}/NC$	
	$D_{C2} + D_{C4} = 1.26 \times \alpha_2\, Q_{BO}\, Q_{TO}/NC$	(s/h)

5 Total delay to cars on all approaches (i = 1,2,4)

$$D_{C1} + D_{C2} + D_{C4} = (0.27 \times Q_{BO} \times Q_{TO}/NC) + (1.26 \times \alpha_2\, Q_{BO}\, Q_{TO}/NC)$$

$$D_C = Q_{BO}\, Q_{TO} \times (0.27 + 1.26\alpha_2)/NC \quad \text{(s/h)}$$

$$D_C = Q_{BO} \times (0.27 + 1.26\alpha_2)/(NC \times (1+2\,\alpha_2)) \quad \text{(s/veh)}$$

B8.2.6 Results

The average delay to bus is reduced; the average delay to vehicles on all approaches increases.

Average bus delay:

$$D_B = 0.15 \times Q_{BO}\, Q_{TO}/NC \quad \text{(s/h)}$$

$$D_B = 0.15 \times Q_{TO}/NC \quad \text{(s/bus)}$$

For representative Auckland traffic conditions (Q_{TO} = 1000 veh/h, NC = 30) reduction of bus delay is:

D_B = 5.0s/bus

Average car delay (increase):

$D_C = Q_{BO}\ Q_{TO} \times (0.27 + 1.26\alpha_2)/NC$ (s/h)

$D_C = Q_{BO} \times (0.27 + 1.26\alpha_2)/(NC \times (1+2\ \alpha_2))$ (s/veh)

For representative Auckland conditions (NC = 30, Q_{BO} =20, Q_{TO} = 1,000, α_2=α_4=0.5) average increase in car delay on all approaches is D_C = 0.24s/veh (for T-intersection) and 0.27s/veh (for cross road).

B8.3 Transit active signal (signal priority for the bus detected on the approach to the intersection)

B8.3.1 Operation

Approaching the intersection the bus triggers the signal phase change. By the time the bus arrives at the intersection the traffic signal changes. If the bus arrives on red the red phase is terminated. If it arrives at the end of green the green phase is extended.

B8.3.2 Implications

The benefits – the delay to bus is reduced; the delays to vehicles on the main (with bus) approach, and on the opposite approach (i = 3) are also reduced (consistent with the reduction of the bus delay). The delay to vehicles in the side roads (i = 2, 4) increases.

B8.3.3 Assumptions

- Bus is detected in advance of the intersection and gets advantage on arrival.
- Number of buses arriving on red is 30%.
- Number of buses arriving at the end of green is 5%.
- Number of cars arriving at the end of green is 2.5%.
- Extension of green phase is 3s.
- Traffic signal split is 70% green/30% red favouring the major approach.
- Main approach has two lanes.
- Traffic volumes on side roads are equal.
- Vehicles arrive in the middle of the phase, whether red or green.

B8.3.4 Notation

D_B – reduction of bus delay (s/bus)

D_C – car delay (s/veh)

Q_{TO} – volume of through traffic (veh/h)

Q_{BO} – number of buses (bus/h)

NC – number of signal cycles per hour

α_i – proportion of approach traffic to main traffic flow Q_{TO}

D_{BR} – reduction of bus delay on the red phase (s/bus)

D_{BG} – reduction of bus delay on the green phase (s/bus)

D_{Ci} – car delay on other approach (s/car)

B8.3.5 Analysis

The analysis is broken down into individual components:

1 Buses arriving on the red phase.

30% of buses arrive on red phase; since they do not wait their delay is reduced by half of the red phase.

Red phase	$0.3 \times 3600/NC$	(s)
Half red phase	$540/NC$	(s)

Reduced delay to all buses on the red phase: $0.3Q_{BO} \times 540/NC$

	$D_{BR} = 162 \times Q_{BO}/NC$	(s/h)

2 Buses arriving at the end of the green phase.

5% of buses arrive at the end of the green phase and benefit from the 3s extension of green; since they do not wait, their delay is reduced by the full red phase.

Red phase	$0.3 \times 3600/NC$	(s)

Reduced delay to all benefiting buses on the green phase:

	$0.05Q_{BO} \times 0.3 \times 3600/NC$	
	$D_{BG} = 54 \times Q_{BO}/NC$	(s/h)
Average reduction of the bus delay	$DB = DBR + DBG = 216 \times QBO/NC$	(s/h)
	$D_B = 216/NC$	(s/bus)

3 Cars arriving on the red phase on the main 'with bus' approach.

Cars arriving on the red phase with the bus get the same benefits as the bus (the affected cars are only those arriving on the 'bus cycles'); red phase is 30% of the cycle, 30% of buses arrive on red phase; since they do not wait, their delay is reduced by half of the red phase.

Red phase	$0.3 \times 3600/NC = 1080/NC$	(s)
Half red phase	$540/NC$	(s)
Number of cycles with bus	$0.3 \times Q_{BO}$	
Vehicle arrival rate	$3600/Q_{TO}$	(s/veh)
Number of vehicles on red	$(1080/NC)/(3600/Q_{TO}) = 0.3 \times Q_{TO}/NC$	
Number of affected vehicles	$(0.3 \times Q_{TO}/NC) \times (0.3 \times Q_{BO}) = 0.09\ Q_{BO}\ Q_{TO}/NC$	
Reduced delay to all cars on red phase	$(0.09\ Q_{BO}\ Q_{TO}/NC) \times (540/NC)$	
	$D_{CR} = 48.6 \times Q_{BO} Q_{TO}\ /NC^2$	(s/h)

4 Cars arriving at the end of the green phase on the main 'with bus' approach.

Cars arriving at the end of the green phase with the bus get the same benefits as the bus; it was assumed that 2.5% of cars arrive at the end of the green phase and can potentially benefit from the 3s extension; however, the affected cars are only those arriving on the 'bus cycles'; since they do not wait, their delay is reduced by the full red phase.

Red phase $0.3 \times 3600/NC = 1080/NC$ (s)

Number of cycles with bus $0.05 \times Q_{BO}$

Proportion of 'bus cycles' $0.05 \times Q_{BO}/NC$

Number of vehicles arriving at the end of green $0.025 \times Q_{TO}$ (veh/h)

Number of benefiting vehicles

$$(0.025 \times Q_{TO}) \times (0.05 \times Q_{BO}/NC) = 0.00125\ Q_{BO}\ Q_{TO}/NC \quad \text{(veh/h)}$$

Reduced delay to all benefiting vehicles:

$$(0.00125\ Q_{BO}\ Q_{TO}/NC) \times (1080/NC)$$

$$D_{CG} = 1.35 \times Q_{BO}\,Q_{TO}/NC^2 \quad \text{(s/h)}$$

5 Cars arriving on the red phase on the opposite approach (i = 3)

Cars arriving on the red phase on the opposite approach get the same benefits as the bus (the affected cars are only those arriving on the 'bus cycles'); the red phase is 30% of the cycle, 30% of buses arrive on the red phase; since they do not wait, their delay is reduced by half of the red phase.

Red phase $0.3 \times 3600/NC = 1080/NC$ (s)

Half red phase $540/NC$ (s)

Number of cycles with bus $0.3 \times Q_{BO}$

Vehicle arrival rate $3600/(\alpha_3 Q_{TO})$ (s/veh)

Number of vehicles on red $(1080/NC)/(3600/\alpha_3 Q_{TO}) = 0.3 \times \alpha_3 Q_{TO}/NC$

Number of affected vehicles $(0.3 \times \alpha_3 Q_{TO}/NC) \times (0.3 \times Q_{BO}) = 0.09\ \alpha_3 Q_{BO} Q_{TO}/NC$

Reduced delay to all cars on red phase $(0.09\ \alpha_3 Q_{BO}\ Q_{TO}/NC) \times (540/NC)$

$$D_{3R} = 48.6 \times \alpha_3 Q_{BO}\,Q_{TO}/NC^2 \quad \text{(s/h)}$$

6 Cars arriving at the end of the green phase on the opposite approach (i = 3)

Cars arriving at the end of the green phase with the bus get the same benefits as the bus; it was assumed that 2.5% of cars arrive at the end of the green phase and can potentially benefit from the 3s extension; however, the affected cars are only those arriving on the 'bus cycles'; since they do not wait, their delay is reduced by the full red phase.

Red phase $0.3 \times 3600/NC = 1{,}080/NC$ (s)

Number of cycles with bus $0.05 \times Q_{BO}$

Proportion of 'bus cycles' $0.05 \times Q_{BO}/NC$

Number of vehicles arriving at the end of green $0.025 \times \alpha_3 Q_{TO}$ (veh/h)

Number of benefiting vehicles

$$(0.025 \times \alpha_3 Q_{TO}) \times (0.05 \times Q_{BO}/NC) = 0.00125\ \alpha_3 Q_{BO}\ Q_{TO}/NC \qquad \text{(veh/h)}$$

Reduced delay to all benefiting vehicles: $(0.00125\ \alpha_3 Q_{BO}\ Q_{TO}/NC) \times (1{,}080/NC)$

$D_{3G} = 1.35 \times \alpha_3 Q_{BO} Q_{TO}/NC^2$ (s/h)

7 Increased car delay on the side road (i = 2) – arrival on green

Side road green phase corresponds with the main approach to the red phase; bus arrival on red cuts the side road green by half; cut off vehicles will have to wait the full red phase.

Number of cycles with bus	$0.3 \times Q_{BO}$	
Green phase	$0.3 \times 3600/NC = 1080/NC$	(s)
Half green phase	$540/NC$	(s)
Side road volume	$\alpha_2 Q_{TO}$	(veh/h)
Vehicle arrival rate	$3600/(\alpha_2 Q_{TO})$	(s/veh)
Number of cut off vehicles	$(0.3 \times Q_{BO}) \times (540/NC)/(3600/(\alpha_2 Q_{TO}))$	
	$= 0.045 \times \alpha_2\ Q_{BO}\ Q_{TO}/NC$	(veh/h)
Red phase	$0.7 \times 3600/NC = 2520/NC$	(s)
Increased delay	$(0.045 \times \alpha_2\ Q_{BO}\ Q_{TO}/NC) \times (2520/NC)$	(s/h)
	$D_{2G} = 113.4 \times \alpha_2 Q_{BO} Q_{TO}\ /NC^2$	(s/h)

8 Increased car delay on the side road (i = 2) – arrival on red

Side road red phase corresponds with the main approach green phase; bus arrival at the end of the green phase extends the red in the side road by 3s; therefore all side road arrivals on red on bus cycles are delayed by 3s.

Number of cycles with bus	$0.05 \times Q_{BO}$	
Red phase	$0.7 \times 3600/NC = 2520/NC$	(s)
Red phase extended by	3.0	(s)
Side road volume	$\alpha_2 Q_{TO}$	(veh/h)
Vehicle arrival rate	$3600/(\alpha_2 Q_{TO})$	(s/veh)
Number of delayed vehicles	$(0.05 \times Q_{BO}) \times (2520/NC)/(3600/(\alpha_2 Q_{TO}))$ $= 0.035 \times \alpha_2\ Q_{BO}\ Q_{TO}/NC$	(veh/h)
Increased delay	$(0.035 \times \alpha_2\ Q_{BO}\ Q_{TO}/NC) \times 3.0$	(s/h)
	$D_{2R} = 0.105 \times \alpha_2 Q_{BO} Q_{TO}\ /NC$	(s/h)

9 Total increase of car delay (all approaches):

Side road red phase corresponds with the main approach green phase; bus arrival at the end of green extends red in the side road by 3s; therefore all side road arrivals on red on bus cycles are delayed by 3s.

$$D_C = -(D_{CR} + D_{CG} + D_{3R} + D_{3G}) + 2 \times (D_{2G} + D_{2R}) \qquad \text{(s/h)}$$

$$D_C = Q_{BO}\ Q_{TO}\ (\alpha_2\ ((226.8/NC) + 0.210) - 49.95 \times (1 + \alpha_3)/NC)/NC \qquad \text{(s/h)}$$

$$D_C = Q_{BO}(\alpha_2((226.8/NC)+0.210)-49.95x(1+\alpha_3)/NC)/(NC(1+2x\alpha_2+\alpha_3)) \qquad \text{(s/veh)}$$

B8.3.6 Results

The average delay to bus is reduced; the average delay to vehicles on all approaches increases.

Average bus delay: $D_B = D_{BR} + D_{BG} = 216 \times Q_{BO}/NC$ (s/h)

$D_B = 216/NC$ (s/bus)

For representative Auckland traffic conditions (NC = 30) reduction of bus delay is D_B = 7.2s/bus

Average car delay (increase):

$$D_C = Q_{BO}\, Q_{TO}\, (\alpha_2\, ((226.8/NC) + 0.210) - 49.95 \times (1 + \alpha_3)/NC)/NC \quad \text{(s/h)}$$

$$D_C = Q_{BO}(\alpha_2((226.8/NC)+0.210)-49.95\text{x}(1+\alpha_3)/NC)/(NC(1+2\text{x}\alpha_2+\alpha_3)) \quad \text{(s/veh)}$$

For representative Auckland conditions (NC = 30, Q_{BO} =20, Q_{TO} = 1000, $\alpha_2 = \alpha_4$= 0.5 and α_3= 0.6) average increase in car delay on all approaches is D_C = -0.05s/veh (for T-intersection) and -0.49s/veh (for cross road).

B8.4 Bus queue jump lane (an additional short lane to allow bus to bypass the queue)

B8.4.1 Operation

Buses are able to bypass the queue of the waiting cars, because a short bus lane is installed on the approach to the intersection. Therefore buses have free access to the stop line from where they continue with the traffic stream into the bus lane on the far side of the intersection. The delay to the bus is reduced by bypassing the queue. There is no adverse impact on the other vehicles, as the signal cycle is not affected.

B8.4.2 Implications

The delay to the bus is reduced by bypassing the queue. There is no adverse impact on the other vehicles, as the duration of the green phase is not affected.

B8.4.3 Assumptions

- The bus either continues to an existing bus lane on the far side of the intersection or turns left.
- Traffic signal split is 70% green/30% red favouring the major approach.
- Traffic signal operation is not affected.
- Number of buses arriving on red is 30%.
- Main approach has two lanes.
- Vehicles arrive in the middle of the phase, whether red or green.
- Queue dissipation rate is 2s/veh.

B8.4.4 Notation

D_B – reduction of bus delay (s/bus)

Q_{TO} – volume of through traffic (veh/h)

Q_{BO} – number of buses (bus/h)

NC – number of signal cycles per hour

KL – queue length (veh/lane)

B8.4.5 Analysis

1 Queue length

Arrivals on red phase	$0.3 \times Q_{TO}$	(veh/h/approach)
Arrivals on red phase	$0.3 \times Q_{TO}/2$	(veh/h/lane)
Arrivals on red phase	$0.15 \times Q_{TO}/NC$	(veh/h/lane/cycle)
Queue length	$KL = 0.15 \times Q_{TO}/NC$	(veh/h/lane/cycle)

2 Average reduction of the bus delay

Bus arrives at the middle of red phase and bypasses the queue, thus saving 2.0s per overtaken vehicle.

Half queue length:	$0.5 \times 0.15 \times Q_{TO}/NC$	(veh/h/lane/cycle)
Time for queue to dissipate:	$2.0 \times 0.5 \times 0.15 \times Q_{TO}/NC$	(s)
Reduction of bus delay:	$D_B = 0.15 \times Q_{TO}/NC$	(s/bus)
	$D_B = 0.15 \times Q_{BO}\ Q_{TO}/NC$	(s/h)

B8.5 Bus right turn only

B8.5.1 Operation

Bus turns right from a dedicated right turn bay.

B8.5.2 Implications

The delay to the bus, and to the vehicles on the main 'with bus' approach, are not affected. The delay to cars is increased on the opposing approach, as the turning buses require late release of the opposite traffic. As the opposite traffic flow is lower than the main approach traffic flow, the green time lost by the late release does not have to be compensated and therefore the side road traffic is not affected.

B8.5.3 Assumptions

- Bus has free access to the stop line.
- Opposite traffic late release is 3s per each turning bus.
- Opposite traffic volume is 60% of the main traffic flow.
- All buses turn right, ie number of 'bus cycles' = $Q_{BO.}$
- Traffic signal split is 70% green/30% red favouring the major approach.

B8.5.4 Notation

D_C – reduction of car delay (s/veh)

Q_{BO} – number of buses (bus/h)

Q_{TO} – volume of through traffic (veh/h)

α_3 – proportion of opposite approach traffic to main traffic flow Q_{TO} (α_3 = 0.6)

NC – number of signal cycles per hour

KL – queue length on the opposite approach (veh/lane)

B8.5.5 Analysis

1 Queue length on the opposite approach

Arrivals on red phase	$0.3 \times \alpha_3 Q_{TO}$	(veh/h/approach)
Arrivals on red phase	$0.3 \times \alpha_3 Q_{TO}/NC$	(veh/h/cycle)
Queue length	$KL = 0.3 \times \alpha_3 Q_{TO}/NC$	(veh/h/lane/cycle)

2 Average increase of the car delay.

Number of affected vehicles:	$KL \times Q_{BO} = 0.3 \times \alpha_3 Q_{BO} Q_{TO}/NC$	
Additional car delay:	$D_C = 3.0 \times 0.3 \times \alpha_3 Q_{BO} Q_{TO}/NC$	
	$D_C = 0.9 \times \alpha_3 Q_{BO} Q_{TO}/NC$	(s/h)
	$D_C = (0.9 \times \alpha_3 Q_{BO} Q_{TO}/NC)/(Q_{TO} \times (1 + \alpha_3))$ (s/veh)	

For representative Auckland conditions (NC = 30, Q_{BO} =20, Q_{TO} = 1000 and α_3 = 0.6) average increase in car delay on all approaches is D_C = 0.2s/veh (for both T-intersection and cross road).

B8.6 Bus gate (with the existing bus lane allowing buses to access right turn lane)

B8.6.1 Operation

Buses in the bus lane having to turn right at the intersection. In order to cross the general purpose traffic lanes a bus gate is installed in advance of the stop line. Without the bus gate the bus would have to weave through the general traffic ahead of the intersection and travel at low speed. With the bus gate the bus travels through the intersection without reducing speed.

B8.6.2 Implications

The main traffic (with bus) flow is affected by the time given to the bus to cross the through lanes. Also the opposite approach and cross roads traffic flows are affected.

B8.6.3 Assumptions

- Bus gate is installed in advance of the intersection.
- Bus gate late traffic release is 5s.
- Bus speed is 40km/h in the bus lane, weaving speed 20km/h.
- General traffic speed is 25km/h.
- Bus weaving distance is 50m.
- Traffic signal split is 70% green/30% red favouring the major approach.

- Main approach has two lanes.
- Traffic volumes in side roads are equal ($\alpha_2 = \alpha_4$).

B8.6.4 Notation

D_C – overall reduction of car delay (s/veh)

D_{Ci} – reduction of car delay on approach ***i*** (s/veh)

D_B – reduction of bus delay (s/bus)

Q_{BO} – number of buses (bus/h)

Q_{TO} – volume of through traffic (veh/h)

α_3 – proportion of opposite approach traffic to main traffic flow Q_{TO}

α_2 – proportion of cross road traffic to main traffic flow Q_{TO}

NC – number of signal cycles per hour

B8.6.5 Analysis

1 Without a bus gate

The bus has to weave from the bus lane to the right turn lane.

Number of buses arriving on red phase	$0.3 \times Q_{BO}$	
Bus travel time over 50m at 20km/h	$50 \times 3.6/20 = 9.0$	(s/bus)
All buses	$(0.3 \times Q_{BO}) \times 9.0 = 2.7Q_{BO}$	(s/h)

2 With the bus gate – bus.

Buses turn right without delay.

Bus travel time over 50m at 4okm/h	$50 \times 3.6/40 = 4.5$	(s/bus)
All buses:	$(0.3 \times Q_{BO}) \times 4.5 = 1.35Q_{BO}$	(s/h)

3 Reduced bus delay:

$D_B = (2.7Q_{BO}) - (1.35Q_{BO}) = 1.35Q_{BO}$	(s/h)
$D_B = 1.35Q_{BO}/Q_{BO} = 1.35$	(s/bus)

4 With the bus gate – car, main approach

All affected vehicles delayed by 5.0s

Proportion of 'bus cycles'	$0.3Q_{BO}/NC$	
Vehicle arrival rate	$3600/Q_{TO}$	(s/veh)
Red phase	$0.3 \times 3{,}600$	(s/h)
Vehicles arriving on red	$0.3\ Q_{TO}$	(veh/h)
Number of affected vehicles	$(0.3\ Q_{TO}) \times (0.3Q_{BO}/NC) = 0.09Q_{BO}\ Q_{TO}/NC$	

$$D_{C1} = (0.09Q_{BO}\ Q_{TO}/NC) \times 5.0 = 0.45Q_{BO}\ Q_{TO}/NC$$

5 With the bus gate – car, cross streets

All affected vehicles delayed by 5.0s

All vehicles arriving on red phase $0.7\ \alpha_2\ Q_{TO}$

Number of affected vehicles $(0.7\alpha_2 Q_{TO}) \times (0.3Q_{BO}/NC) = 0.21\ \alpha_2 Q_{BO}\ Q_{TO}/NC$

$D_{C2} = D_{C4} = (0.21\ \alpha_2 Q_{BO}\ Q_{TO}/NC) \times 5.0 = 1.05\ \alpha_2 Q_{BO}\ Q_{TO}/NC$

6 With the bus gate – car, opposite approach

All affected vehicles delayed by 5.0s

All vehicles arriving on red phase $0.3\ \alpha_3\ Q_{TO}$

Number of affected vehicles $(0.3\ \alpha_3\ Q_{TO}) \times (0.3Q_{BO}/NC) = 0.09\alpha_3 Q_{BO}\ Q_{TO}/NC$

$D_{C3} = (0.09\ \alpha_3 Q_{BO} Q_{TO}/NC) \times 5.0 = 0.45\ \alpha_3 Q_{BO}\ Q_{TO}/NC$

7 With the bus gate – additional car delay, all approaches.

$$D_C = D_{C1} + D_{C2} + D_{C3} + D_{C4}$$

$$D_C = Q_{BO}\ Q_{TO}(0.45 + 2.1\alpha_2 + 0.45\alpha_3)/NC \text{ (s/h)}$$

$$D_C = (Q_{BO}\ (0.45 + 2.1\alpha_2 + 0.45\alpha_3))/((1 + 2\ \alpha_2\ + \alpha_3) \times NC) \text{ (s/veh)}$$

For representative Auckland conditions ($NC = 30$, $Q_{BO} = 20$, $\alpha_2 = 0.5$ and $\alpha_3 = 0.6$) average reduction of bus delay is $D_B = 1.35$s/bus, while an increase in car delay on all approaches is $D_C = 0.37$s/veh (for T-intersection) and 0.41s/veh (for cross road)..

B9 Algorithms to estimate default values – road segment

B9.1 Introduction

Due to the limited useful information from the literature review, the research team developed algorithms to estimate default values for road segment treatments. The assumptions adopted and equations developed to calculate the delays and travel time for vehicles receiving priority on the priority lane and other vehicles along the road segment are detailed in this section. These algorithms and adopted assumptions have been discussed with the research steering group.

B9.1.1 Notation

V_i Initial speed (km/h)

V_B Bus speed 'after' (km/h)

V_C Car speed 'after' (km/h)

L Lane length (km)

R_B Bus growth rate (%)

R_C Car growth rate initial (%)

R_{MC} Car growth rate modified over 10 years (%)

O_B Bus occupancy

O_C Car occupancy

N_{TL} Number of through lanes for general traffic

β_2 Proportion of T2 vehicles (%)

β_3 Proportion of T3 vehicles (%)

O_2 Occupancy of T2

O_3 Occupancy of T3

Q_{BO} Number of buses initial (bus/h)

Q_{TO} Through traffic volume (veh/h)

D_b Bus delay change (s/h) or (s/bus)

D_c Car delay change (s/h) or (s/veh)

B9.1.2 Modified car growth rate

Modal shift resulting from the increasing attractiveness of bus transport reduces the car annual growth rate. The modified car growth rate is calculated over a 10-year period:

- Current number of travellers $Q_{TO} \times O_C + Q_{BO} \times O_B$
- In 10 years $(Q_{TO}O_C + Q_{BO}O_B) \times (1+10R_C)$
- Bus passengers in 10 years $Q_{BO}O_B \times (1+10R_B)$
- Car occupants in 10 years = all travellers in 10 years – bus passengers in 10 years
- Number of cars in 10 years = car occupants/O_C
- Additional cars in 10 years = number of cars – Q_{TO}

$$R_{MC} = (((Q_{TO}O_C + Q_{BO}O_B)(1+10R_C) - Q_{BO}O_B(1+10R_B))/O_C - Q_{TO})/10Q_{TO}$$

B9.1.3 People throughput

- Total $Q_{BO}O_B + (Q_{TO} - Q_{BO}) \times O_C$ (people/all lanes)

<u>Corresponding general lane</u>

- Bus lane $Q_{BO}O_B$ $(Q_{TO} - Q_{BO})\ O_C/N_{TL}$
- T3 lane $Q_{BO}O_B + \beta_3 Q_{TO}O_3$ $(Q_{TO} - Q_{BO} - \beta_3 Q_{TO})\ O_C/N_{TL}$
- T2 lane $Q_{BO}O_B + Q_{TO}(\beta_3 O_3 + \beta_2 O_2)$ $(Q_{TO} - Q_{BO} - Q_{TO}(\beta_2 + \beta_3))\ O_C/N_{TL}$

Note:

- All (people/lane)
- In the above equations, O_C has not been modified to show for removing the high occupancy T2 and T3 vehicles.

B9.2 With-flow bus lane

- Initial travel time: $T_I = L/V_i$ (h)

  Same for bus and car $T_i = 3600\ L/V_i$ (s/bus) or (s/car)

- With bus lane:

  Bus $T_B = 3600\ L/V_B$ (s/bus)

  or $T_B = 3600\ LQ_{BO}/V_B$ (s/h)

  Car $T_C = 3600\ L/V_C$ (s/veh)

  or $T_C = 3600\ LQ_{TO}/V_C$ (s/h)

- Bus delay reduction (for $V_B > V_i$)

  $D_b = 3600\ L\ (1/V_i - 1/V_B)$ (s/bus)

  or $D_b = 3600\ LQ_{BO}(1/V_i - 1/V_B)$ (s/h)

- Car delay increase (for $V_C > V_i$)

  $D_c = 3600\ L\ (1/V_i - 1/V_C)$ (s/bus)

  or $D_c = 3600\ LQ_{TO}(1/V_i - 1/V_C)$ (s/h)

B9.3 Contra-flow bus lane

- Initial travel time, same for bus and car:

  $T_i = 3600L/V_i$ (s/bus) or (s/car)

- With contraflow bus lane:
  - By removing buses from the main traffic, the capacity of the general purpose lanes will marginally increase resulting in a minor improvement of car travel quality – this has been ignored as negligible.
  - By placing buses in the opposing carriageway, bus speed will substantially increase. There will be no adverse effect on the opposing traffic, because the bus lane will use spare capacity.

- Bus delay reduction (for $V_B > V_i$)

  $D_b = 3600\ L\ (1/V_i - 1/V_B)$ (s/bus)

  or $D_b = 3600\ LQ_{BO}(1/V_i - 1/V_B)$ (s/h)

  Note: No impact on car travel time.

B9.3.1 Bus gate

The bus gate addresses a discontinuity of the bus lane in the mid-block, where the bus lane stops, because of the geometric constraints.

Approaching bus triggers the change of the traffic signal to the red phase, stopping general traffic and allowing the bus to continue without interruption.

Assumed traffic delay 5s; no delay to bus.

Bus gate: Delays to cars – all affected delayed by 5s.

Affected cars: $Q_{BO}Q_{TO} / NC$

Delay to cars:

$$D_c = 5.0 \times Q_{BO}Q_{TO} / NC \qquad \text{(s/h)}$$

$$D_c = 5.0 \times Q_{BO} / NC \qquad \text{(s/veh)}$$

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Appendix C: Default values used in BAT model

The table below lists the default values used in the model, with the source of substantiation for each value. The values in the table represent the average values appropriate for typical traffic operation conditions. Some of these values are accessible - the user can replace them with data specific to the investigated site. Other values, built into the model, are inaccessible.

Default	Value	Unit	Source
Number of signal cycles	30	/hour	Typical 120s cycle length observed in Auckland and accepted by the steering group (SG).
Bus speed in T2 lane	32	km/h	Traffic surveys in Auckland, accepted by SG.
Bus speed with other treatments	35	km/h	Traffic surveys in Auckland, accepted by SG.
Car speed with treatments	15 – 27	km/h	Speed depends on treatment, accepted by SG.
Bus demand growth rate	4 – 8	%	Demand depends on treatment, accepted by SG.
Cost of delay	31.75	$/h	*Economic evaluation manual* (EEM)
Main approach green time	70	%	Signal split observed in Auckland and accepted by SG.
Car occupancy	1.40	person	EEM1, table A2.4 (Urban arterial, AM peak), supported by Pinnacle Research (www.pinnacleresearch.co.nz/research/survey/vehicle_occupancy.pdf)
Bus occupancy	40	person	Bus occupancy surveys, accepted by SG.
Traffic growth rate	2.0	%	EEM (New Zealand)
Queue dissipation rate	2.0	s/veh	Generally accepted value, confirmed by surveys and accepted by SG.
Traffic flow on side roads	30	%	Analysis of SCATS data in Auckland
Reduction of bus delay with bus advance	-10.0	s/bus	Surveys of an average queue
Increase in car delay on all approaches with bus advance	0.3	s/veh	Derived analytically
Buses arriving at the end of green	5.0	%	Traffic surveys in Auckland, accepted by SG.
Cars arriving at the end of green	2.5	%	Traffic surveys in Auckland, accepted by SG.
Reduction of bus delay with transit active signal (TAS)	-7.2	s/bus	Derived analytically, consistent with literature
Increase in car delay on all approaches with TAS	0.3	s/veh	Derived analytically
Reduction of bus delay with bus queue jump lane	-5.0	s/bus	Derived analytically
Increase in car delay with exclusive bus right turn	0.2	s/veh	Derived analytically

Appendix D: BAT user manual

Contents

Disclaimer

BAT has been developed using Microsoft Excel 2007 and has not been tested using other Excel versions. BAT is capable of providing broad indications of appropriate bus priority treatments based on average values and situations. The default values adopted in the model are averages and are expected to represent most of the situations with adequate accuracy. However, there may be situations falling outside the acceptable range. It is therefore necessary to subject the treatments identified by the model to a Project Feasibility Report (PFR) or Scheme Assessment Report (SAR) analysis as required by NZTA, before the decision on the implementation is reached.

D1 Introduction

D1.1 What is BAT?

BAT stands for bus priority assessment tool.

It is a decision assisting analytical tool for selecting appropriate bus priority interventions for any given situation and is governed by the weightings of four different key performance indicators (KPIs) decided by the user.

Background research on the development of the analytical model is discussed in the main body of this report.

D1.2 What is this manual?

This manual provides step-by-step instructions guiding you through the BAT.

IN THIS MANUAL YOU WILL FIND…

- software requirement and settings (section D2)
- the concept of the BAT (section D3)
- information required before using BAT (section D4)
- the step-by-step interface guide (section D5)
- frequently asked questions (FAQ) (section D6).

HOW DO YOU USE THIS MANUAL?

This manual allows you to access the BAT by following these steps:

1 Ensure your computer meets the software requirements and settings.

2 Ensure you have all information required for running BAT.

3 Follow the step-by-step interface guide in section D5.

It is recommended you provide data that closely resembles the real-life traffic situation of the study area to produce feasible results.

To link the decision assisting concept, discussed in section D3, with the interface guide, the interface guide has been divided into three sub-sections:

- Main Menu (section D5.1)
- Intersection Model (section D5.2)
- Transport Corridor Model (section D5.3).

Troubleshooting of possible situations you may encounter is summarised in section D6 ‘Frequently asked questions’.

D2 Software requirements and settings

BAT is created in Microsoft Excel 2007 with built in macros developed using Visual Basic for Applications (VBA). Therefore, all graphic interfaces shown in this document are Microsoft Excel 2007 interface.

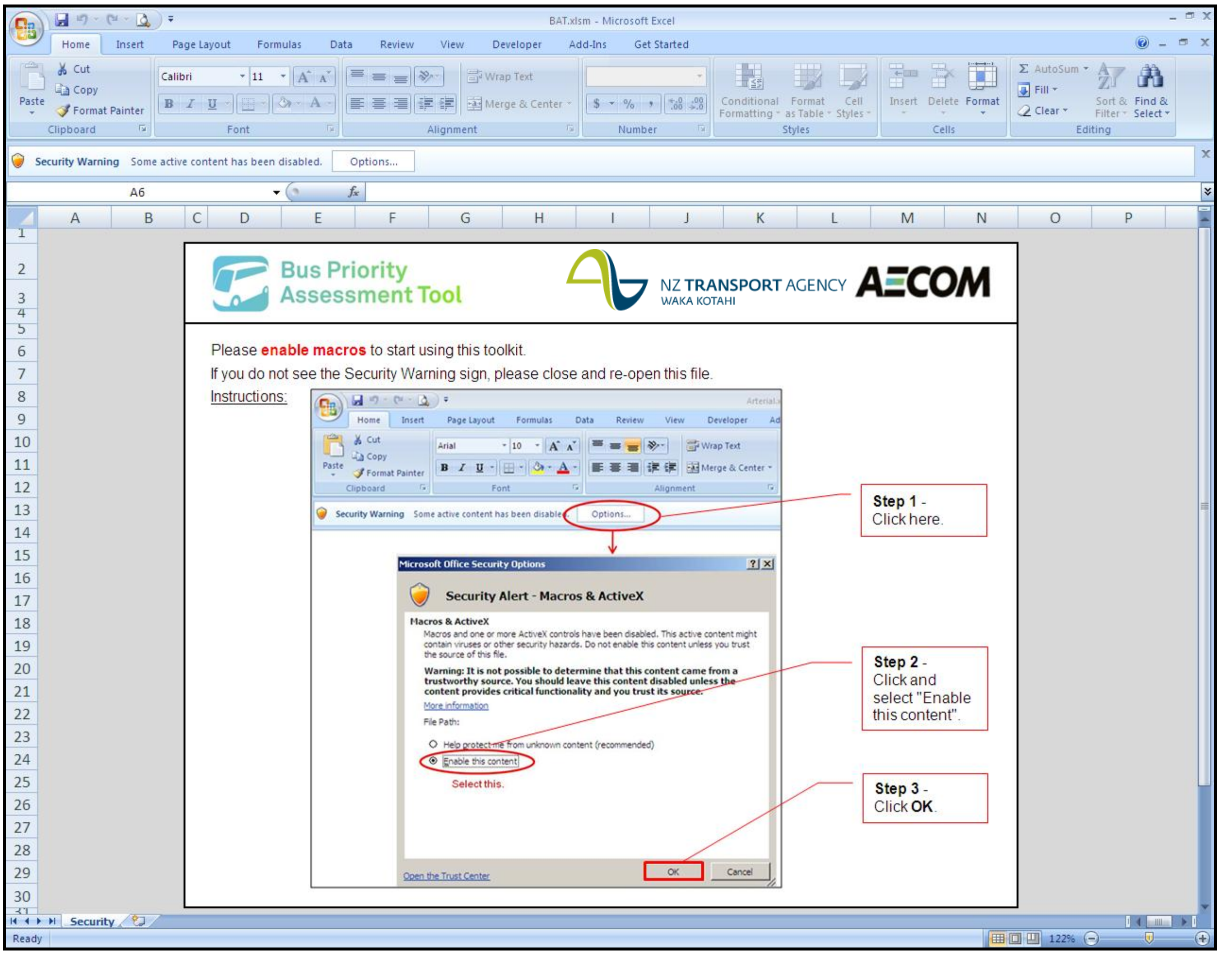
BAT can be executed using Microsoft Excel.

What are Macros?

Macros are a series of commands that will automate a repeated task. For BAT, macros are developed to automate calculations to determine the most appropriate bus priority interventions for varying user input.

BAT has been created to prompt you to enable macros after opening the file (see next page for instructions on enabling macros).

Once you open the file, the initial screen of the BAT is shown below.



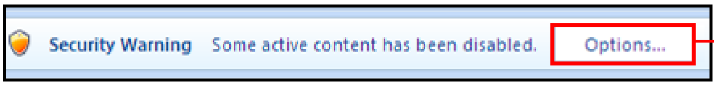
What if the initial screen is not the same as the above?

For software security reasons, macros are usually disabled initially. When macros are disabled, the screen above will appear.

However if your Excel macro settings have been previously set to enable all macros, the screen above will not appear. The **Main Menu** screen will appear instead and you can run the BAT.

How do I enable macros?

1 Click **Options** on the Security Warning Message Bar at the top of your screen.

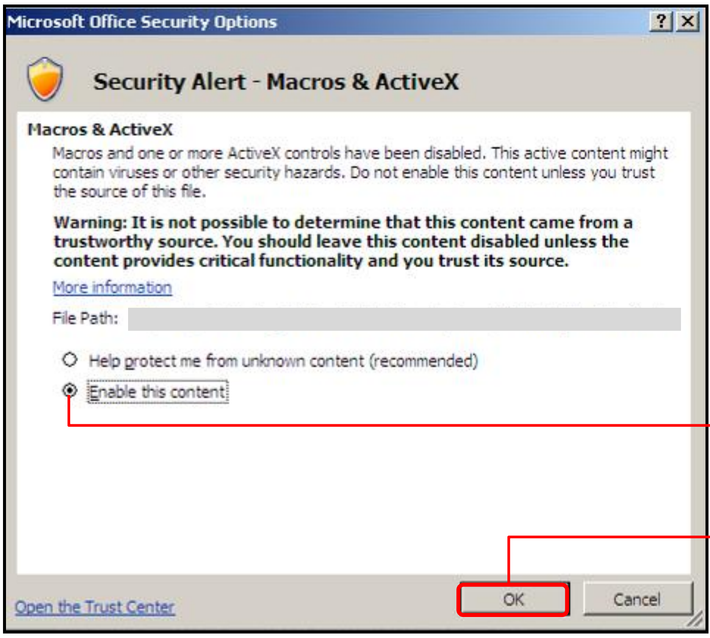


Step 1 –
Click this button

2 Microsoft Office Security Options dialogue appears.

2a) Select **Enable this content**.

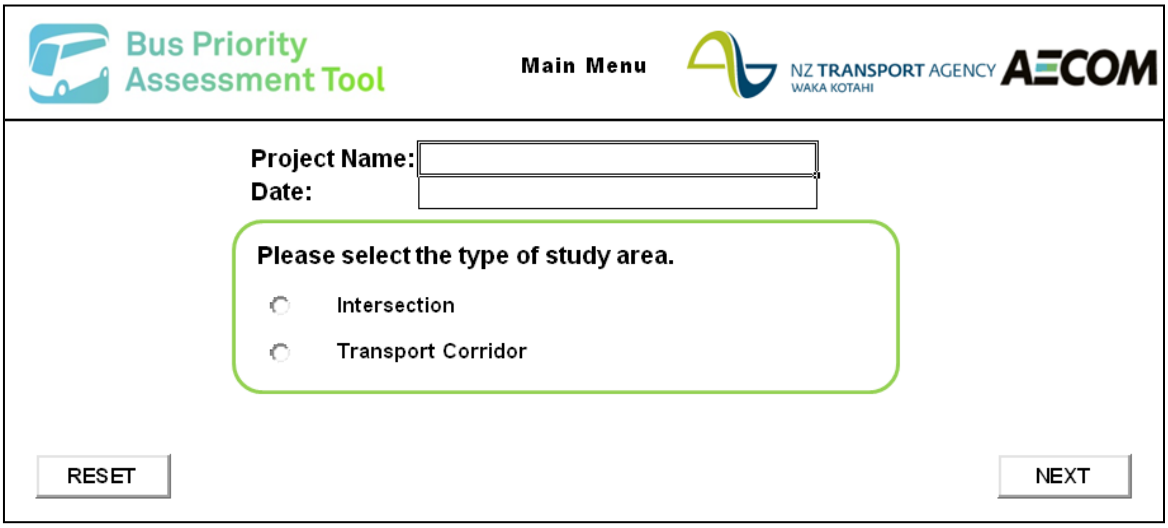
2b) Click **OK**.



Step 2a –
Click the **o** icon to select.

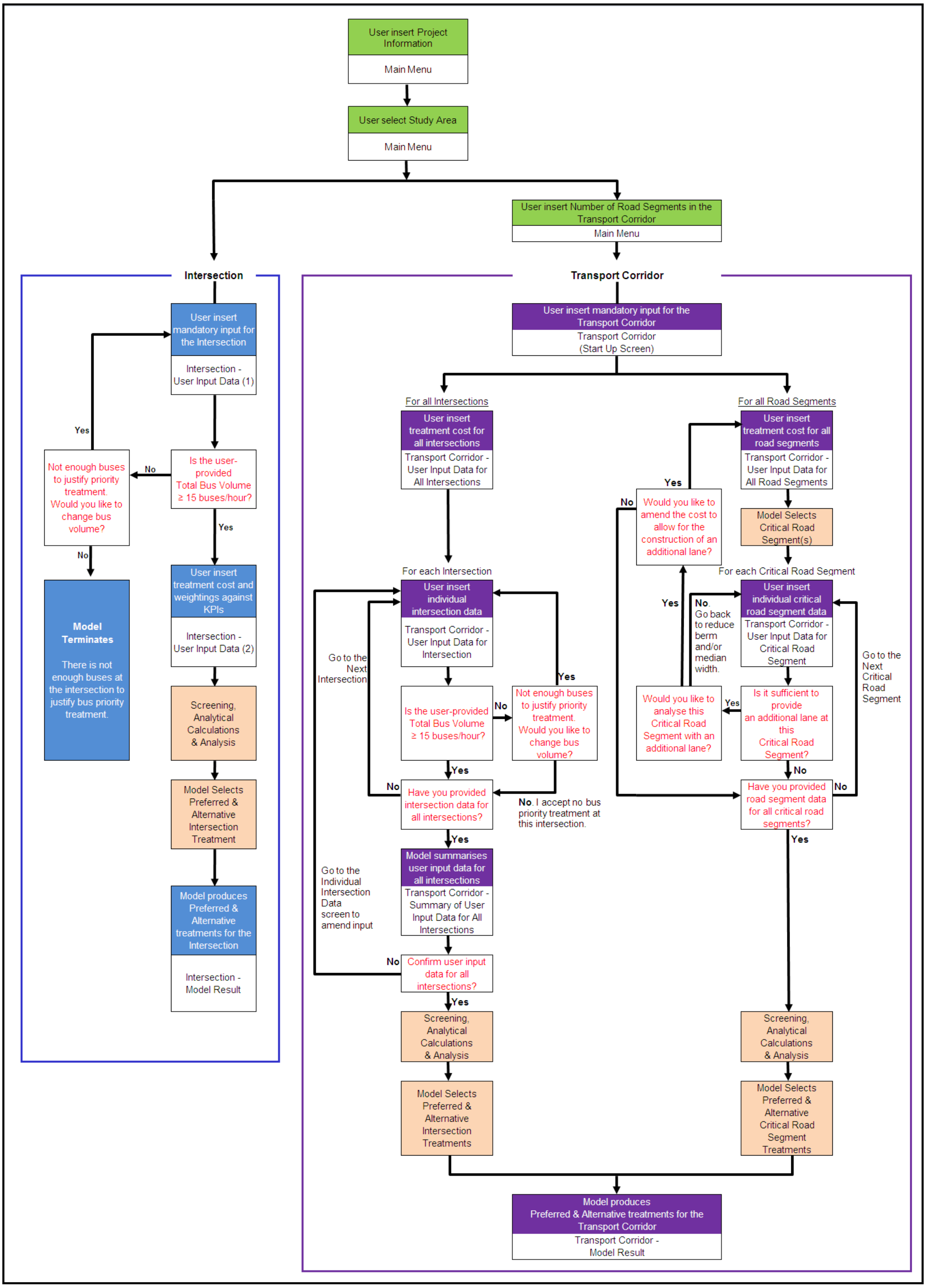
Step 2b –
Click the **OK** button.

3 The '**Main Menu'** start up screen (as shown below) appears.



D3 The concept

BAT is a decision assisting model which follows the process depicted in the flowchart below.



As indicated in the flowchart, the model commences with a **Main Menu** screen, requesting you to insert project information and to select the study area. These are highlighted as:

Description of the process in the Main Menu screen
Name of the screen that user sees, ie **Main Menu**

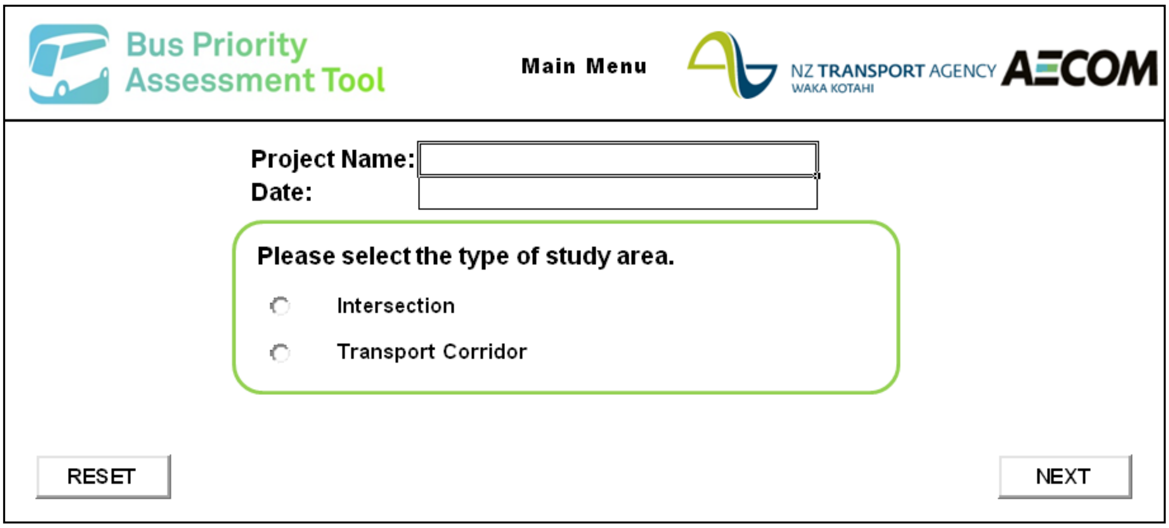
Following your study area selection in the **Main Menu** screen, the model executes either the **Intersection Model** (the blue path) or the **Transport Corridor Model** (the purple path). The different colours and symbols along these two paths are explained below:

For **Intersection** Model	For **Transport Corridor** Model
Description of the process for **Intersection Model**	Description of the process for **Transport Corridor Model**
Name of the screen you see in the **Intersection Model**	Name of the screen you see in the **Transport Corridor Model**
Description of the hidden analytical process for **Intersection Model**	Description of the hidden analytical process for **Transport Corridor Model**
Question for you to make decision	Question for you to make decision

WHERE DO I FIND THE NAME OF THE SCREEN IN BAT?

The name of each screen is displayed at the top centre of the screen. See example below where the name of the screen is circled in red.

EXAMPLE



D4 What information do I need before using BAT?

You need to have the following mandatory data ready for insertion into the BAT.

BAT does not provide any built-in default values for this information and BAT will not proceed further for analysis if you do not provide any of this information.

A checklist of the mandatory data you need to insert into the BAT is included in section D7 of this manual.

For both Intersection and Transport Corridor Models	
1	Project name
2	Date
3	Weightings in percentages (%) for the following key performance indicators (KPIs): • Overall bus and car traveller delay • Reduced car growth rate over 10 years • Lane person throughput in 10 years • Cost of vehicle emission. Note: Sum of weightings for the four KPIs has to be equal to 100%.
For Intersection Model	
1	Budget
2	Existing intersection type – select either signalised ‘T-intersection’ or signalised ‘cross road’ intersection.
3	Volume (vehicles per hour) – this excludes bus volume.
4	Number of lanes per movement for the main approach – insert ‘0.5’ for a short lane.
5	Number of lanes for the opposite and side approaches.
6	Select either ‘Yes’ or ‘No’ to the following questions: • Any existing kerbside bus lane? • Is provision of bus advance feasible? – This question only appears for ‘cross road’ intersection.
7	Cost of intersection treatment for: • bus advance • transit active signal • queue jump lane • bus right turn only • bus gate for bus right turn.
For Transport Corridor Model	
1	Number of road segments along the transport corridor – select 1 to 5 road segments.
2	Budget
3	Existing intersection type for each intersection along the transport corridor – select either signalised ‘T-intersection’ or signalised ‘cross road’ intersection.
4	Cost of the following intersection treatments for each intersection along the transport corridor: • bus advance

<table>
<tr><td></td><td>transit active signal
queue jump lane
bus right turn only
bus gate for bus right turn.</td></tr>
<tr><td>5</td><td>For each intersection along the transport corridor, insert:
volume (vehicles per hour) – this excludes bus volume
number of lanes per movement for the main approach – insert ‘0.5’ for a short lane
number of approaching lanes for the opposite and side approaches
select either ‘Yes’ or ‘No’ to the following questions:
Any existing kerbside bus lane?
Is provision of bus advance feasible? – this question only appears for ‘cross road’ intersection.</td></tr>
<tr><td>6</td><td>For each road segment along the transport corridor, insert:
number of through lanes – minimum of two lanes
segment length (metres)
number of through buses per hour
total through traffic volume per hour – this includes bus volume
cost of the following road segment treatment:
with-flow bus lane
contra-flow bus lane
reversible bus lane
bus gate
T2 transit lane
T3 transit lane.</td></tr>
<tr><td>7</td><td>BAT automatically selects the critical segment(s) along the transport corridor.
For each critical segment along the transport corridor, insert:
berm width
median width
select either ‘Yes’ or ‘No’ to the following questions:
Is the berm over the full length?
Is the median over the full length?
Is there any on-street parking in front of shops?
Is it feasible to provide a contra-flow lane?
Any geometric constraints preventing the continuity of the lane?</td></tr>
</table>

D5 Step by step – the user interface guide

This section provides a comprehensive step-by-step procedure to guide you through the decision assisting process as shown in section D3.

Model screenshots are shown in each of the following sub-sections:

- Section D5.1 – Main Menu
- Section D5.2 – Intersection Model
- Section D5.3 – Transport Corridor Model

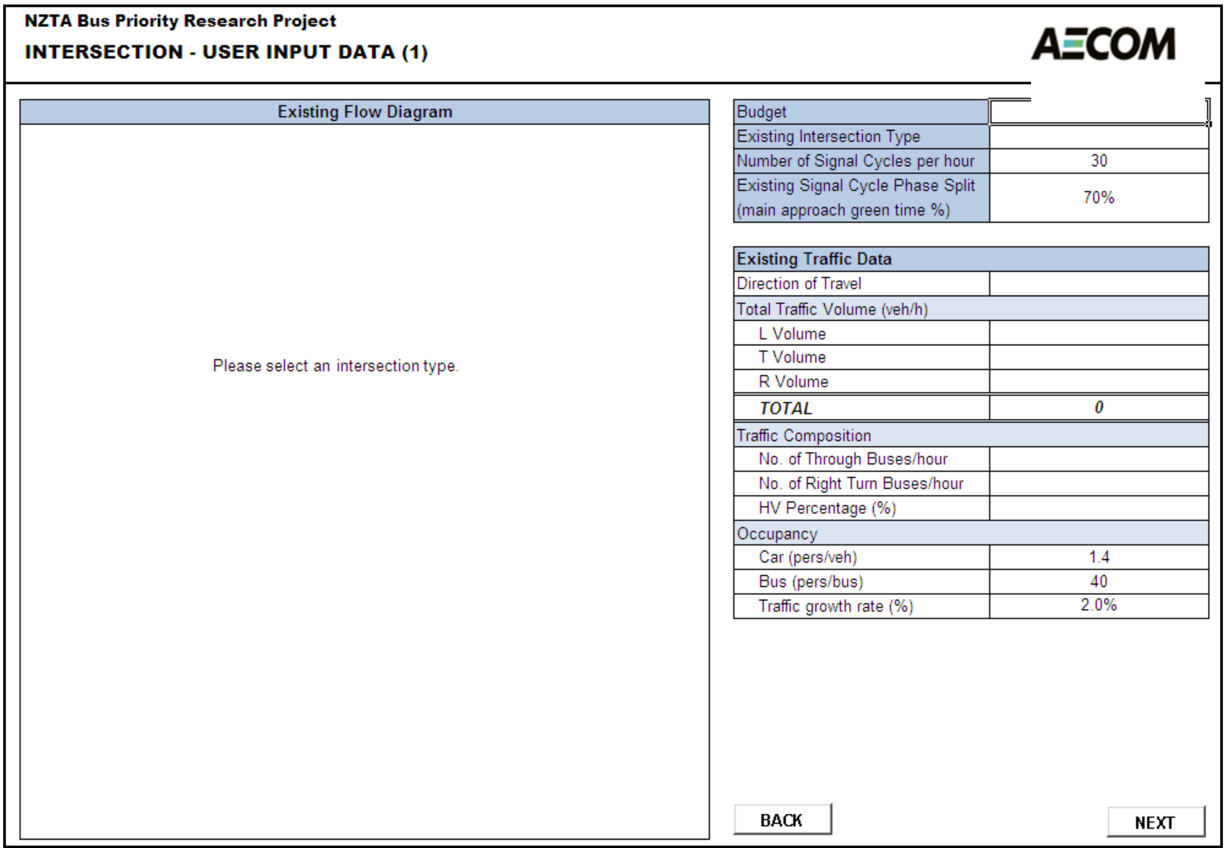
As a user-friendly tool, there are **Buttons** and **Warning Message Boxes** to help guide you through the model.

The two common buttons which appear on most screens are the **BACK** and **NEXT** buttons.

The functions of these two common buttons are explained in the example below. Explanations on other buttons and the Warning Message Box are included in the following sub-sections.

EXAMPLE

In the **Intersection – User Input Data (1)** screen shown below, there are **BACK** and **NEXT** buttons at the bottom of the screen.



By clicking **BACK**

- You will go back to the previous screen.

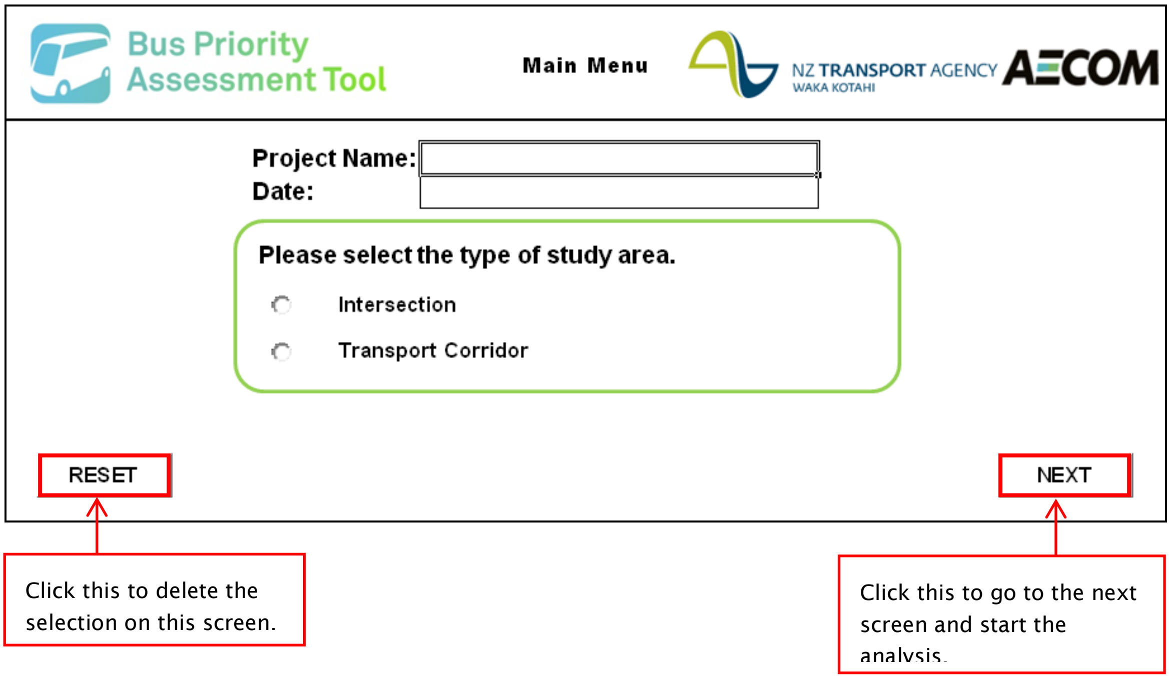
By clicking **NEXT**

- You will go to the next screen.
- If you clicked this button without providing sufficient information, a **Warning Message Box** appears and you will not be able to go to the next screen.
  Click the **OK** button to close the **Warning Message Box;** cells containing missing information will be highlighted in grey.

D5.1 Main Menu

How do I get here?

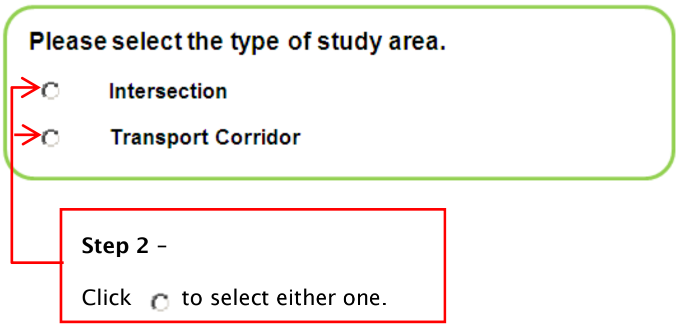
After macros are enabled (see section D2 for instructions to enable macros), the **Main Menu** start up screen below appears.



What to do next?

Step 1 Insert the **Project Name** and the **Date**.

Step 2 Select the type of study area by clicking next to either **Intersection** or **Transport Corridor**.



Step 3 This step depends on the decision you made in step 2 above:

- If **Intersection** is selected in step 2, go to step 4; otherwise
- If **Transport Corridor** is selected in step 2, go directly to step 5.

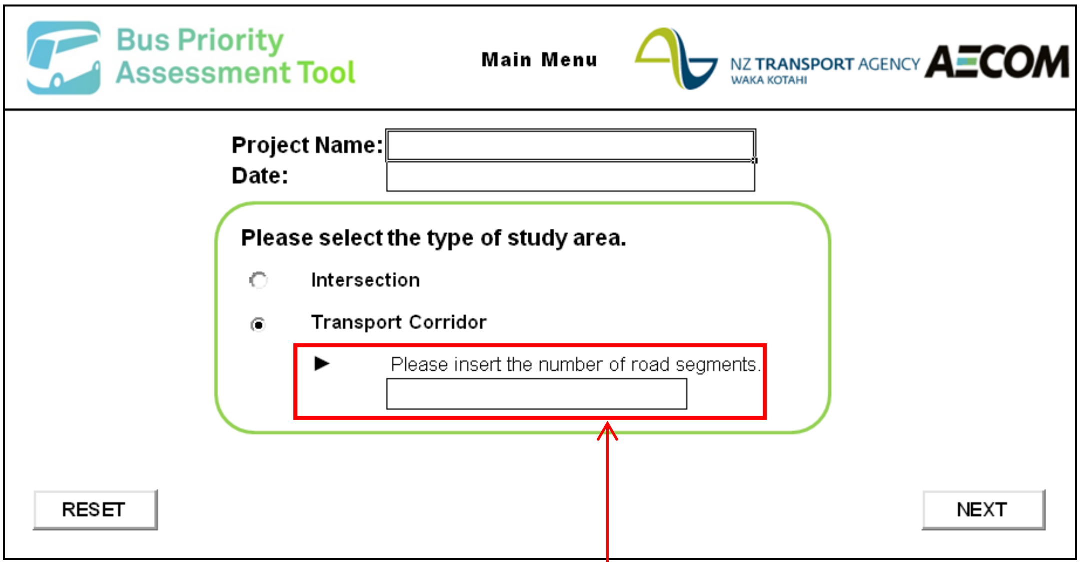
Step 4 Click **NEXT** at the bottom right-hand corner of the screen to start the analysis.

→ Skip step 5 and go to section D5.2 of this manual for further procedures on executing the **Intersection Model**.

Step 5 Insert the number of road segments by following the instructions below:

! Ignore this step if you have selected 'Intersection' in step 2.

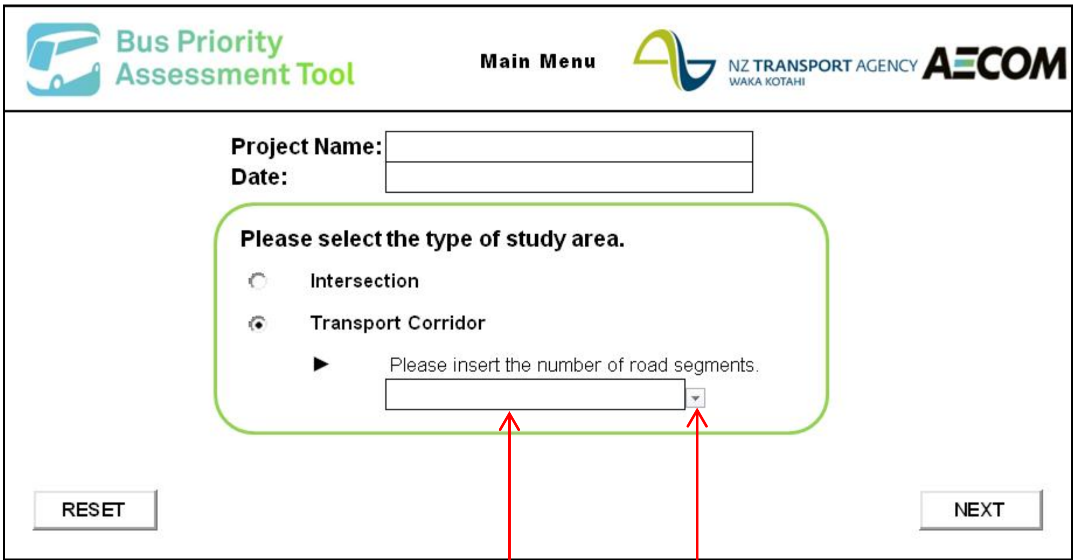
5a **Main Menu** screen automatically updates.



Step 5a –
Screen updated to show extra user input required when **Transport Corridor** is selected.

5b Click on the cell underneath 'Please insert the number of road segments'.

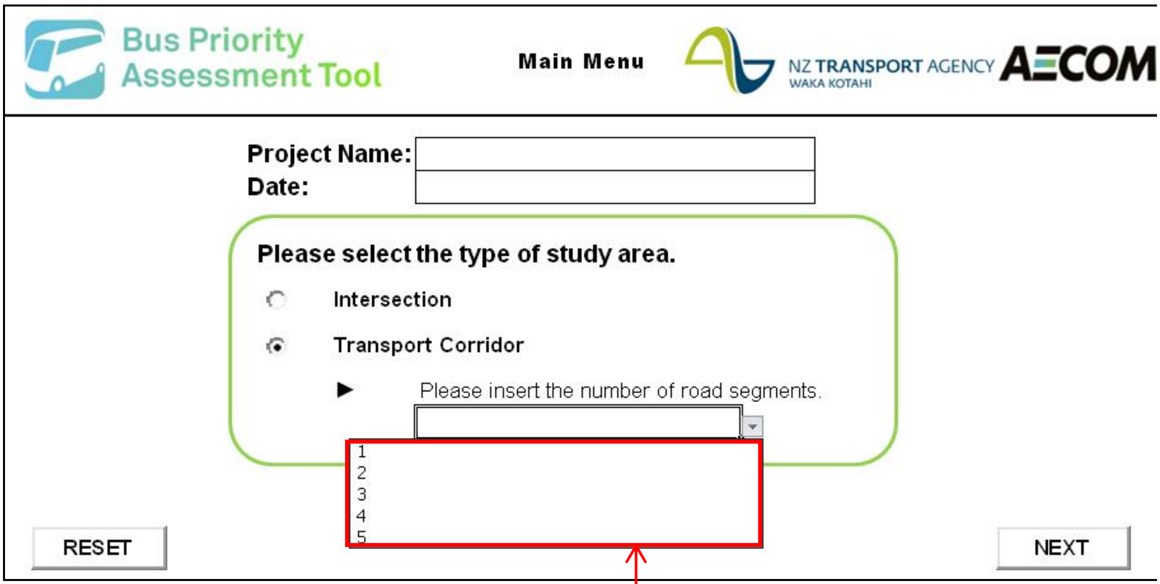
5c Click on the icon to the right of the cell.



Step 5b –
Click this cell.

Step 5c –
Click on the icon , to the right of this cell.

5d Click on the number (1 to 5) from the drop down list to select the number of road segments.



Step 5d –
Click to select the number of road segments.

What if I clicked the NEXT button without selecting the number of road segments?

The **Warning Message Box** below appears and you will not be able to go to the next screen. Click **OK** button to close the message box.

5e Click **NEXT** at the bottom right hand corner of the screen to start the analysis.

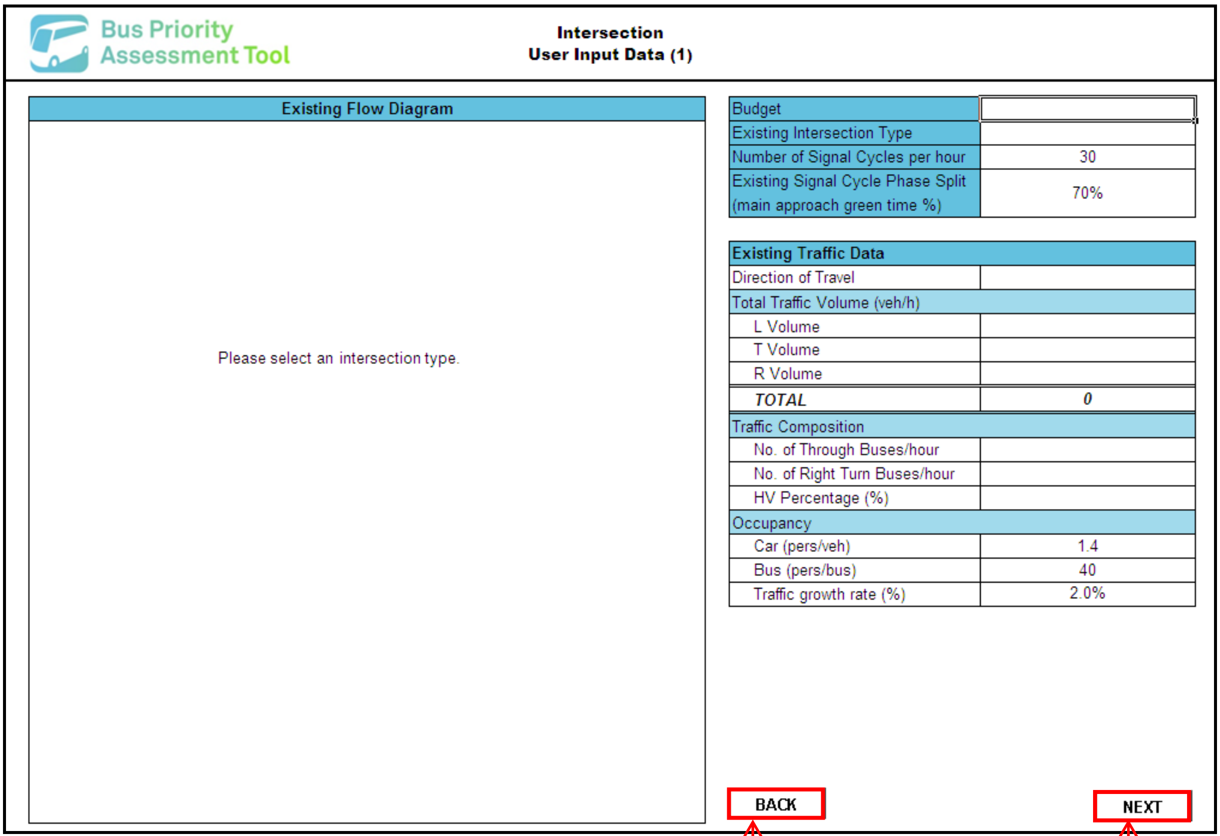
→ Go to section D5.3 of this manual for further procedures on executing the **Transport Corridor Model**.

D5.2 Intersection Model

HOW DO I GET HERE?

In the **Main Menu** screen, select **Intersection** in step 2 of section D5.1 and click:

NEXT, **Intersection – User Input Data (1)** start up screen below appears.

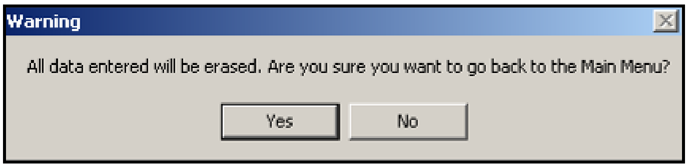


Click this to go back to the **Main Menu** screen (see section F5.1 of this manual).

Click this to go to the next screen.

What will happen after I click the BACK button?

The **Warning Message Box** below appears to warn you that all data entered will be erased.



Click **Yes** – to confirm deletion of all data and go back to the **Main Menu** screen (section F5.1 of this manual), or

Click **No** – to close the message box without deleting any of the user input data.

WHAT TO DO NEXT?

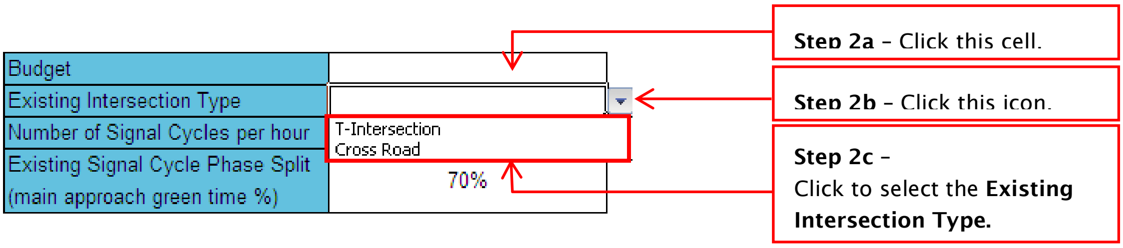
Step 1 Insert the **Budget**.

Step 2 Select the **Existing Intersection Type** by following the instructions below:

2a Click the cell next to Existing Intersection Type.

2b Click on the icon to the right of the cell.

2c Click to select either signalised T-Intersection or signalised Cross Road.



Step 3 The selection of **Existing Intersection Type** in step 2 automatically updates the **Existing Flow Diagram** to show either a T-Intersection or a Cross Road Intersection.

- If **T-Intersection** is selected in step 2, go to step 4, otherwise
- If **Cross Road** is selected in step 2, go directly to step 5.

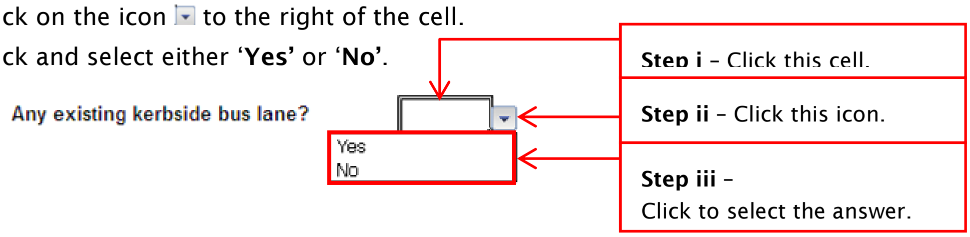
Step 4 **Signalised T-Intersection**

!Ignore this step if you have selected 'Cross Road' in step 3 above and go directly to step 5.

4a Screen automatically updates to show the T-intersection flow diagram. See figure D5.1.

4b Insert the following mandatory information in the **Existing Flow Diagram**. These cells are highlighted in grey in figure D5.1.

- Volume (veh/hr) – this excludes bus volume.
- Number of lanes per movement for the main approach – insert '0.5' for a short lane.
- Number of buses per hour going through and turning right.
- Number of approaching lanes for the opposite and side approaches, n2 and n3.
- Answer the question 'Any existing kerbside bus lane?' by following the instructions below:
  i. Click on the cell next to 'Any existing kerbside bus lane?'
  ii. Click on the icon to the right of the cell.
  iii. Click and select either '**Yes**' or '**No**'.



4c If necessary, amend the accessible default values to better reflect the traffic situation at the intersection. These values are highlighted in yellow in figure D5.1.

4d BAT will not proceed further if any of these values are left blank. See section D8 for more explanation about the accessible default values for the Intersection Model.

4e Insert the optional data input. This is not mandatory – you can go to the next screen if these cells (highlighted in green in figure D5.1) are left blank.

See section D8 for more explanation about the optional data input for the Intersection Model.

4f Click **NEXT** to start the analysis and go directly to step 6.

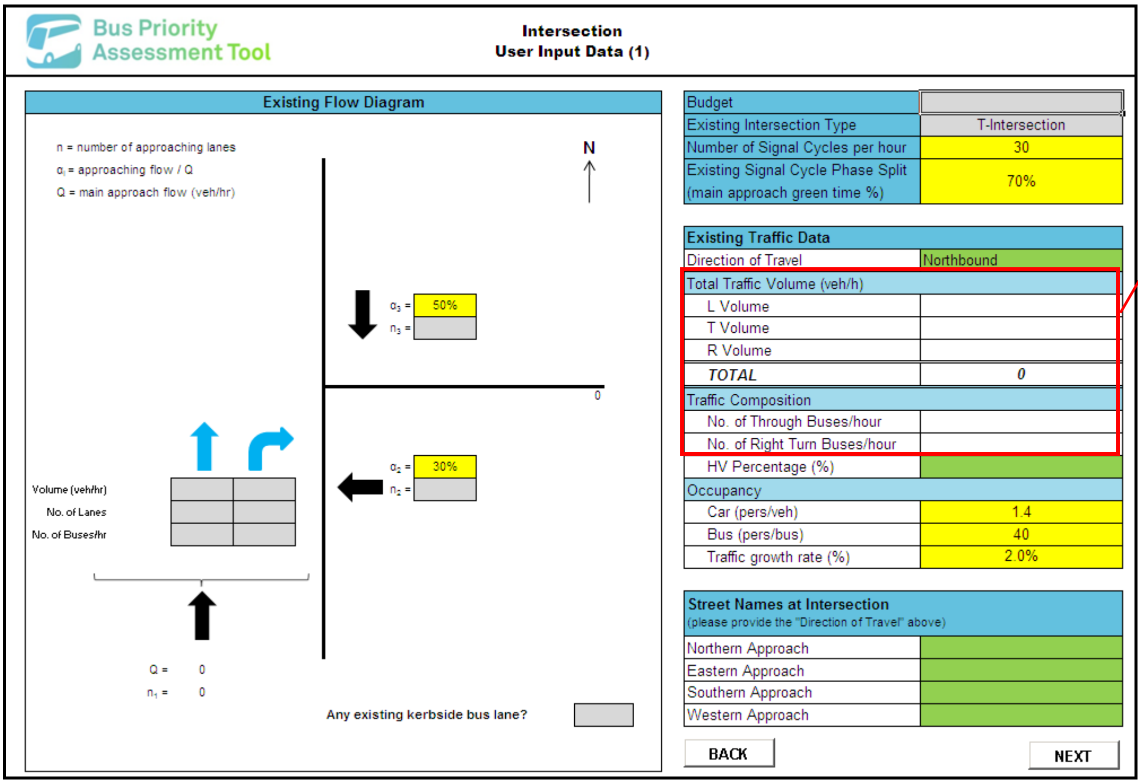
Colour key for figures D5.1 and D5.2:

Mandatory information

Accessible default value – Refer to section D7 for further explanation.

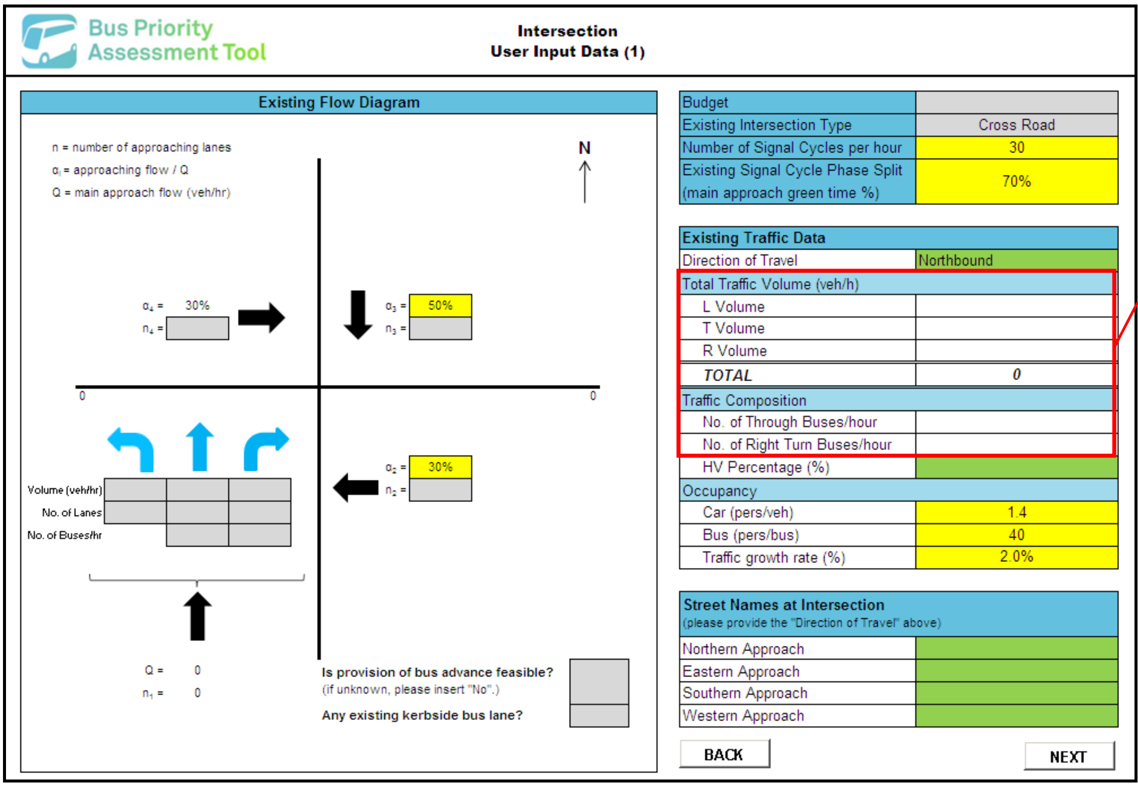
Optional data input – Refer to section D7 for further explanation and instructions.

Figure D5.1 Intersection – User Input Data (1) with Existing Flow Diagram for T-Intersection



BAT automatically extracts data for these cells from the **Existing Flow Diagram**.

Figure D5.2 Intersection – User Input Data (1) with Existing Flow Diagram for Cross Road Intersection



BAT automatically extracts data for these cells from the **Existing Flow Diagram**.

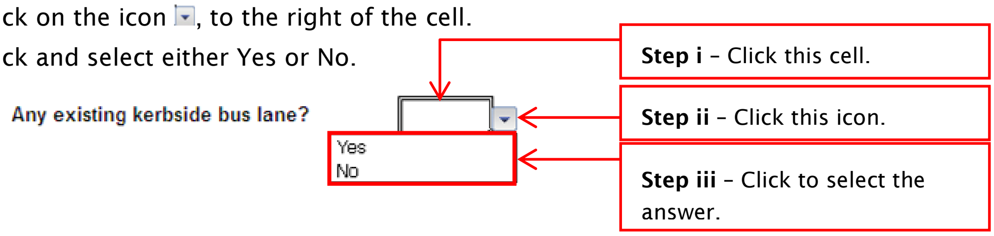
Step 5 Signalised Cross Road Intersection

! Ignore this step if you have selected ‘T-Intersection’ in step 3.

5a Screen automatically updates to show the Cross Road flow diagram. See figure D5.2.

5b Insert the following mandatory information in the **Existing Flow Diagram**. These cells are highlighted in grey in figure D5.2.

- Volume (veh/hr) – this excludes bus volume.
- Number of lanes per movement for the main approach – insert ‘0.5’ for a short lane.
- Number of buses per hour going through and turning right.
- Number of approaching lanes for the opposite and side approaches, n_2, n_3 and n_4.
- Answer the questions ‘Any existing kerbside bus lane?’ and ‘Is provision of bus advance feasible?’ by following the instructions below:
  - i. Click on the cell next to the question.
  - ii. Click on the icon, to the right of the cell.
  - iii. Click and select either Yes or No.



5c If necessary, amend the accessible default values to better reflect the traffic situation at the intersection. These values are highlighted in yellow in figure D5.2.

BAT will not proceed further if any of these values are left blank. See section D8 for more explanation about the accessible default values for the Intersection Model.

5d Insert the optional data input. This is not mandatory – you can go to the next screen if these cells (highlighted in green in figure D5.2) are left blank.

See section D8 for more explanation about the optional data input for the Intersection Model.

5e Click **NEXT** to start the analysis and go to step 6.

Step 6 Assessing the feasibility of providing bus priority treatment

This will be done automatically by BAT.

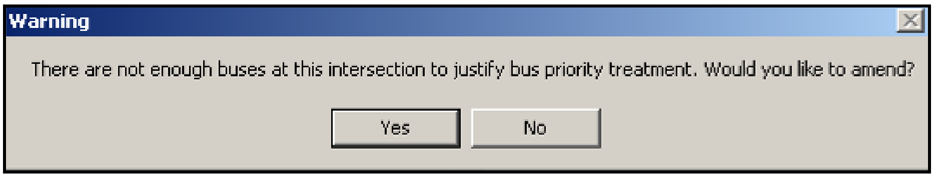
If the total bus volume (ie through bus volume + right turn bus volume) provided in step 4 or step 5 is:

- less than 15 buses per hour, go to step 7, or
- greater than or equal to 15 buses per hour, go directly to step 8.

Step 7 If the total bus volume is less than 15 buses per hour

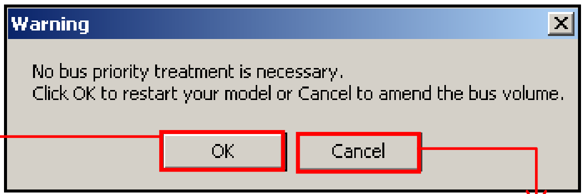
! Ignore this step if the total bus volume is more than or equal to 15 buses per hour.

The **Warning Message Box** below appears, telling you that there are not enough buses at the intersection.



Click **Yes** – to close the message box and the model sends you back to step 4 (for T-Intersection) or step 5 (for Cross Road Intersection) to amend the bus volume in the **Existing Flow Diagram**; or

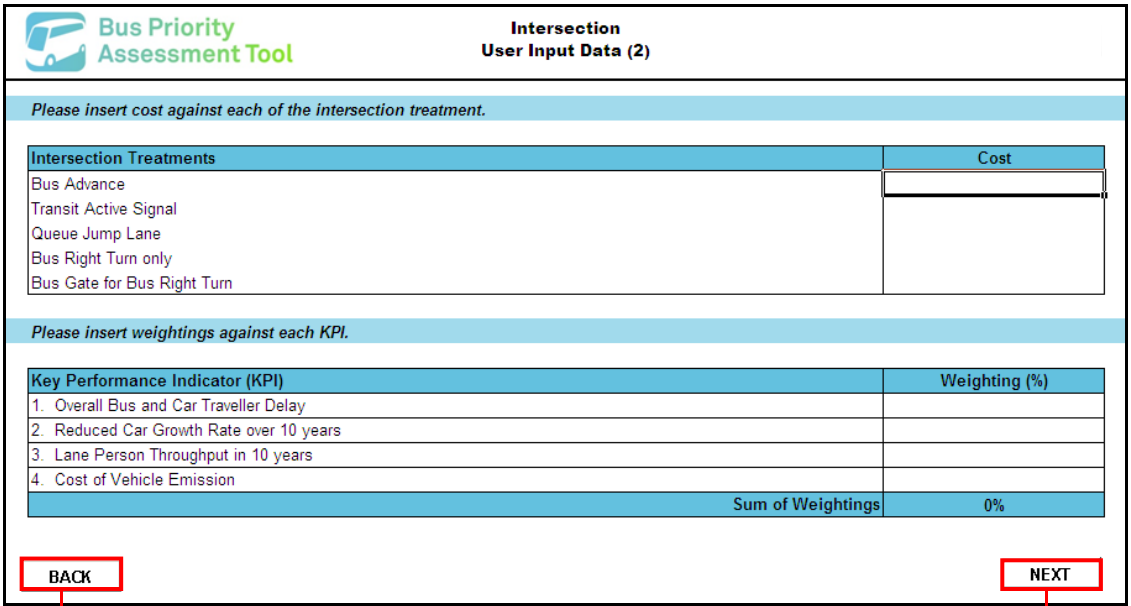
Click **No** – to confirm that the bus volume entered is correct.
The **Warning Message Box** below appears to notify you that no bus priority treatment is necessary.



Click this to delete all data entered and go back to the **Main Menu** screen (section D5.1 of this manual).

Click this to close the message box. The model sends you back to amend the bus volume in the **Existing Flow Diagram**.
- ► Go to step 4 (for T-Intersection), or
- ► Go to step 5 (for Cross Road Intersection).

Step 8 The Intersection – User Input Data (2) screen appears.



Click this to go back to the **Intersection – User Input Data (1)** screen (either figure D5.1 or figure D5.2).

Click this to go to the next screen.

Step 9 Insert the **cost** for each intersection treatment.

What if I do not know the cost of each treatment? Can I click NEXT?

No, the model does not proceed if the costs of all treatments have not been provided.

If you clicked NEXT, the **Warning Message Box** below appears; prompting you to enter the cost of all intersection treatments. Click **OK** to close the message box. Empty cost cells will be highlighted in grey.

If you do not know the cost of each treatment and would like to examine all treatments independent of the costs, insert treatment cost less than or equal to the **Budget** in step 1.

Step 10 Insert the **weighting** for the relevant KPI.

Note: The sum of weightings has to be equal to 100%.

What if I click NEXT but my sum of weightings does not equal to 100%?

The **Warning Message Box** below appears, prompting you to amend weightings.
Click **OK** to close the message box and amend the weightings.

Step 11 Click NEXT and the **Intersection – Model Result** screen appears.

See the next page for further explanation of the components in this screen.

INTERSECTION MODEL OUTPUT SCREEN

Bus Priority Assessment Tool

Intersection Model Result

NZ TRANSPORT AGENCY WAKA KOTAHI AECOM

Model result based on the following user input data:

1

Key Performance Indicator (KPI)	User Input Weighting (%)
1. Overall Bus and Car Traveller Delay	10%
2. Reduced Car Growth Rate over 10 years	20%
3. Lane Person Throughput in 10 years	30%
4. Cost of Vehicle Emission	40%

Intersection Treatments	User Input Cost
Bus Advance	N/A
Transit Active Signal	$ 10,000.00
Queue Jump Lane	$ 20,000.00
Bus Right Turn only	$ 30,000.00
Bus Gate for Bus Right Turn	$ 40,000.00

Model Result Summary

	Preferred Treatment	Alternative Treatment
Treatment Description	Transit Active Signal	Queue Jump Lane
Indicative BCR	1.1	0.9

2

3 **Change Data Input**

4 **Restart Model**

Print Result 5

Notes:

1 Summary of the data you inserted in **Intersection – User Input Data (2)** screen. See steps 8 to 10.

If any of data you inserted needs to be changed, click **Change Data Input** button.

2 Summary table showing the preferred and alternative treatments with their corresponding indicative benefit-cost ratio (BCR).

3 Click this button to go back to the **Intersection – User Input (1)** screen to edit data input.

4 Click this button to delete all data entered and go back to the **Main Menu** screen (section D5.1 of this manual).

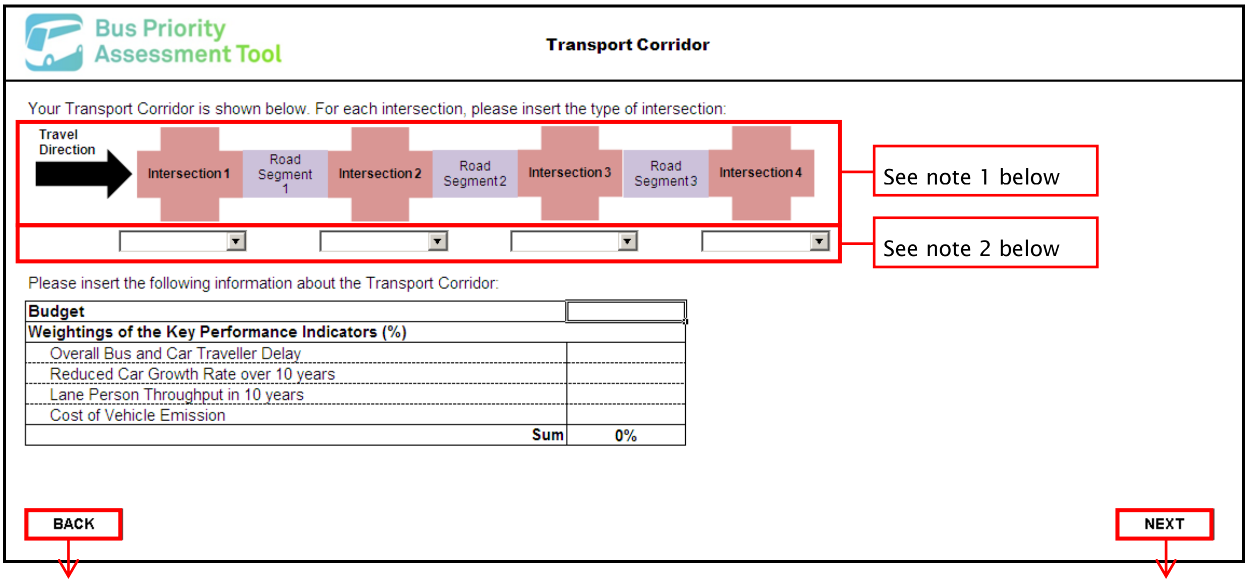
5 Click this to print the current result page.

D5.3 Transport Corridor Model

HOW DO I GET HERE?

In the **Main Menu** screen (see section D5.1), if you selected **Transport Corridor** in step 2 and selected the number of road segments in step 5, the **Transport Corridor** start up screen below appears.

Note that the screen below is an example of what you would see if you clicked and selected ‘3’ in step 5d of section D5.2.



See note 1 below

See note 2 below

Click this to go back to the **Main Menu** screen (section D5.1 of this manual).

Click this to go to the next screen.

Note 1 Diagram automatically updates to reflect the number of road segments along the transport corridor you provided in the **Main Menu** screen.

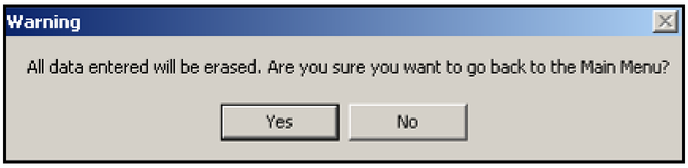
Refer to step 5d of section D5.1.

Note 2 For each intersection along the Transport Corridor, select **Existing Intersection Type** from the drop down list.

Refer to step 1 on page 21 for instructions to select **Existing Intersection Type**.

What will happen after I click the BACK button?

The **Warning Message Box** below appears to warn you that all data entered will be erased.



Click **Yes** – to confirm the deletion of all data and go back to the **Main Menu** screen (section D5.1 of this manual), or

Click **No** – to close the message box without deleting any of the user input data.

WHAT TO DO NEXT?

Step 1 Select the **Existing Intersection Type** for each intersection along the transport corridor.

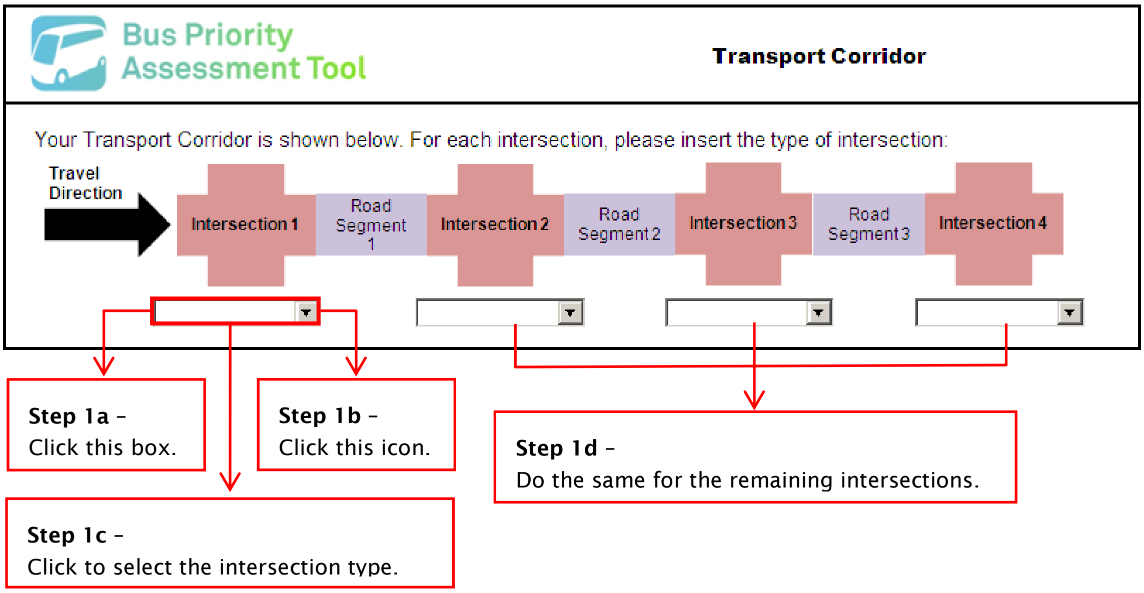
1a Click the box underneath each intersection.

1b Click the icon to the right of the box.

1c Click to select either signalised **T-Intersection** or signalised **Cross Road**.

1d Repeat steps 1a to 1c for other intersections along the transport corridor.

1e Go to step 2 when you have selected the intersection type for all intersections.



Step 2 Insert the **Budget**.

Step 3 Insert the **weighting** for the relevant KPI.

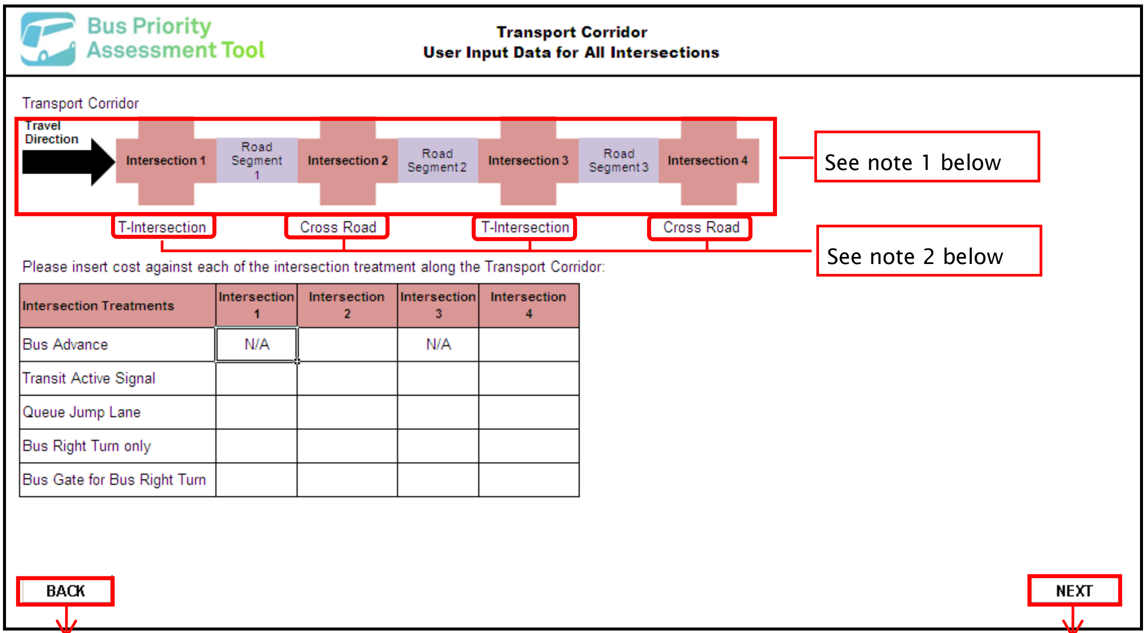
Note: The sum of weightings has to be equal to 100%.

What if I click NEXT but my sum of weightings does not equal to 100%?

The **Warning Message Box** below appears; prompting you to amend weightings.
Click **OK** to close the message box and amend the weightings.

Step 4 Click **NEXT**.

Step 5 The **Transport Corridor – User Input Data for All Intersections** screen appears.



Click this to go back to **Transport Corridor** start up screen.

Click this to go to the next screen.

Note 1 Same diagram as in the **Transport Corridor** Start Up screen.

Note 2 Automatically updates to reflect your intersection type selection in step 1 of section D5.3.

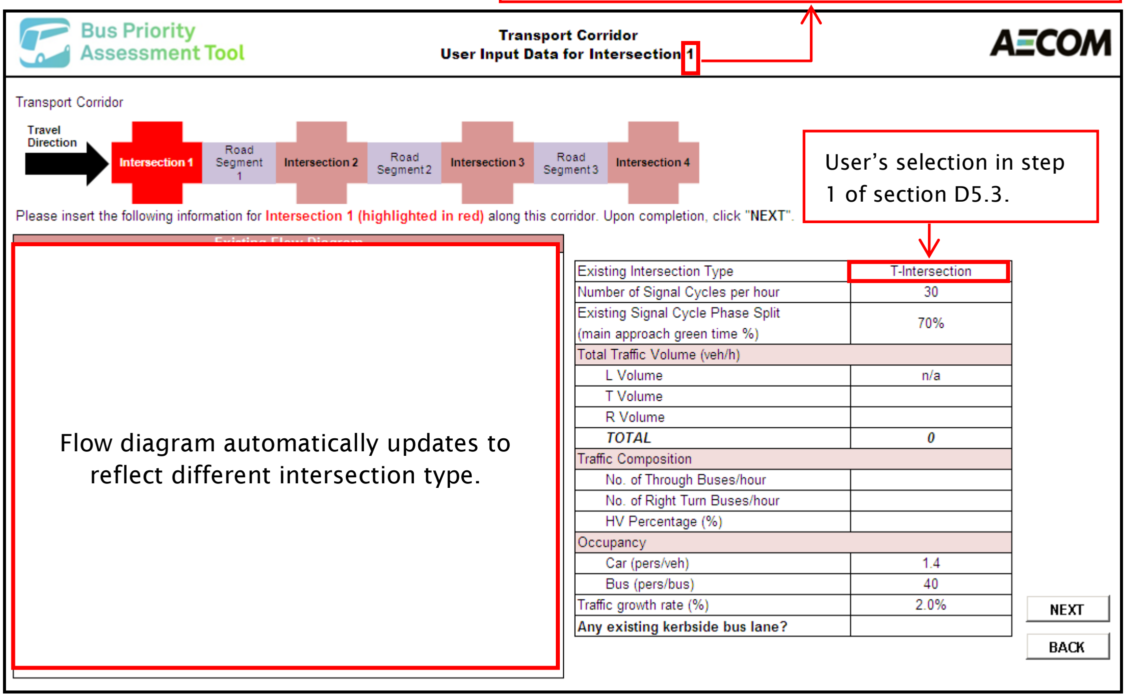
Click **BACK** if you want to change any of the intersection types.

Step 6 Insert the **cost** for each intersection treatment.

Note: **Bus Advance** treatment is only feasible at a cross-road intersection. Therefore, cost cells for **Bus Advance** are labelled as 'N/A' for T-intersections.

Step 7 Click **NEXT** and the **Transport Corridor – User Input Data for Intersection 1** appears.

Intersection number – this screen is for Intersection 1.



Step 8 Based on your selection (input) in step 1 of section D5.3, the **Existing Flow Diagram** automatically updates to show either a T-intersection or a Cross Road intersection.

- If **T-Intersection** is selected in step 1, go to step 9, otherwise
- If **Cross Road Intersection** is selected in step 1, go directly to step 10.

Step 9 **Signalised T-Intersection**

! Ignore this step if you have selected 'Cross Road' for this intersection in step 1 and go directly to step 10.

9a Screen automatically updates to show the T-Intersection flow diagram. See figure D5.3.

9b Insert the following mandatory information in the **Existing Flow Diagram**. These cells are highlighted in grey in figure D5.3.

- Volume (veh/hr) – this excludes bus volume.
- Number of lanes per movement for the main approach – insert '0.5' for a short lane.
- Number of buses per hour going through and turning right.
- Number of approaching lanes for the opposite and side approaches, n_2 and n_3.
- Answer the question 'Any existing kerbside bus lane?'

9c If necessary, amend the accessible default values to better reflect the traffic situation at the intersection. These values are highlighted in yellow in figure D5.3.

BAT will not proceed further if any of these values are left blank. See section D8 for more explanation about the accessible default values for the **Transport Corridor – Intersection Model**.

9d Insert the optional data. This is not mandatory – you can go to the next screen if the cell (highlighted in green in figure D5.3) is left blank.

9e Click **NEXT** and go directly to step 11.

Step 10 **Signalised Cross Road Intersection**

! Ignore this step if you have selected 'T-Intersection' for this intersection in step 1.

10a Screen automatically updates to show the **Cross Road** flow diagram. See figure D5.4

10b Insert the following mandatory information in the **Existing Flow Diagram**. These cells are highlighted in grey in figure D5.4.

- Volume (veh/hr) – this excludes bus volume.
- Number of lanes per movement for the main approach – insert '0.5' for a short lane.
- Number of buses per hour going through and turning right.
- Number of approaching lanes for the opposite and side approaches, n_2, n_3 and n_4.
- Answer the questions 'Any existing kerbside bus lane?' and 'Is provision of bus advance feasible?'

10c If necessary, amend the accessible default values to better reflect the traffic situation at the intersection. These values are highlighted in yellow in figure D5.4.

BAT will not proceed further if any of these values are left blank. See section D8 for more explanation about the accessible default values for the **Transport Corridor – Intersection Model**.

10d Insert the optional data. This is not mandatory – you can go to the next screen if the cell (highlighted in green in figure D5.4) is left blank.

10e Click **NEXT** and go to step 11.

Colour key for figures D5.3 and D5.4:

Mandatory information

Accessible default value – refer to section D8 for further explanation.

Optional data input

Figure D5.3 Transport Corridor – User Input Data for T-Intersection

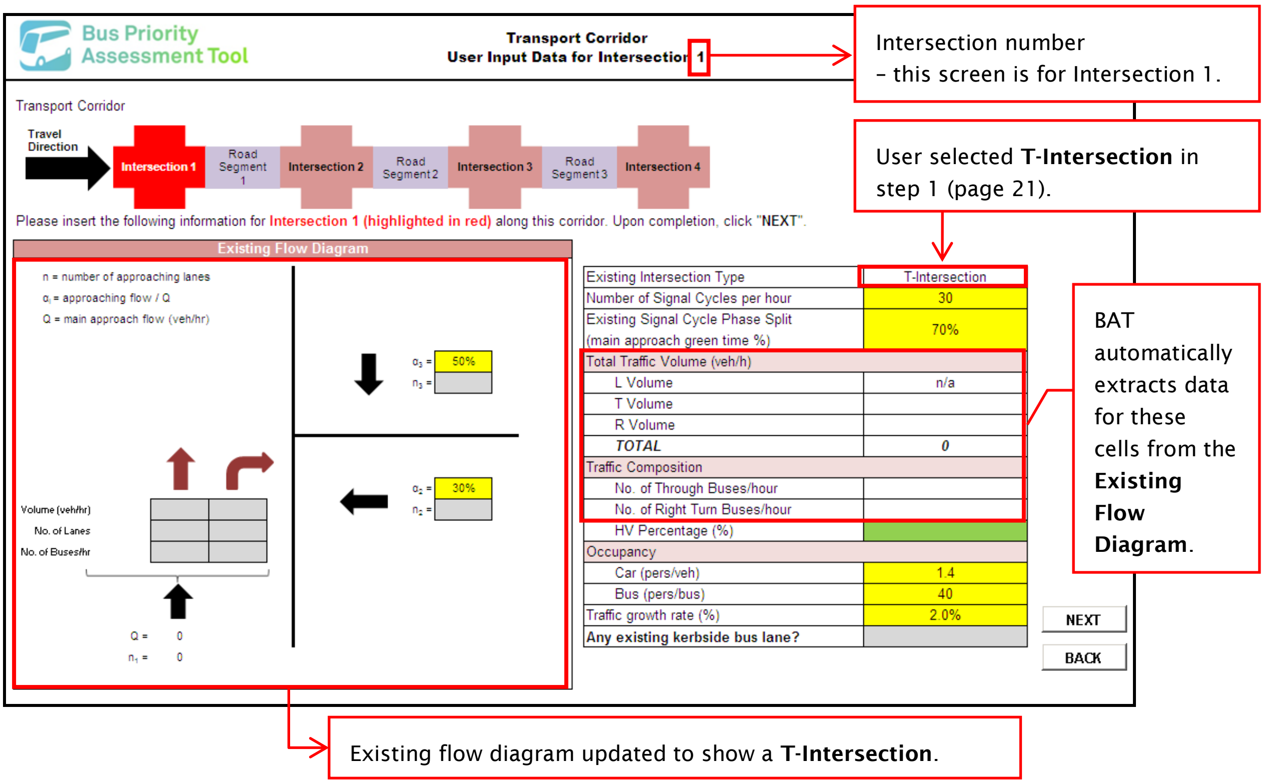
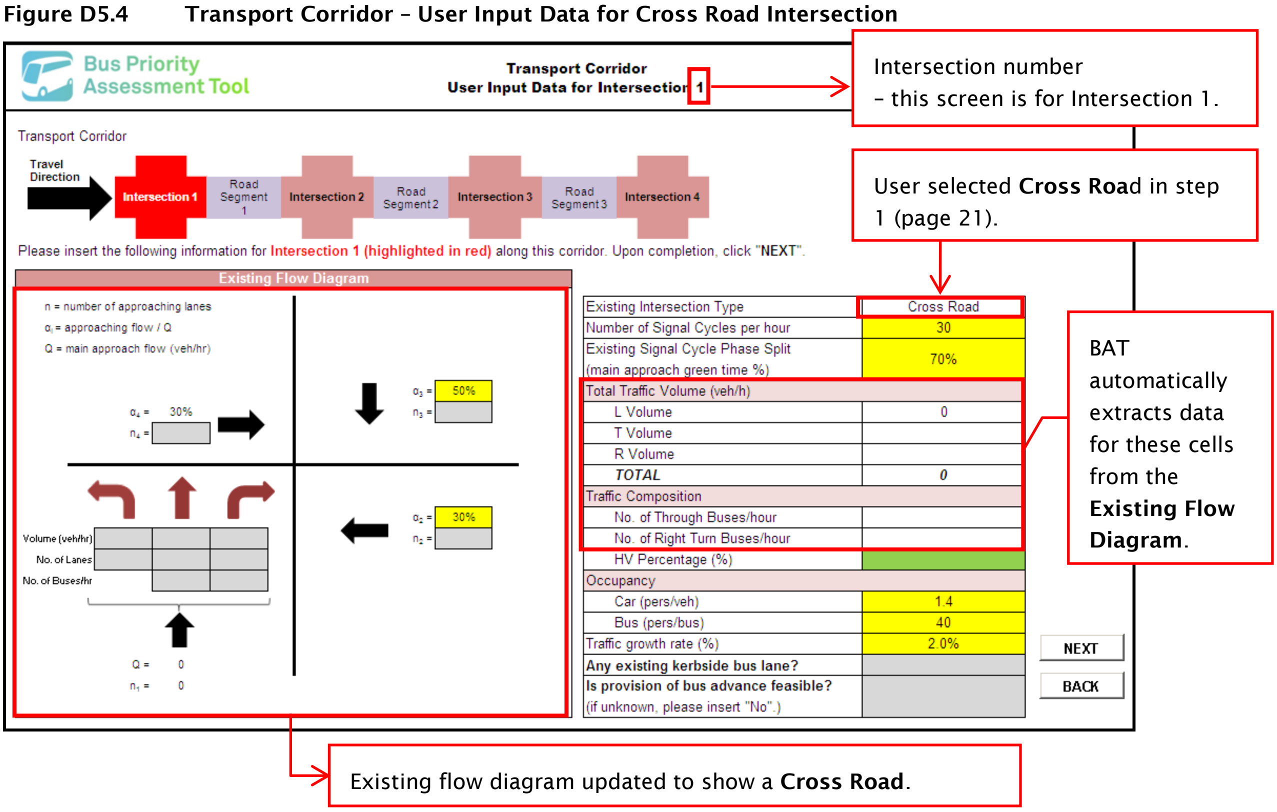


Figure D5.4 Transport Corridor – User Input Data for Cross Road Intersection



Step 11 Assessing the feasibility of providing bus priority treatment

This will be done automatically by BAT.

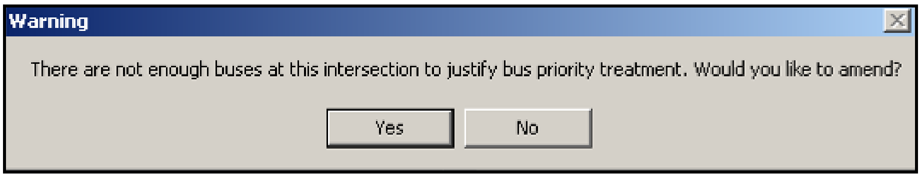
If the total bus volume (ie through bus volume + right turn bus volume) provided in step 9 or step 10 is:

- less than 15 buses per hour, go to step 12, or
- greater than or equal to 15 buses per hour, go directly to step 13.

Step 12 If the total bus volume you provided is less than 15 buses per hour

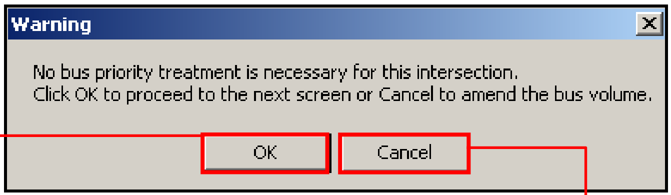
! Ignore this step if the total bus volume is more than or equal to 15 buses per hour.

The **Warning Message Box** below appears, telling you that there are not enough buses at the intersection.



Click **Yes** – to close the message box and go back to step 9 or step 10 to amend the bus volume in the **Existing Flow Diagram,** or

Click **No** – to confirm that the bus volume entered is correct.
The **Warning Message Box** below appears to notify you that no bus priority treatment is necessary.



Click this to accept that no bus priority treatment is required for this intersection.
► Go to step 13.

Click this to close the message box. The model sends you back to amend the bus volume in the **Existing Flow Diagram**.
► Go to step 9 (for T-intersection), or
► Go to step 10 (for Cross Road intersection).

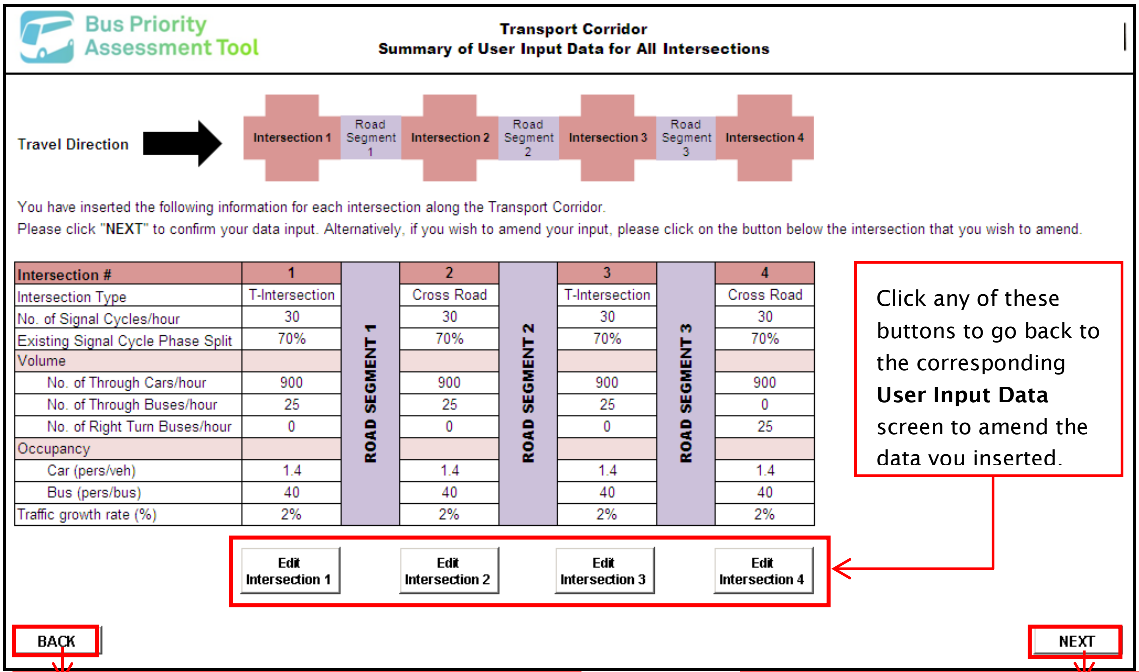
Step 13 Have you provided intersection data for all intersections along the Transport Corridor?

- If yes, go to step 14.
- If not, the **Transport Corridor – User Input Data** screen appears for the next intersection. Go back to step 8 to input intersection data for the next intersection.

Step 14 You confirm the individual intersection input

The **Transport Corridor – Summary of User Input Data for All Intersections** screen appears. This screen summarises your input for all individual intersections along the transport corridor. Either:

- Click **NEXT** to confirm your input for all intersections and go to step 15, or
- Go back to the corresponding **User Input Data** screen to amend your input data.


Bus Priority Assessment Tool

Transport Corridor
Summary of User Input Data for All Intersections

Travel Direction

Intersection 1 | Road Segment 1 | Intersection 2 | Road Segment 2 | Intersection 3 | Road Segment 3 | Intersection 4

You have inserted the following information for each intersection along the Transport Corridor.
Please click "NEXT" to confirm your data input. Alternatively, if you wish to amend your input, please click on the button below the intersection that you wish to amend.

Intersection #	1	ROAD SEGMENT 1	2	ROAD SEGMENT 2	3	ROAD SEGMENT 3	4
Intersection Type	T-Intersection		Cross Road		T-Intersection		Cross Road
No. of Signal Cycles/hour	30		30		30		30
Existing Signal Cycle Phase Split	70%		70%		70%		70%
Volume							
No. of Through Cars/hour	900		900		900		900
No. of Through Buses/hour	25		25		25		0
No. of Right Turn Buses/hour	0		0		0		25
Occupancy							
Car (pers/veh)	1.4		1.4		1.4		1.4
Bus (pers/bus)	40		40		40		40
Traffic growth rate (%)	2%		2%		2%		2%

Edit Intersection 1 | Edit Intersection 2 | Edit Intersection 3 | Edit Intersection 4

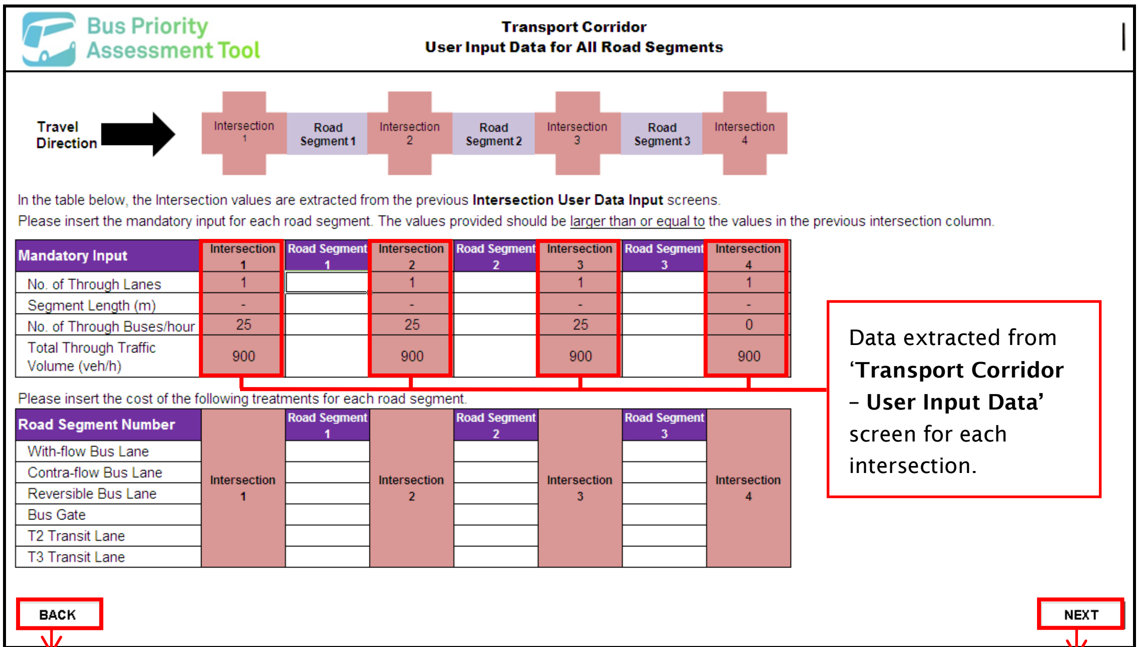
BACK NEXT

Click any of these buttons to go back to the corresponding **User Input Data** screen to amend the data you inserted.

Click this to go back to **Transport Corridor – User Input Data** screen for the last intersection.

Click to confirm intersection data.
► Go to step 15.

Step 15 The **Transport Corridor – User Input Data for All Road Segments** screen appears.


Bus Priority Assessment Tool

Transport Corridor
User Input Data for All Road Segments

Travel Direction

Intersection 1 | Road Segment 1 | Intersection 2 | Road Segment 2 | Intersection 3 | Road Segment 3 | Intersection 4

In the table below, the Intersection values are extracted from the previous **Intersection User Data Input** screens.
Please insert the mandatory input for each road segment. The values provided should be larger than or equal to the values in the previous intersection column.

Mandatory Input	Intersection 1	Road Segment 1	Intersection 2	Road Segment 2	Intersection 3	Road Segment 3	Intersection 4
No. of Through Lanes	1		1		1		1
Segment Length (m)	-		-		-		-
No. of Through Buses/hour	25		25		25		0
Total Through Traffic Volume (veh/h)	900		900		900		900

Please insert the cost of the following treatments for each road segment.

Road Segment Number	Intersection 1	Road Segment 1	Intersection 2	Road Segment 2	Intersection 3	Road Segment 3	Intersection 4
With-flow Bus Lane							
Contra-flow Bus Lane							
Reversible Bus Lane							
Bus Gate							
T2 Transit Lane							
T3 Transit Lane							

BACK NEXT

Data extracted from **'Transport Corridor – User Input Data'** screen for each intersection.

Click this to go back to **Transport Corridor – Summary of User Input Data for All Intersections** screen.

Click this to go to the next screen.

Step 16 Insert mandatory information for all road segments along the transport corridor.

For each **road segment** column, insert the following mandatory information:

- Number of through lanes – minimum of two lanes.
- Segment length – in metres.
- Number of through buses per hour – has to be greater than or equal to the through bus volume in the previous intersection.
- Total through traffic volume per hour – has to be greater than or equal to the through traffic volume in the previous intersection.
- Cost of each treatment.

Step 17 Click **NEXT** and go to step 18.

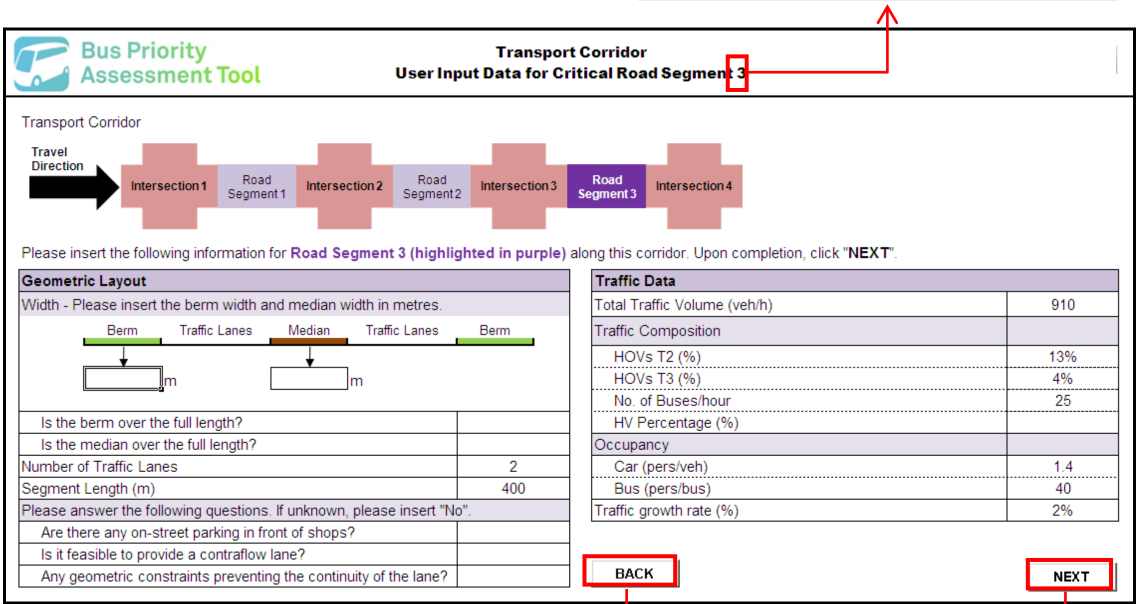
Step 18 Selection of Critical Road Segment

This will be done automatically by BAT.

The model automatically selects the critical road segment(s) based on the road segment data you provided in step 16.

Step 19 The **Transport Corridor – User Input Data for Critical Road Segment** screen shows below.

This means that **Road Segment 3** is a critical road segment.

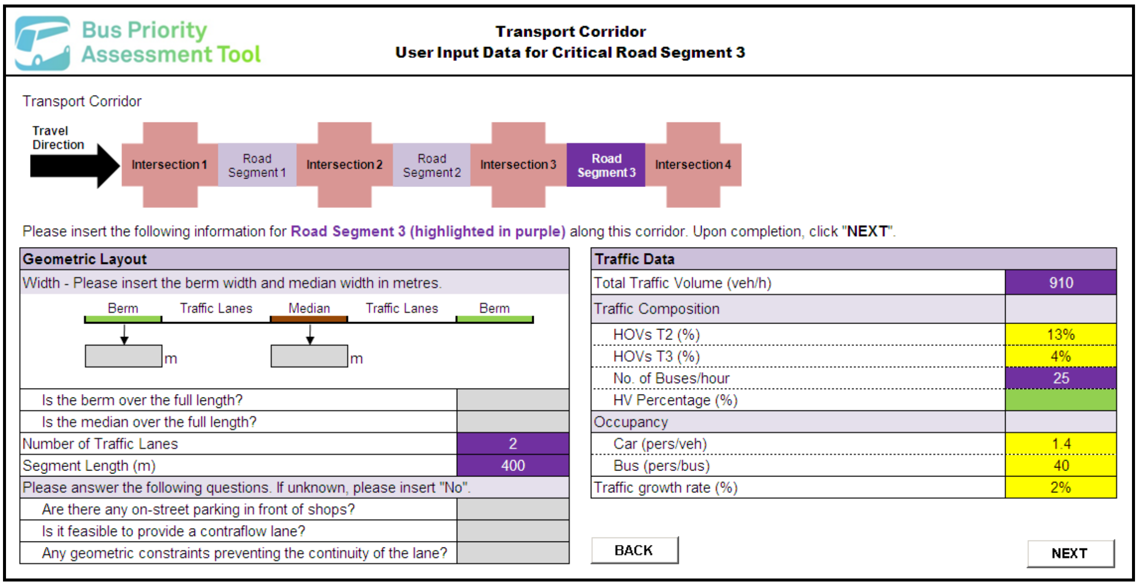


Click this to go back to either:

- **User Input Data** screen for previous critical road segment, or
- **Transport Corridor – User Input Data for All Road Segments** screen if this is the first critical road segment.

Click this to go to the next screen.

Step 20 Insert mandatory information for the Critical Road Segment



20a Model automatically extracts the following data from previous **Transport Corridor – User Input Data for All Road Segments** screen. These are highlighted in purple in the screenshot above.

- number of lanes
- segment length (m)
- total traffic volume (veh/h)
- number of buses/hour (bus/h).

Note: If you would like to amend any of these values, click **BACK** to return to step 15.

20b Insert the following mandatory information in the **Transport Corridor – User Input Data for Critical Road Segment** screen. These cells are highlighted in grey in the screenshot shown in step 18.

- Berm width – in metres.

  Note: If the existing berm width is not available to be used for an extra traffic lane, please insert zero.

- Median width – in metres.

  Note: If the existing median width is not available to be used for an extra traffic lane, please insert zero.

- Select **Yes** or **No** for the questions below:
  - Is the berm over the full length?
  - Is the median over the full length?
  - Is there any on-street parking in front of shops?
  - Is it feasible to provide a contra-flow lane?
  - Any geometric constraints preventing the continuity of the lane?

20c If necessary, amend the accessible default values to better reflect the traffic situation at the intersection. These values are highlighted in yellow in the screenshot above.

BAT will not proceed further if any of these values are left blank. See section D8 for more explanation about the accessible default values for the Transport Corridor – Critical Road Segment Model.

20d Insert the optional data. This is not mandatory – you can go to the next screen if the cell (highlighted in green in the screenshot above) is left blank.

20e Click **NEXT** and go to step 21.

Step 21 **Assessing the feasibility of providing an additional lane at this critical road segment**

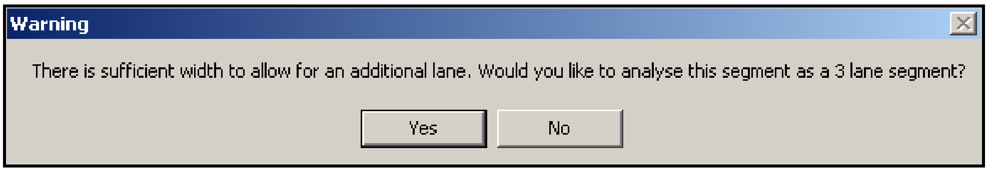
This will be done automatically by BAT.

- If there is sufficient width to provide an additional lane, go to step 22, otherwise
- If there is insufficient width to provide an additional lane, go to step 23.

Step 22 **If there is sufficient width to provide an additional lane**

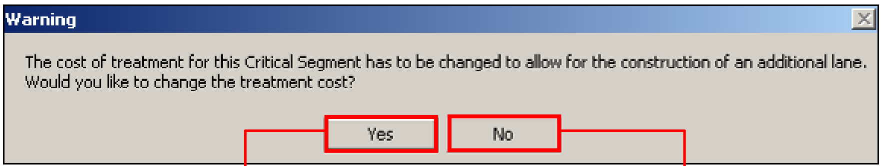
! BAT automatically ignores this step if there is insufficient width to provide an additional lane

The **Warning Message Box** below appears.



Click **Yes** – to allow the model to analyse this critical road segment with an additional lane.

The **Warning Message Box** below appears to remind you that the treatment cost may be different with an additional lane.

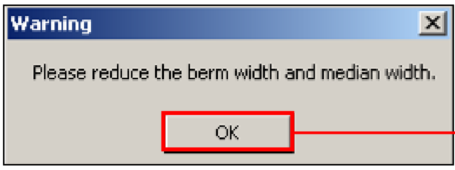


Click this to change the treatment cost. BAT will automatically direct you to **Transport Corridor – User Input Data for All Road Segments** screen.
► Go to step 15.

Click this to confirm that the treatment cost takes into account the cost of having an additional lane.
► Go to step 23.

Click **No** – to continue to analyse the critical segment with the current lane configuration without using the additional width available.

The **Warning Message Box** below appears to ask you to reduce the berm width and/or the median width.



Click this to close the Warning Message Box.
BAT will automatically direct the user to the **Transport Corridor – User Input Data for Critical Road Segment** screen to amend the widths.
► Go to step 20.

Step 23 BAT automatically analyses if you have provided information for all the critical road segments.

- If all information has been provided, BAT will automatically direct you to step 24, otherwise
- The Transport Corridor – User Input Data for Critical Road Segment screen appears for the next critical road segment.

► Go back to step 20 to input critical road segment data for the next critical road segment.

Step 24 The **Transport Corridor – Model Result** screen appears.

See the next page for further explanation of the components in this screen.

Transport Corridor Model Output Screen

Bus Priority Assessment Tool

Transport Corridor
Model Result

NZ TRANSPORT AGENCY WAKA KOTAHI AECOM

Model result based on the following user input data:

1

Key Performance Indicator (KPI)	User Input Weighting (%)
1. Overall Bus and Car Traveller Delay	10%
2. Reduced Car Growth Rate over 10 years	20%
3. Lane Person Throughput in 10 years	30%
4. Cost of Vehicle Emission	40%

Travel Direction →

	User Input Treatment Cost	Intersection 1	Road Segment 1	Intersection 2	Road Segment 2	Intersection 3	Road Segment 3	Intersection 4
Intersection	Bus Advance	N/A	n/a	$ 20,000.00	n/a	N/A	n/a	$ 20,000.00
	Transit Active Signal	$ 25,000.00	n/a	$ 25,000.00	n/a	$ 25,000.00	n/a	$ 25,000.00
	Queue Jump Lane	$ 15,000.00	n/a	$ 15,000.00	n/a	$ 15,000.00	n/a	$ 15,000.00
	Bus Right Turn only	$ 30,000.00	n/a	$ 30,000.00	n/a	$ 30,000.00	n/a	$ 30,000.00
	Bus Gate for Bus Right Turn	$ 35,000.00	n/a	$ 35,000.00	n/a	$ 35,000.00	n/a	$ 35,000.00
Road Segment	With-flow Bus Lane	n/a	$ 250,000.00	n/a	$ 250,000.00	n/a	$ 250,000.00	n/a
	Contra-flow Bus Lane	n/a	$ 280,000.00	n/a	$ 280,000.00	n/a	$ 280,000.00	n/a
	Reversible Bus Lane	n/a	$ 300,000.00	n/a	$ 300,000.00	n/a	$ 300,000.00	n/a
	Bus Gate	n/a	$ 350,000.00	n/a	$ 350,000.00	n/a	$ 350,000.00	n/a
	T2 Transit Lane	n/a	$ 260,000.00	n/a	$ 260,000.00	n/a	$ 260,000.00	n/a
	T3 Transit Lane	n/a	$ 260,000.00	n/a	$ 260,000.00	n/a	$ 260,000.00	n/a

Model Result Summary

	Intersection 1	Road Segment 1	Intersection 2	Road Segment 2	Intersection 3	Road Segment 3	Intersection 4
Preferred treatment	Transit Active Signal	Contra-flow Bus Lane	Transit Active Signal	Contra-flow Bus Lane	Transit Active Signal	Contra-flow Bus Lane	Bus Gate for Bus Right Turn
Cost	$ 25,000	$ 280,000	$ 25,000	$ 280,000	$ 25,000	$ 280,000	$ 35,000
Alternative Treatment	Queue Jump Lane	T2 Transit Lane	No alternative treatment.	T2 Transit Lane	Queue Jump Lane	T2 Transit Lane	Bus Right Turn only
Cost	$ 15,000	$ 260,000	N/A	$ 260,000	$ 15,000	$ 260,000	$ 30,000

2

User Input Total Funding allowed for the Corridor $ 900,000.00
Total Cost for Preferred Treatments along the Transport Corridor = $ 950,000.00

5 Insufficient Funding Allowed
Please click Change Data Input button below if you wish to amend the input data

3 **Change Data Input**

4 **Restart Model**

6 **Print Result**

Notes:

1 Summary of the data you have inserted. See steps 3, 5 and 15.

If any of the data you inserted needs to be changed, click **Change Data Input** button.

2 Summary table showing the preferred and alternative treatments with the corresponding treatment cost you provided.

3 Click this button to go back to the **Transport Corridor** screen (back to step 1 of section 5.3) to edit the data input.

4 Click this button to delete all data entered and go back to the **Main Menu** screen (section D5.1 of this manual).

5 This error appears if you input funding which was less than the total cost for the preferred treatments.

6 Click this to print the current result page.

Why is there 'N/A' in the summary table?

For any intersection which has **N/A** in the cells representing the preferred/alternative treatments in the summary table, there are not enough buses to justify bus priority treatment at the intersection. You have accepted and agreed in step 12 that bus priority treatment is not required for the intersection.

D6 Frequently asked questions (FAQ)

D6.1 Software requirements and settings

Question: How do I check my current macro settings?

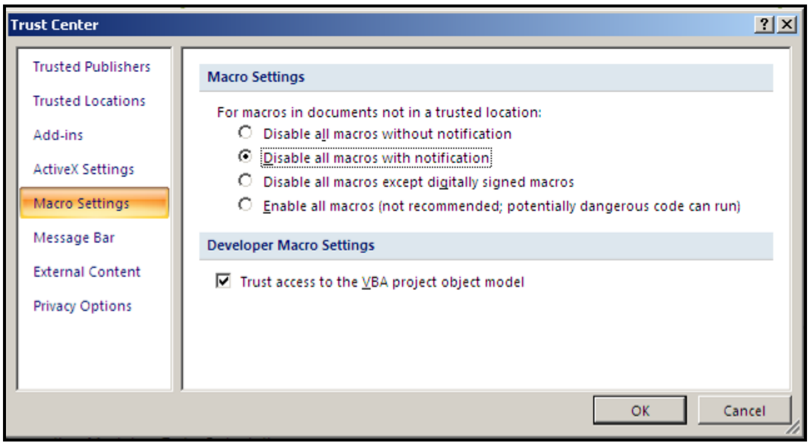
Answer: Macro settings are located in the Trust Center. To access this,

1 Click the **Developer** tab.

2 Under **Code**, click **Macro Security**; the **Trust Center** dialogue box appears.

3 In the Trust Center, click Macro Settings.

4 You will see your current macro settings selection.
For example, the macro setting shown below is 'Disable all macros with notification'. This is usually the default macro setting.



Question: What if I changed my macro settings? Do I have to change them every time I open up the file?

Answer: No. Once you have changed your macro settings, they will remain the same the next time you open the file.

D6.2 Using the model

Question: What if the available budget is unknown?

Answer: You should insert a budget larger than the costs of all considered treatments. This will ensure that all the treatments will pass the screen.

Question: Why the preferred treatment has lower BCR value than the alternative treatment?

Answer: The BCR value is only an indicative value and does not control the selection of treatments.

Question: Does the 'Overall Bus and Car Traveller Delay' include the delay caused by or to pedestrians at intersections?

Answer: No. The model calculates the bus and car travellers on the road.

Question: **What if all road segments along a transport corridor have a homogeneous traffic flow? Would it affect the selection of critical segment?**

Answer: No. If all road segments have a homogeneous traffic flow, the critical segment will be the one segment which has the highest traffic flow or the highest degree of saturation.

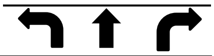
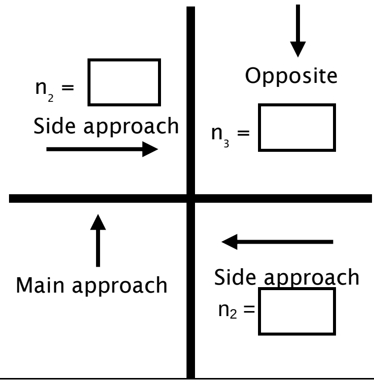
Question: **How do I know if I will lose all my input if I accidentally click the BACK button?**

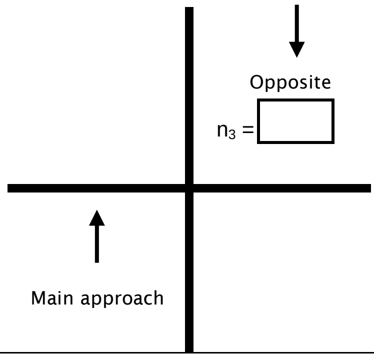
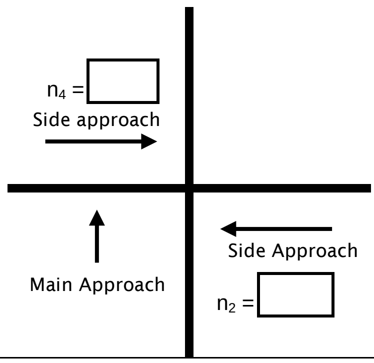
Answer: Most **BACK** buttons will not result in the lost of data you have inserted.
However, BAT will prompt you to reconfirm your action if the **BACK** button will delete all data you have inserted.

Question: **Can I save my work and continue later?**

Answer: No. BAT has been programmed to disallow you to save your work. The usual Excel saving method (either by hitting CTRL+S or Home-Save) has been overwritten by BAT. Therefore, once you close the BAT model, you have to recommence the work. Changes made prior to closing the BAT model will be deleted.

D7 Checklist for compiling mandatory data

No.	Description	Unit	User input value
	For both Intersection and Transport Corridor Models		
1	Project name		
2	Date		
3	Study area (select one)		Intersection/Transport Corridor
4	**Key performance indicator (KPI) weightings** Note: Sum of weightings for the KPIs has to be equal to 100%.		
	• Overall bus and car traveller delay	%	
	• Reduced car growth rate over 10 years	%	
	• Lane person throughput in 10 years	%	
	• Cost of vehicle emission	%	
	Intersection Model (Provide information for items A1 – A6 **only** if you have selected 'Intersection' in item 3 above)		
A1	Budget	$	
A2	Existing intersection type		T-intersection/Cross Road
A3	For the **main approach** only, insert the following: • Existing volume (excluding bus volume) • Existing bus volume • Number of lanes per movement Note: Insert '0.5' for a short lane.	veh/hr bus/hr	 Volume Bus volume No. of lanes
A4	Number of approaching lanes for the **opposite** and **side** approaches		
A5	Answer the following questions:		
	• Any existing kerbside bus lane?		Yes/No
	• Is provision of bus advance feasible? Note: Answer **only if** you have selected 'cross road' in item A2 above.		Yes/No
A6	Cost of intersection treatment:		
	• Bus advance	$	

		• Transit active signal	$	
		• Queue jump lane	$	
		• Bus right turn only	$	
		• Bus gate for bus right turn	$	
	Transport Corridor Model (Provide information for items B1 – B4 **only** if you have selected 'Cross Road' in item 3 above)			
B1	Number of road segments along the transport corridor			1 | 2 | 3 | 4 | 5
B2	Budget		$	
B3	Provide the following information for **each intersection** along the transport corridor.			
	i	Existing intersection type		T-intersection/Cross Road
	ii	For the **Main Approach** only, insert the following: • Existing volume (excluding bus volume) • Existing bus volume • Number of lanes per movement Note: Insert '0.5' for a short lane.	veh/hr bus/hr	Volume | | | Bus volume | | | No. of lanes | | |
	iii	Number of approaching lanes for the **opposite** approach.		
	iv	Number of approaching lanes for the **side** approaches.		
	v	Answer the following questions:		
		• Any existing kerbside bus lane?		Yes/No
		• Is provision of bus advance feasible? Note: Answer **only if** you have selected 'Cross Road' in item B3-i above.		Yes/No
	vi	Cost of intersection treatment:		
		• Bus advance	$	

		• Transit active signal	$	
		• Queue jump lane	$	
		• Bus right turn only	$	
		• Bus gate for bus right turn	$	
B4	Provide the following information for **each road segment** along the transport corridor			
	i	Number of through lanes – minimum of two lanes		
	ii	Segment length	m	
	iii	Total through traffic volume per hour (including bus volume)	veh/hr	
	iv	Number of through buses per hour	bus/hr	
	v	Cross section width • berm width • median width	 m m	Berm · Traffic lanes · Median · Traffic lanes · Berm m m
	vi	Answer the following questions: • Is the berm over the full length? Note: Answer only if there is a berm.		Yes/No
		• Is the median over the full length? Note: Answer only if there is a median.		Yes/No
		• Are there any on-street parking in front of shops?		Yes/No
		• Is it feasible to provide a contra-flow lane?		Yes/No
		• Any geometric constraints preventing the continuity of the lane?		Yes/No
	vii	Cost of road segment treatment:		
		• with-flow bus lane	$	
		• contra-flow bus lane	$	
		• reversible bus lane	$	
		• bus gate	$	
		• T2 transit lane	$	
		• T3 transit lane	$	

D8 BAT accessible default values and optional data input

In the user input screen for both the Intersection Model and Transport Corridor Model, BAT has three types of data you can insert or amend. These are:

Mandatory input data
- You have to provide a value for this data.
- BAT will not proceed further if any of these values are left blank.

Accessible default values
- These values are initially provided by BAT. You can amend these values accordingly but the values cannot be left blank.
- BAT will not proceed further if any of these values are left blank.
- See section D8.1: 'Accessible default values' below for further explanation.

Optional data input
- It is not mandatory to provide this information.
- See section D8.2: 'Optional data input' below for further explanation.

D8.1 Accessible default values

The accessible default values are highlighted in yellow in:

- figures D5.1 and D5.2 for the Intersection Model
- figures D5.3 and D5.4 for the Transport Corridor Model.

These values are consistent with findings from the main body of the report.

You can amend these values accordingly but the values cannot be left blank. If any of these values are left blank, BAT will not proceed further.

Description		**Default value**	
		Intersection Model	**Transport Corridor Model**
Number of signal cycles per hour		30	30
Existing signal cycle phase split (main approach green time percentage)		70%	70%
Approaching flow / Main approach flow	For opposite approach, α_3	50%	50%
	For side approaches, α_2 and α_4	30%	30%
Car occupancy (pers/veh)		1.4	1.4
Bus occupancy (pers/bus)		40	40
Traffic growth rate (%)		2.0%	2.0%
HOVs T2 (%)		n/a	13%
HOVs T3 (%)		n/a	4%

D8.2 Optional data input

D8.2.1 Intersection Model

BAT has already input the following optional data which is highlighted in green in figures D5.1 and D5.2:

- HV percentage (%)
- Direction of travel – select northbound, eastbound, southbound or westbound
- Street names at intersection.

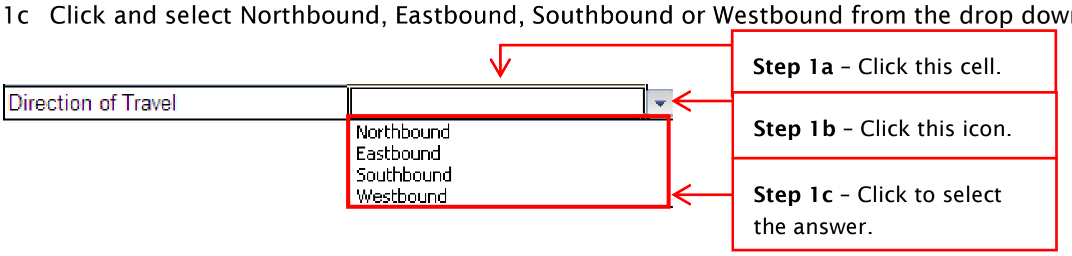
HOW DO I INSERT STREET NAMES?

Step 1 Select the **Direction of Travel** by following the instructions below:

1a Click on the cell next **to Direction of Travel**.

1b Click on the icon to the right of the cell.

1c Click and select Northbound, Eastbound, Southbound or Westbound from the drop down list.



Step 2 Insert the **Street Names** for each approach at the intersection.

Step 3 The **Existing Flow Diagram** automatically updates to show:

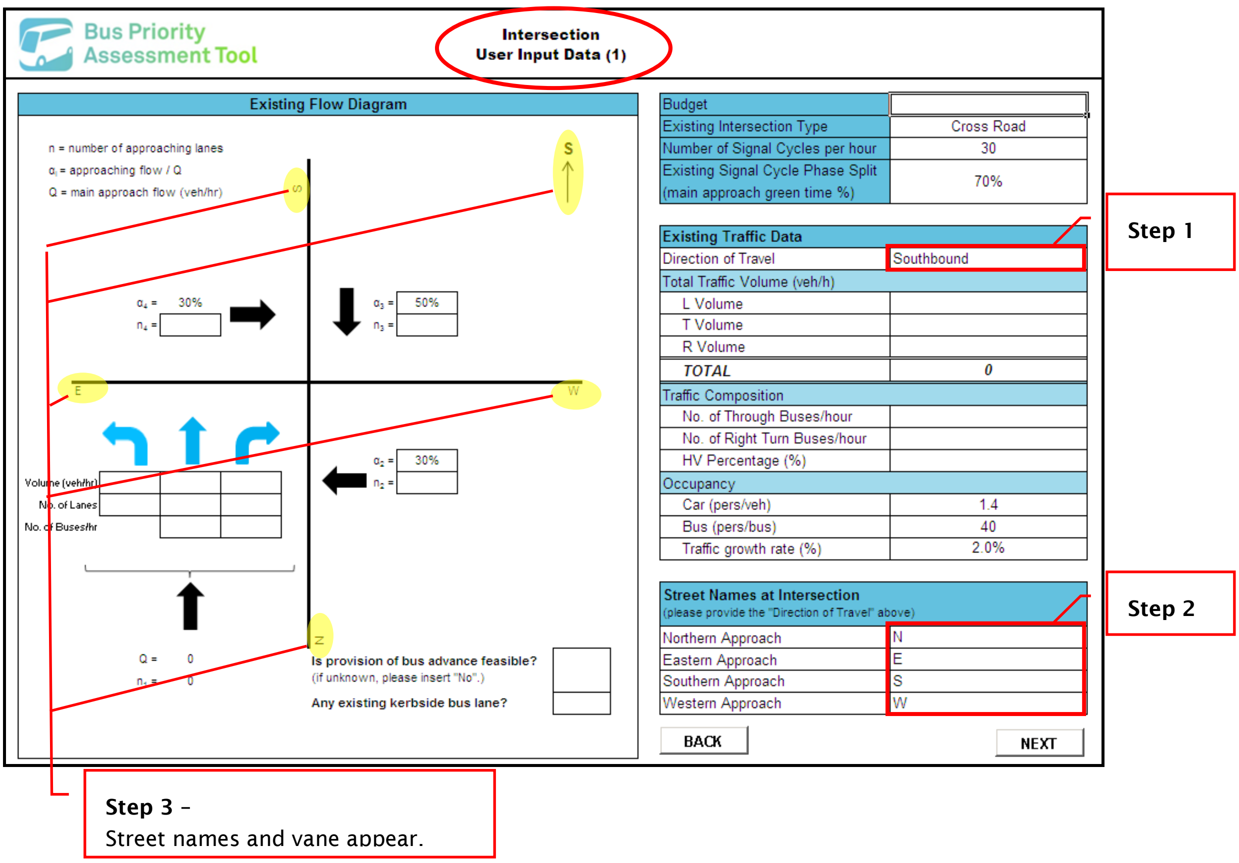
- street name for each approach
- a vane (at the top right-hand corner) to show the direction of travel.

EXAMPLE

By following the procedure above, the screen below shows the following user input:

Step 1 User selected 'Northbound' as the **Direction of Travel**

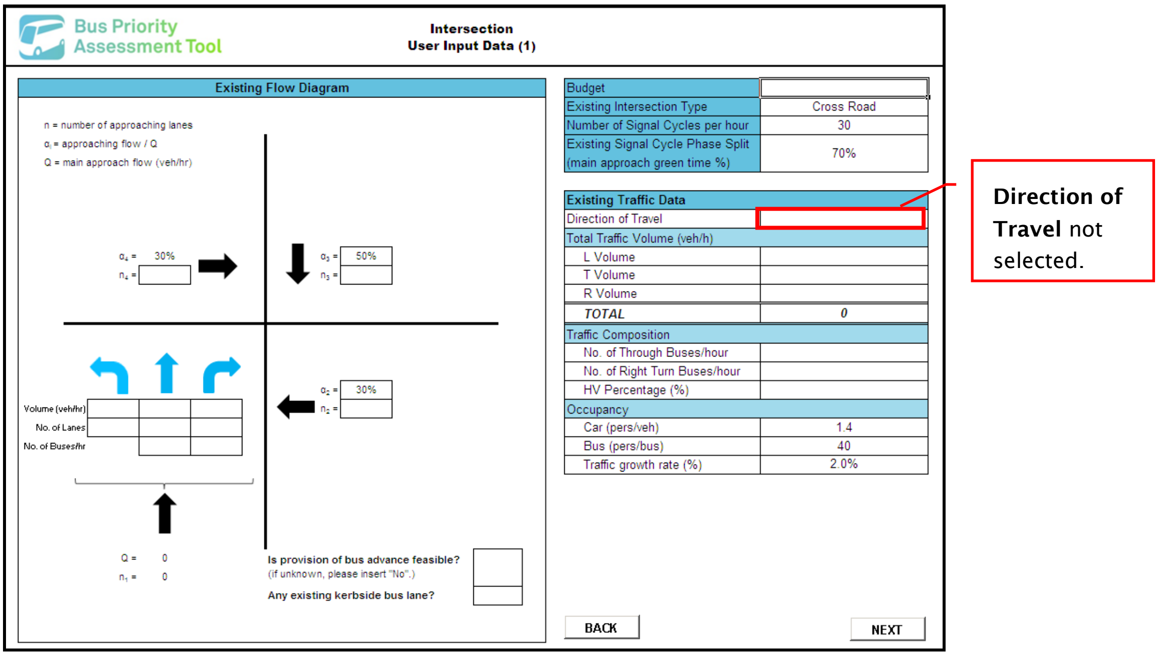
Step 2 User inserted 'N,E,S,W' as **Street Names** for the northern, eastern, southern and western approaches.



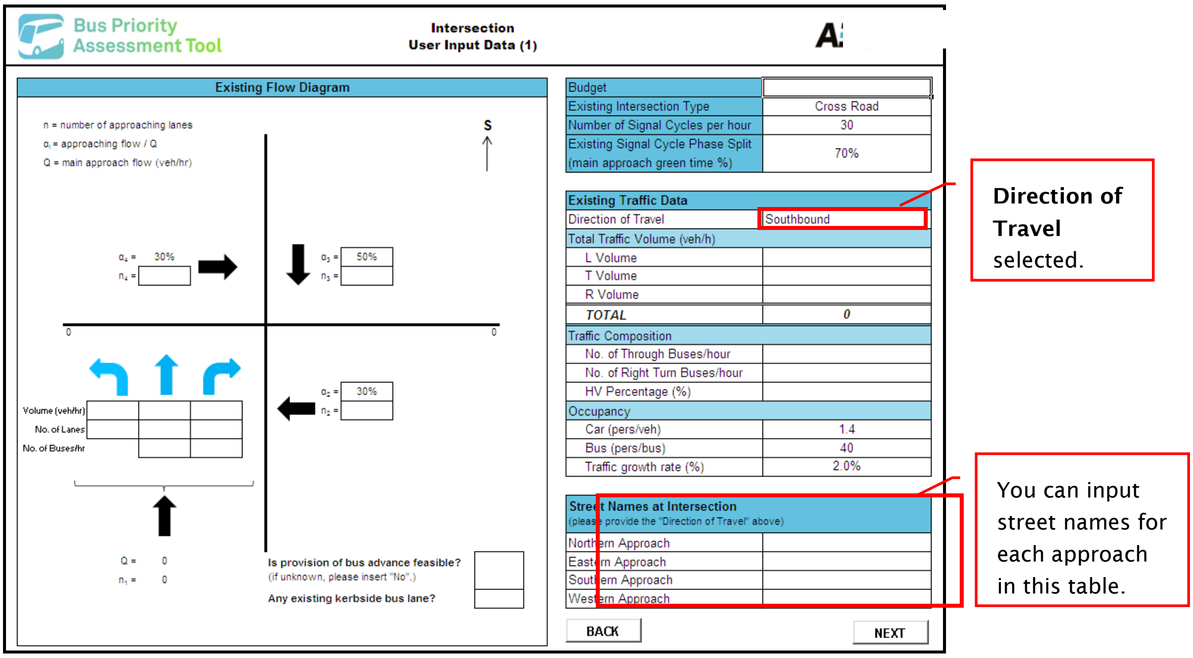
WHY DOESN'T BAT ALLOW ME TO INSERT STREET NAMES?

BAT will only allow you to insert street names if you have selected the **Direction of Travel**.

- If you have not selected the **Direction of Travel**, BAT will display the screen below. You are not allowed to insert street names.



- If you have selected the **Direction of Travel**, BAT will display the screen below. You can insert street names for each approach.



D8.2.2 Transport Corridor Model

The only optional data input in the Transport Corridor Model is **HV percentage (%)**.

It is present in the following BAT screens:

- **Transport Corridor – User Input Data** screen for every intersection along the transport corridor
- **Transport Corridor – User Input Data for Critical Road Segment** screen for every critical road segment along the transport corridor.

Appendix E: Glossary

AVL	automatic vehicle locating
BAT	bus priority assessment tool
BCR	benefit-cost ratio
B-phase	Traffic signal setting allowing for the early release of bus before other traffic
BPISG	Bus Priority Initiatives Steering Group
BRT	bus rapid transport
BSEB	Brisbane South East Busway
CBD	central business district
CCC	Christchurch City Council
DfT	Department for Transport, UK
GP	general purpose
GPS	geographical positioning system
HCV	heavy commercial vehicle
HOT	high occupancy toll lane
HOV	high occupancy vehicle, a vehicle with two or more occupants
KPI	key performance indicator
LBPN	London Bus Priority Network
LCV	light commercial vehicle
LPT	Liverpool to Parramatta Rapid Bus Transitway
NSCC	North Shore City Council (Auckland)
No-car lanes	priority lanes reserved for trucks and buses only
NZTA	New Zealand Transport Agency
PFR	project feasibility report
PT	passenger transport
QBC	quality bus corridor
RCA	road controlling authority (NZTA, Auckland Transport, regional councils, local councils)
SAR	scheme assessment report
SCOOT	split, cycle and offset optimisation technique
SH	state highway
SOV	single occupant vehicle
SVD	selective vehicle detection
T2	High occupancy vehicle with two occupants
T3	High occupancy vehicle with three occupants
Transit lane	Another name for high occupancy lane (motorcycles and cyclists are also permitted users under New Zealand Land Transport Rules)
TSP	transit signal priority
vph	vehicles per hour
WCC	Wellington City Council