Getting more from our roads: an evaluation of special vehicle lanes on urban arterials

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An important note for the reader

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Abbreviations and acronyms

AVO	average vehicle occupancy
Caltrans	California Department of Transportation
EEM	*Economic evaluation manual*
GPS	*Government policy statement on land transport funding 2012/13 – 2021/22*
HOT	high occupancy toll
HOV	high occupancy vehicle
HOV 2+	proportion of the traffic volume with two or more occupants
HOV 3+	proportion of the traffic volume with three or more occupants
pcu	passenger car units
SOV	single-occupant vehicle
Transport Agency	New Zealand Transport Agency
T2	transit lane allowing light vehicles with two or more occupants
T3	transit lane allowing light vehicles with three or more occupants

Contents

Executive summary

With increasing demand for travel and limited opportunities for increasing capacity within urban areas there is increasing pressure to make more effective use of the capacity available. One approach is the introduction of special vehicle lanes where particular classes of traffic, typically buses and high occupancy vehicles (HOV) are permitted to use the lane.

The purposes of the research were to:

- investigate design, operational and safety issues associated with the introduction of special vehicle lanes, sourcing both local and international evidence
- develop an evaluation framework and warrants for selecting special vehicle lane with a view to optimising the movement of **people** and **goods** along arterial corridors
- develop an analytical tool to assess the benefits of special vehicle lanes for the corridor users in motorised vehicles.

This report combines a literature review of the experience with special vehicle lanes both in New Zealand and overseas concentrating on special vehicle lanes on arterial roads within urban areas, but also includes consideration of the effects of introducing special vehicle lane on freeways since their use in this context is more extensive.

The report also presents the process and findings of developing a corridor assessment model to evaluate the potential viability of implementing special vehicle lanes (whether they are reserved for buses in the form of bus lanes or HOVs in the form of transit lanes) based on a robust evaluation framework.

Measures of effectiveness

Historically a range of measures have been determined for HOV schemes but these mainly relate to the performance of the special vehicle lane itself. There is also little evidence of any comprehensive cost-benefit analysis of schemes, looking at the overall impacts on users and the costs of introducing and maintaining and enforcing the special vehicle lanes.

The lack of a comprehensive framework for measuring the effectiveness of special vehicle lanes linked to the policy objectives means that schemes are vulnerable to pressures for their termination and a number of projects where the specific objectives appear to have been met have been terminated.

Hence, the recommended measures of effectiveness developed as part of this research (and presented in the table over the page) have the following attributes in that they:

- are closely linked to the policy objectives
- consider the whole of corridor performance (eg economic efficiency and corridor productivity) and individual lane performance
- are relatively simple to measure, and can be easily reported on
- are reflective of the need to consider the operational performance (ie compliance, reliability and level of service by mode) and the user safety.

This has led to the development of warrants as the minimum performance criteria for considering a special vehicle lane. The warrants are reflective of the need to compare the special vehicle lane against a general traffic lane as well as the whole of corridor performance by considering eligibility, road function, compliance and enforcement.

Impacts on capacity

The introduction of special vehicle lanes is likely to have impacts on the operational characteristics of the road in which they are located (and this factor is recognised in several sources) there is very little published analysis of the effects in practice. Work in San Francisco has identified a loss of capacity in special vehicle lane in a freeway of up to 20%. Analysis of a special vehicle lane on an arterial route in Auckland undertaken as part of this study has suggested a reduction of capacity of about 15% on the special vehicle lane and about 8% on the adjacent general traffic lane. Furthermore, there was a steeper degradation in speed when the special vehicle lane was in operation. Both of these are consistent with the theory of "side-friction" in the selection of the appropriate speeds.

Behavioural response

There is rather more information on the longer term behavioural impacts in terms of average vehicle occupancy in the corridor affected and in general although not in all cases these have shown an increase as travellers take advantage of the faster travel times in the special vehicle lane. There is evidence both for the impacts on arterial roads as well as freeways. In general as might be expected the increases in average vehicle occupancy are related to the potential journey time savings but these need to be assessed within the context of the overall package offered to HOVs. As an example a very large increase in average vehicle occupancy was achieved in a case where the time savings were modest but where the special vehicle lane was accompanied by employer incentives for carpooling.

Impacts on productivity

A key finding from this research is the process for managing the impact and benefits of special vehicle lanes using the corridor productivity measure in its monetised form. In planning for the special vehicle lanes, a balance may be needed between the process to manage congestion by expanding eligibility and the need to restrict eligibility when the special vehicle lane becomes congested. The aim should be to minimise this gap between the peak productivity prior to the general traffic lane becoming congested, and the peak productivity prior to the special vehicle lane becoming congested. It is the level of behaviour change that will influence this gap.

Corridor assessment model

An analytical model created in Microsoft Excel has been developed to assess the relative performance of special vehicles on arterial roads, accounting for the major influential factors in urban corridors based on methodologies established in the *Highway capacity manual*.

This analytical model provides a simple and useful tool to assess the predicted performance of corridors with a special vehicle lane and provides a quantifiable estimate of performance, rather than relying on a policy decision for selecting whether a special vehicle lane is desired, and what that should allow.

The model can be accessed at www.nzta.govt.nz/resources/research/reports/557.

The key findings from the evaluation of a number of corridors in Auckland with special vehicle lane are that:

- The established equations to estimate travel times and delays are fairly robust as evidenced by only minor modifications to signal timings to calibrate the models to journey times.
- The evaluation indicates when the corridor becomes congested; the use of special vehicle lanes provides a more efficient outcome in moving more people in a quicker time than for general traffic lanes.
- The evaluation indicates that that there is an opportunity to determine the level of public transport patronage that would justify on economic grounds, the use of a bus lane over a transit lane (ie the level of bus patronage is sufficiently high that any increase in vehicle use would lead to a loss in economic performance of the corridor).

Further investigation and development

While the work has achieved the objectives, there are a number of areas that would benefit from further research:

- The impact of having special vehicle lanes on capacity because of limited data sample. Traffic engineering theory suggests that differential speed, and lane widths are two contributing factors to lane capacity and the rate at which the base speeds reduce.
- Impact of transit lanes on mode choice, or choice to carpool – there is very little evidence to either confirm or deny that the choice to carpool is an elastic relationship. The elasticities for mode choice to use car or public transport are well established, but not for high occupancy vehicles and determining whether car passengers are changing to public transport and vice versa. The Fanshawe Street example indicates that a large number of car passengers have switched to bus services demonstrated by a much lower proportion of high occupancy vehicles compared to other corridors in the Auckland region.
- Safety of special vehicle lanes – there is very little evidence at this stage but there will be a lot of crash data available in New Zealand and probably in Australia as well. There are extensive bus lane and transit lane components to in the urban networks in Australia and New Zealand, hence it is foreseeable that the relative safety of special vehicle lanes could be evaluated.
- Refinement of the corridor assessment model to assess multiple layouts in a single run and assess intersection capacities (depending on the data requirements), and to determine the threshold for patronage and vehicle use to justify type of special vehicle lane rather than relying on a demand analysis.

Abstract

With increasing demand for travel and limited opportunities for increasing capacity within urban areas there is increasing pressure to make more effective use of the capacity available. One approach is the introduction of special vehicle lanes where particular classes of traffic, typically buses and high occupancy vehicles are permitted to use the lane.

Vehicles eligible to use special vehicle lanes typically represent only a limited part of the total traffic flow, resulting in lower and more reliable travel times for those vehicles. However, where existing road space is reallocated, other traffic may face increased congestion as the capacity available for this is reduced. Users may respond by changing their behaviour to take advantage of improved travel conditions in the special vehicle lane.

Because the setup costs of special vehicle lanes are typically small, their economic assessment therefore depends critically on whether the reduction in costs for the managed traffic is greater than any increase for the remaining traffic.

This report considers evidence on these issues using New Zealand data and international research and outlines a systematic approach and analytical modelling techniques for the assessment of special vehicle lanes on arterial roads.

1 Introduction

1.1 Background

With increasing demand for travel within major urban areas and limited opportunities for increasing roadway capacity, there is growing pressure to make more effective use of the infrastructure that is currently available.

Special vehicle lanes involve the allocation or reallocation of road space so that only particular classes of traffic are permitted to use a particular lane or lanes, with the rest of the traffic sharing the remaining general traffic lane or lanes. Across New Zealand there are various priority treatments for high occupancy vehicles (HOVs) including transit lanes (T2 or T3), bus lanes and transit/truck lanes (installed in conjunction with ramp signals on the Auckland motorway network). Current practice is to either provide facilities mid-block or to provide a queue jump lane at traffic signals to allow buses to bypass the waiting queue, although this is changing to provide special vehicle lanes through signalised intersections following the change in the *Land Transport Rule: Traffic Control Devices* to clarify this position.

The selection of the treatment to use has, more often than not, been based on a policy decision without the evidence to support one form of treatment over another. In practice, the demand for bus services may outstrip the number of buses available to service the demand, therefore leaving a large amount of road space under-utilised. The potential for cyclists to use bus lanes and transit lanes also introduces a different dynamic in that there is less vehicle-cyclist conflict in bus lanes than in transit lanes. The under-utilisation of a bus lane provides a high-quality facility for cyclists.

Vehicles permitted to use special vehicle lanes represent a limited part of the total traffic flow, and their allocation to a special vehicle lane results in faster and more reliable travel times for these vehicles. However, where existing road space is reallocated rather than new capacity provided (as is often the case in urban areas), other traffic may face increased congestion and travel times as the road space available is reduced. This can impact on public perception and the political acceptability of special vehicle lanes. Balancing the impact on these two groups forms one of the main elements of the success of the intervention.

This paper combines a literature review of the experience with special vehicle lanes both in New Zealand and overseas and also includes an analysis of the performance of the longest running transit lane in New Zealand along Onewa Road on the North Shore in Auckland. The study concentrates on the operation of special vehicle lanes on arterial roads within urban areas but also includes consideration of the effects of introducing special vehicle lanes on freeways since their use in this context is more extensive. While the concept of special vehicle lanes includes lanes reserved for buses, this study also considers special vehicle lane options for higher occupancy private cars and to a lesser extent for freight vehicles.

1.2 Research objectives

The purposes of the research were to:

- investigate design, operational and safety issues associated with the introduction of special vehicle lanes, sourcing both local and international evidence

- develop an evaluation framework and warrants for selecting special vehicle lanes with a view to optimising the movement of people and goods along arterial corridors
- develop an analytical tool to assess the benefits of special vehicle lanes for corridor users in motorised vehicles.

1.3 Report structure

The report is structured as follows:

- Chapter 2 provides the results of the literature review.
- Chapter 3 presents:
  - existing modelling methodologies
  - the framework and methodology for developing an analytical tool in the form of a spreadsheet model to evaluate the effectiveness of special vehicle lanes along typical urban corridors
- Chapter 4 provides results of the case studies used to demonstrate the effectiveness of special vehicle lanes on urban corridors in the Auckland region.
- Chapter 5 presents the conclusions of the research.
- The appendices contain the model outputs for the case studies used to demonstrate the effectiveness of special vehicle lanes. Appendix C is a separate document which can be accessed at www.nzta.govt.nz/resources/research/reports/557.

2 Literature review

The literature review studies special vehicle lanes in New Zealand and other countries and covers the following topics:

- the policy framework in New Zealand
- typical objectives used overseas in the implementation of special vehicle lane programmes
- evaluation frameworks for special vehicle lanes
- warrants for the use of special vehicle lanes
- planning for the implementation of special vehicle lanes
- the effects of special vehicle lanes on corridor operations and behavioural response
- existing modelling techniques.

2.1 Overview

In the New Zealand context, a special vehicle lane (as defined in the Land Transport Rule: Traffic Control Devices 2004) is a lane defined by signs or markings with its use restricted to a specified class or classes of vehicle; and can be a bus lane, a transit lane, a cycle lane or a light-rail vehicle track. The ability to implement special vehicle lanes is covered in the Government Roading Powers Act 1989 (for the NZ Transport Agency) and the Local Government Act 2002 (for local authorities).

2.1.1 Legal definition

The Traffic Control Devices Rule defines the requirements for traffic control devices (signs, markings, traffic signals etc) that can be implemented and legally enforced in New Zealand.

A bus lane means a lane reserved by a marking or sign installed at the start of the lane and at each point at which the lane resumes after an intersection, for the use of (unless any or all are specifically excluded by the signs):

- buses
- cycles, mopeds and motorcycles.

A transit lane (also known as a high occupancy vehicle (HOV) lane or carpool lane) is a special vehicle lane defined as a lane reserved for the use of the following (unless specifically excluded by a sign installed at the start of the lane):

- passenger service vehicles (buses and taxis)
- motor vehicles carrying not less than the number of persons (including the driver) specified on the sign
- cycles

- motorcycles
- mopeds.

The Rule allows for other types of special vehicle lane provided the signs proposed have been approved for use on the network. Current examples include the priority lanes (allowing trucks plus vehicles eligible to use transit lanes) on the on-ramps to the Auckland motorway network.

2.1.2 Use of special vehicle lanes

The use of special vehicle lanes by road users is governed by the Land Transport (Road User) Rule 2004. Section 2.3 of the Rule outlines the requirements and restrictions for users of the roadway in relation to special vehicle lanes. An extract from the Rule is as follows:

1) A driver, when driving, must not use—

A special vehicle lane reserved for a specific class or classes of vehicle unless —

i. the vehicle is one of the class or classes of vehicle for which the lane is reserved; or

ii. the vehicle is an emergency vehicle being used in an emergency.

2) A driver may also drive wholly or partly in a lane that is unavailable to the driver under subclause (1) or clause 4.6(2) to (4) if the driver—

a) drives in the lane to cross it to—

i. make a turn; or

ii. leave a road; or

iii. enter a marked lane or line of traffic from the side of the road; or

iv. enter a marked lane or line of traffic from another marked lane; or

v. park in a place clear of a special vehicle lane, if the lane that the driver crosses is a special vehicle lane; or

vi. enter a specified stopping place or loading zone to pick up or drop off passengers or a load, if the driver is driving a passenger service vehicle or goods vehicle and the lane that the driver crosses is not reserved for a vehicle of that class; and

b) drives in the lane for the minimum length necessary to complete the manoeuvre and for no more than a maximum length of 50 m; and

c) gives way to vehicles entitled to use the lane.

In practice this means that drivers are not eligible to use a special vehicle lane (as defined under the Traffic Control Devices Rule and signed and marked accordingly), unless they need to execute a turning movement and have to enter the lane within 50m of the turning point.

2.1.3 Types

Special vehicle lane treatments on urban arterials can be grouped into two categories:

1 Segment (mid-block) treatments

2 Intersection treatments.

In designing a special vehicle lane along a corridor, several treatments may be incorporated. Careful consideration needs to be given to ensuring that the treatments selected are compatible for the purpose of providing the intended special vehicle lane.

Typical mid-block treatments include:

- kerbside special vehicle lane
- special vehicle lane in the second lane
- median special vehicle lane
- segregated special vehicle lane
- contraflow lanes.

Typical intersection treatments include:

- queue jump special vehicle lanes
- dedicated special vehicle lanes
- special vehicle lane termination
- gating systems
- special vehicle turning lane
- grade separation of special vehicle lane.

Access treatments to motorways are also available (such as ramp meter bypass lanes); however, the focus of this report is on the use of special vehicle lanes on arterial roads, therefore the application of access treatments is limited to their impact on arterial roads.

Mid-block and intersection treatments can also be complemented by supporting intelligent transport system measures including traffic signal priority (bus pre-emption) and electronic enforcement.

Appendix A has examples of typical treatments.

2.2 Policy framework

The review of the policy framework focuses on policy for the transport system and the role that special vehicle lanes play in the performance of the transport system; however, it must be recognised that complementary land use planning policy and legislation play an important role in shaping the needs of the transport network by influencing demands through development density controls and zoning.

2.2.1 Government Policy Statement on Land Transport Funding

Central government has stated its objective for the transport system to be:

> *An effective, efficient, safe, secure, accessible and resilient transport system that supports the growth of our country's economy, in order to deliver greater prosperity, security and opportunities for all New Zealanders.* (MoT 2011)

To deliver on its transport objective, the government has stated in its *Government policy statement on land transport funding 2012/13 – 2021/22* (GPS) (MoT 2012) that it is focusing on three key areas:

- Economic growth and productivity — transport has an important role to play in enabling the government's overall goal to grow the New Zealand economy to deliver greater prosperity, security and opportunities for all New Zealanders.
- Value for money — improving the performance of the transport system is critical. The government needs to be confident that the transport sector (central and local government in particular) is delivering the right infrastructure and services to the right level, and for the best possible price.
- Road safety — implementing the *Safer journeys* road safety strategy (NRSC 2010) and its new Safe System approach, to achieve a sustained reduction in deaths and serious injuries on the road network over time.

Central government has set the following short- and medium-term impacts in the GPS:

- Improvements in the provision of infrastructure and services that enhance transport efficiency and lower the cost of transportation through:
  - improvements in journey time reliability
  - easing of severe congestion
  - more efficient freight supply chains
  - better use of existing transport capacity
- better access to markets, employment and areas that contribute to economic growth
- reductions in deaths and serious injuries as a result of road crashes
- more transport choices, particularly for those with limited access to a car
- a secure and resilient transport network
- reductions in adverse environmental effects from land transport
- contributions to positive health outcomes.

The GPS also recognises the role of local roads and investment in public transport infrastructure and services in managing congestion and improving access to economic opportunities.

2.2.2 NZ Transport Agency Statement of Intent

The NZ Transport Agency (the Transport Agency) is a crown entity set up to contribute to an affordable, integrated, safe, responsive and sustainable land transport system for New Zealand as set out in the Land Transport Management Act 2003.

Aligned with the GPS, the Transport Agency's long-term goals are to:

- integrate one effective and resilient network for customers
- shape smart efficient, safe and responsible transport choices
- deliver efficient, safe and responsible highway solutions for customers
- maximise effective, efficient and strategic returns for New Zealand.

This is disaggregated to the goals' objectives with the short-to-medium priority objectives relevant to the implementation of special vehicle lanes being:

- Priority 1: Being a customer focused organisation – understanding and responding to transport system users' attitudes, needs and behaviours such as peoples' experiences of congestion, supply chains and access to employment and markets.
- Priority 2: Making the best use of urban capacity – the key result area is that urban public transport makes a greater contribution to network performance by implementing public transport reviews that differentiate between levels of service and reprioritise public transport resources and investment to where it has greatest impact. Special vehicle lanes also have the potential to provide more efficient use of road space (in an economic sense) than general traffic lanes alone.
- Priority 3: Move more freight on fewer trucks – while the focus of this priority is on high-productivity motor vehicles, improving the reliability of the transport network for freight movements, particularly within industries that rely on supply-chain logistics, will result in being able to move more freight with the same vehicle fleet as there will be less lost time.

2.2.3 Regional land transport strategies

Regional land transport strategies are a statutory requirement for regional councils in order to develop their respective land transport programmes. The key inputs into these transport strategies are the GPS and regional policy statements – both statutory requirements. As such, there are common outcomes across the regional land transport strategies for Auckland, Wellington and Christchurch, which are relevant for the consideration of special vehicle lanes, including:

- improved access and supporting economic growth
- improved freight efficiency
- improved journey time reliability
- improved road safety
- improved transport choices (including viability of transport choices)

- reduction in severe congestion
- reduction in emissions and environmental impact
- improved value for money from transport investment.

2.2.4 Key policy outcomes

The consideration of special vehicle lanes as a tool for road space allocation aligns well with themes that are common to the various statutory strategy and policy documents. The following were therefore included as elements in this research project:

- extraction of maximum benefit from transport investment – existing and proposed
- development of more transport mode choices
- reduction of adverse social and environmental effects from transport
- achievement of better access to markets, employment and areas that contribute to economic growth.

2.3 Objectives and goals for special vehicle lanes

2.3.1 High occupancy vehicle lanes

Possible objectives for HOV lanes are quoted in the online *TDM encyclopedia* (Victoria Transport Policy Institute 2010). These are summarised below.

- total person throughput
- travel times: no net increase in travel times during the afternoon rush hour
- safety: no increase in incident and crash rates
- enforcement: minimal violation rate and maximum perception that users obey HOV rules
- beginning and ending transition
- traffic diversion: minimise traffic diversion
- HOV lane utilisation
- transit ridership
- increase in transit service
- number of people per vehicle
- park and ride use, van pools and employer programmes
- public perception.

An alternative set of objectives for HOV schemes is set out in Turnbull et al (2006, chapter 6) and includes:

- increasing the average number of persons per vehicle
- preserving the person movement capacity of the roadway
- enhancing bus transit operations.

In Australia, Austroads (2002) provides a number of objectives that the introduction of a new HOV facility should look to achieve. These include:

- increasing the people-moving capacity of existing and planned roads
- increasing the use and efficiency of road-based public transport
- reducing the consumption of non-renewable transport fuels per person trip
- reducing vehicle emissions and improving air quality
- providing travel time savings and more reliable trip times
- not unduly impacting on the roadway general purpose lanes
- not adversely affecting the safety of general purpose lanes
- establishing public support for the HOV plan and project
- establishing cost-effective HOV facilities.

Common themes in the consideration of HOV facilities are to improve the people-moving performance efficiency of the corridors, without compromising the performance of the general traffic lanes.

2.3.2 Special vehicle lanes allowing trucks

The National Research Council (2010) notes that although there have been many feasibility studies into truck-only lanes on urban arterials, there have been few applications. That report considers the primary objectives governing the implementation of truck-only lanes in urban areas are:

- reducing congestion by considering how effective and under what circumstances truck-only lanes would be cost beneficial
- mitigating impacts of truck traffic in high-truck-volume corridors by diverting trucks to certain corridors, improving flows (thus reducing emissions) and getting trucks off arterials
- separating trucks from cars, thus improving safety and providing reliability benefits (due to a reduction in incident-related delay)
- providing improved travel times and reliability for trucks serving ports and intermodal sites to maintain the economic viability and competitiveness of these facilities
- complementing innovative freight-oriented land use strategies (eg inland ports or freight villages)
- facilitating the implementation of truck automation (truck platooning) and/or truck electrification strategies, electronic toll collection strategies using automatic vehicle identification technologies, and improved weight and safety enforcement of trucks.

TAC (2013) highlights that truck lanes have the potential to improve truck travel time, reliability, safety and reduce emissions, which can increase truck productivity and contribute to the economic development of a region.

There are synergies in the consideration of truck and HOV lanes in that the objectives are driven by the need to improve the performance of the on-road transport system for users of special vehicle lanes (in this case, trucks) but without compromising the overall performance of the corridors under investigation.

2.3.3 Recommended objectives

In general, a wide range of objectives has been considered, with some focused on the performance of special vehicle lanes, and others focused on the corridor or user outcome. This research concludes that to maximise the potential for public and political acceptability, the objectives should be representative of the corridor users (mode including trucks, demand, time of travel and land use being served), but align with the strategic direction set for the transport system. Table 2.1 outlines the suggested objectives for the use of special vehicle lanes.

Table 2.1 Recommended objectives

Policy framework	Suggested special vehicle lane objectives
• Extract maximum benefit from transport investment – existing and proposed. • Develop more transport mode choices. • Reduce adverse social and environmental effects from transport. • Create better access to markets, employment and areas that contribute to economic growth.	• Increasing the economic efficiency of urban corridors by improving the travel time efficiency and journey time reliability for people and freight. • Easing of severe urban congestion though increased vehicle occupancy and uptake of public transport. • Growth in truck movements and traffic movements on alternative routes is no greater than growth on the corridor under examination. • Ensuring that the downstream network has sufficient capacity to accommodate vehicle traffic. • No net increase in the crash rate along the corridor at an aggregate level and a mode specific level.

2.4 Measures of effectiveness

2.4.1 Typical measures of effectiveness

Bauer et al 2005 provide the evaluation framework used in case studies of Brisbane's special vehicle lanes as outlined in table 2.2.

Table 2.2 Example evaluation framework for assessing Brisbane's HOV lanes

Objective	Measure of effectiveness
Person moving efficiency	• average vehicle occupancy • HOV market share
Travel time savings	• travel time difference between HOV and general purpose lanes
Travel time reliability	• standard deviation of travel time in each lane
Transit efficiency	• vehicle productivity (operating cost)

Objective	Measure of effectiveness
	• bus reliability
Corridor efficiency	• total corridor efficiency expressed as a per lane figure
Impact on general purpose lanes	• level of service for general traffic lanes • travel speed for general traffic lanes
Public opinion	• percentage support for HOV lane
Enforcement	• % violation rate
Environmental	• vehicle emissions • vehicle distance travelled • vehicle hours • total fuel consumption
Safety	• crash rate

The measures of effectiveness outlined above have all been evaluated through travel time surveys and traffic counts. Furthermore, this framework establishes performance measures for public transport operations.

Bus service reliability is becoming easier to measure with buses being tracked via global positioning systems, and through performance-based contracts centred on reliability. The forecasting of public transport reliability can in theory be undertaken by understanding the standard deviation of dwell times and calculating the expected standard deviation of running time. In developing the evaluation criteria (and warrants) for the analytical model, the criterion adopted for buses was the bus stop capacity as it is simple to calculate. Further development of the model could consider travel time reliability, as this was not part of the research project.

2.4.1.1 Effectiveness in improving people moving efficiency: behavioural response

In the longer term and on longer roadway sections there are likely to be behavioural impacts which improve the use of the special vehicle lanes and their 'success'. With improved travel times in special vehicle lanes, users may be encouraged to switch from driving vehicles that are required to use the general traffic lanes to modes that can take advantage of the improved travel conditions. This has the benefits of improving the split of traffic between special vehicle and other lanes, and reducing the total volumes of traffic within the corridor, while keeping the number of people unchanged (assuming there is no shift from other routes within the corridor served).

While these changes are likely to occur, there have been no generally accepted guidelines on the scale of this change, and the reported monitoring of this impact is very limited. Two main factors will affect the changes:

1 The extent to which journey times can be saved on the particular special vehicle lane being investigated

2 The extent to which the special vehicle lane proposed forms part of a comprehensive network from which passengers switching to HOV modes can benefit or where there are other measures put in place to support the operation of the special vehicle lane.

Arterial roads

Using the limited data available both from the monitoring of the Onewa Road transit lane (Murray 2003) and some other results from the USA (Turnbull et al 2006), the UK (Leeds City Council 2007) and Norway

(Laegran 2001) the difference in journey time and the change in average vehicle occupancy has been determined for a small number of arterial road schemes. The results are set out in table 2.3.

Table 2.3 Summary of behavioural response to special vehicle lanes on arterial roads

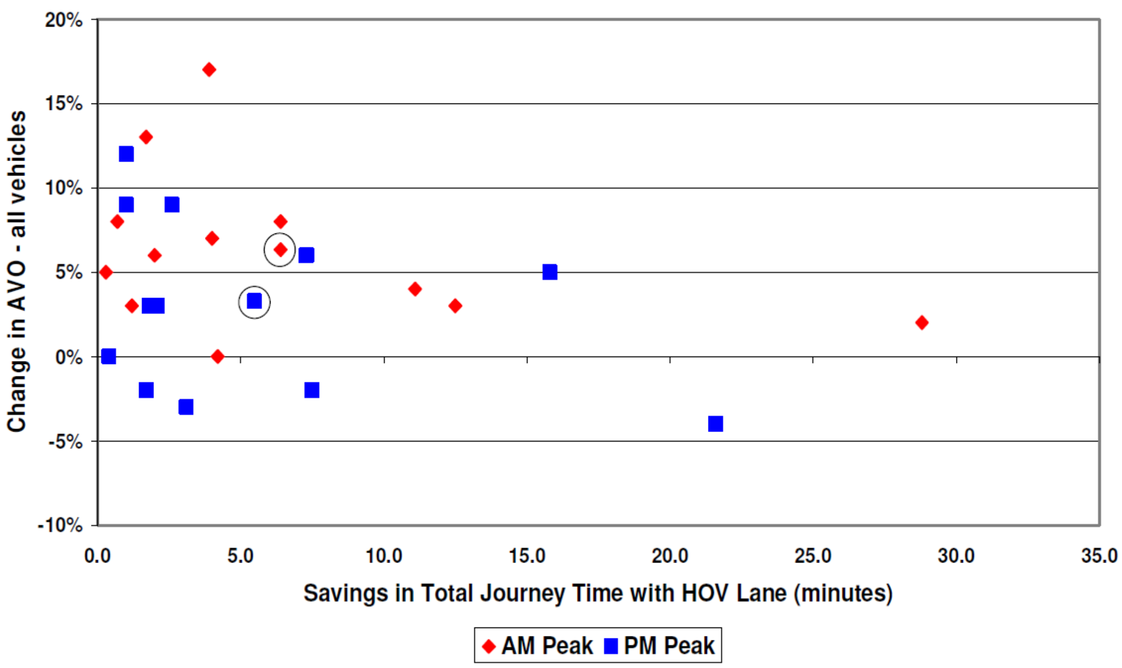
Scheme	Country	Travel time saving (mins)	Type of lane	Increase in share of			
				T2s	T3s	T2s + T3s	Buses
Onewa Rd	New Zealand	20	T3	NA	120%	NA	15%
Vancouver	Canada	3	T2+	23%	12%	22%	NA
Snohomish	US	1	T2+	25%–30%	Included in T2s	25%–30%	NA
Leeds	UK	9	T2+	+5%	Included in T2s	5%	20%
Trondheim	Norway	1.5	T2+	+4%	Included in T2s	4%	NA

While the evidence is very limited, the provision of special vehicle lanes on arterial routes appears to have raised the share of T2 and T3 traffic by a significant proportion. However, for the routes examined, there does not seem to be a particularly well-defined linkage between the level of time savings and the responses estimated by looking at changes in the shares by particular vehicle types.

Freeways

There is more information available on the reaction to the introduction of freeway-based schemes, although again the data available is limited and the picture that emerges does not provide a clear and consistent link between the size of the potential time savings and the switch to higher occupancy modes.

Figure 2.1 Freeways in Los Angeles County: changes in total travel times and changes in average vehicle occupancy with introduction of HOV lanes



The data does, however, suggest that while the determination of the exact details of the relationship is not easy, the introduction of special vehicle lanes on freeways has resulted in increases in the average vehicle occupancy (AVO). This is illustrated by examining the position for the freeways in Los Angeles County in about 2000 as set out in figure 2.1. The average positions for the AM and PM peak are highlighted.

For the AM peak the introduction of HOV lanes appears to have resulted in increases in average vehicle occupancy for almost all the schemes examined. For the PM peak the position is more mixed with some reductions, although this may possibly reflect different commuting patterns and greater variability in the departure times from work or other activities undertaken.

Ramp signal bypass lanes

The motorway ramp signalling system in Auckland also includes special vehicle bypass lanes that allow vehicles with two or more occupants, buses, trucks and motorcyclists. An evaluation of the priority lanes revealed only a small change in vehicle occupancy with travel time benefits ranging between two minutes and five minutes. This tends to suggest that the provision of HOV lanes over short lengths is less likely to influence traveller behaviour because the treatments are effectively spot treatments. However the freeway data suggests there is some relationship between the travel time benefit and the change in vehicle occupancy, as discussed below.

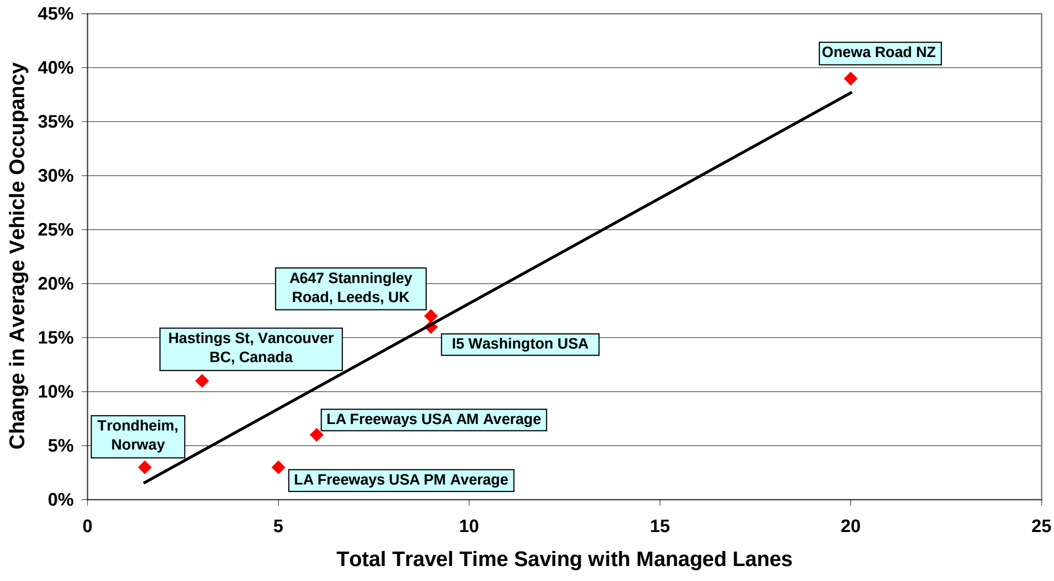
Relationship between vehicle occupancy and travel time saving

It is possible to summarise the results obtained from the various sources discussed above (see figure 2.2). This excludes the results for Snohomish County because of the particular characteristics of its scheme.

By pooling the data, a fairly strong relationship between travel time savings and modal response is achieved, although it should be recognised that this is subject to a considerable degree of uncertainty when applied to particular schemes and proposals.

Given the importance of this response in determining whether special vehicle lanes are likely to be successful, it is desirable that the existing very limited database be supplemented by further detailed data collection from schemes that are currently being implemented.

Figure 2.2 Relationship between average vehicle occupancy and travel time saving



Relevance of research

The standard definition of elasticity (or the measure of behavioural response) is the percentage change of one variable in response to a change in another. Conventional transport choice models relate to demand elasticities, which typically express savings in travel time in percentage terms. For example mode shift to public transport uses typical elasticities of -0.1 to -0.7 (ATC 2006) with a typical average of -0.4 with respect to in-vehicle time. The literature also suggests that long-run elasticities can be double to trip the short-run elasticities.

In the case of Onewa Road, the percentage change in vehicle occupancy is 40% with the percentage change in travel time undefined. From the data obtained from the Automobile Association website (http://maps.aa.co.nz/traffic/journeytimes), the ideal travel time (or uncongested time) is about five minutes, giving a time saving of 80%. Therefore the elasticity in vehicle occupancy is -0.5 with respect to travel time difference. This needs to be put into context in that the Onewa Road T3 lane has been in operation for 20 years and operates over 1.5km, resulting in a long-run elasticity for a long segment.

Data (Victoria Transport Policy Institute 2004) indicates elasticities in the order of 0.2 for an increase in car passengers with respect to fuel price increases, and a similar elasticity for public transport patronage with respect to fuel price. Most elasticity research for HOV lanes has recently been on the price-elasticity of high occupancy toll (HOT) lanes which shows a wide range of elasticities related to increased use of special vehicle lanes with respect to the price. The evaluation of the MnPass express lanes revealed a positive relationship between the toll price and usage (ranging between 0.03 and 0.85) indicating people were willing to pay a higher amount for a greater (perceived or actual) travel time saving.

The behavioural response to the implementation of transit lanes is an area that needs further research. Care must be taken when applying the elasticities in relation to the length of time being examined. The model developed as part of the research project uses a traditional elasticity, but initial versions of the model used the percentage behavioural response which resulted in a dynamic elasticity – and a much greater change over time in response to increased congestion. In the absence of further research, any elasticities in the model should not be greater than public transport elasticity. This is further discussed in section 3.6.1.

2.4.1.2 Effects on safety

There is limited literature on the relative safety of a special vehicle lane compared with that available for general traffic lanes. Bauer et al (2005) referred to research by Sullivan and Devadoss (1993, 49), Newman et al (1998, 18), Newman et al (1998, 23), Newman et al (1998, 18), Sullivan et al (1993, 51) and Boyle (1986, 10). This research indicated that a buffer separated special vehicle lane would not have any discernible difference on the crash rate, but that increases in congestion would exhibit a direct correlation with the crash rate. The latter point has a direct implication for situations where the conversion of a traffic lane is proposed, and where the special vehicle lane is quite narrow and would cause a loss in capacity.

Austroads (2005) contains data on bus-bike crashes. For Western Australia, there was an average of 12 bus-bike crashes per year (1.5% of total bicycle crashes) reported to police between 1987 and 1996 inclusive (Hendrie et al 1995, table A15). A bus was involved in 1.8% of reported bicycle crashes involving another road user (Hendrie et al 2006, table 2.4).

The conclusion in the Austroads (2005) document is that the lack of published data or studies on bus-bike crashes in bus lanes indicates that such crashes have not been identified as a significant issue. The widespread support for and acceptance of cyclist use of bus lanes is further evidence that cyclist safety has not been demonstrated, through practical experience, to be a problem.

Newcombe and Wilson (2010) report that the implementation of bus lanes had no discernible effect on the average crash rate of cyclists and motorcyclists using bus lanes; however, the proportion of mid-block crashes decreased while intersection crashes increased. This paper also considered a link between the bicycle crash rates and lane widths.

The *UK national cycling strategy* (DoT 1996) states there is a need to address traffic engineering, vehicle design and the education of drivers to reduce the disproportionate incidence of serious injuries and fatalities caused by crashes with heavy goods vehicles. Although the strategy does not mention buses specifically, the issues raised appear to be applicable to buses as well as heavy goods vehicles and could be more applicable to HOV lanes than bus lanes where driver education should be to a higher level.

The crash rates along several of Auckland's urban corridors were examined as part of this research to determine whether there was a significant difference between the safety records of corridors with and without special vehicle lanes. The crash rates presented in figures 2.3 to 2.6 have been represented as crashes per million vehicle kilometres travelled from 7am to 9am and 4pm to 6pm to align with the special vehicle lane operating times. The overall crash rates, and the rates for rear-end, crossing/turning and overtaking/lane changing crashes have all been evaluated for the period from 2006 to 2010.

The following corridors were examined as part of this research:

- Onewa Road – Birkenhead Avenue to Bruce Street (T3 lane 7am to 9am inbound and no special vehicle lane outbound)
- Constellation Drive – East Coast Road to SH1 (T2 lane 7am to 9am inbound and 4pm to 6pm outbound)
- Dominion Road – Mt Albert Road to View Road (bus lane 7am to 9am inbound and 4pm to 6pm outbound)
- Sandringham Road – Mt Albert Road to New North Road (bus lane 7am to 9am inbound and 4pm to 6pm outbound)
- Great South Road – Campbell Road to Broadway (bus lane 7am to 9am inbound and 4pm to 6pm outbound)
- Great North Road – Point Chevalier Road to Ponsonby Road (bus lane 7am to 9am inbound and 4pm to 6pm outbound)
- Manukau Road – Pah Road to Broadway (no special vehicle lanes)
- Rata Street/Ash Street/ Great North Road – Titirangi Road to SH16 (no special vehicle lanes)
- New North Road – Blockhouse Bay Road to Bond Street (no special vehicle lanes)

Figure 2.3 Comparison of overall crash rates

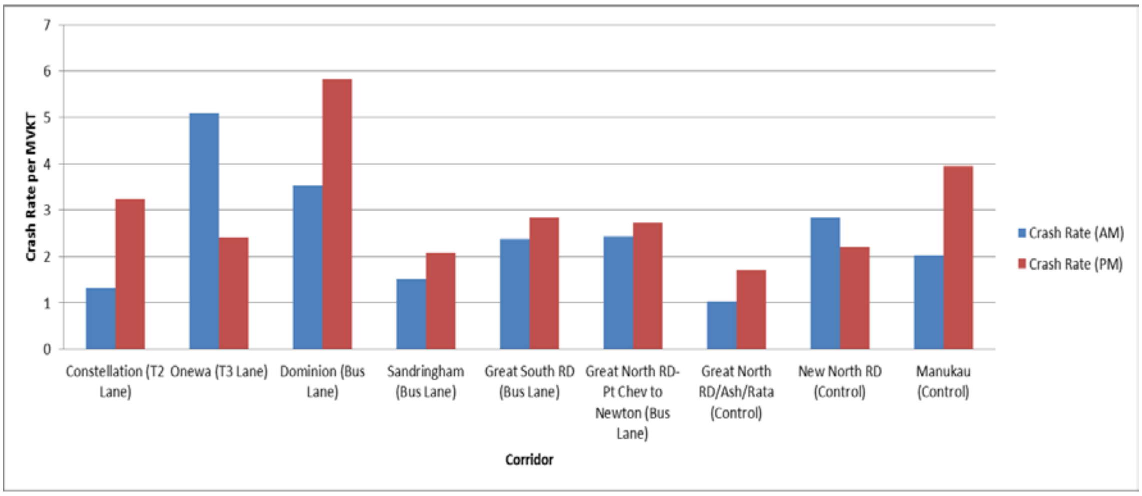


Figure 2.4 Comparison of rear-end crash rates

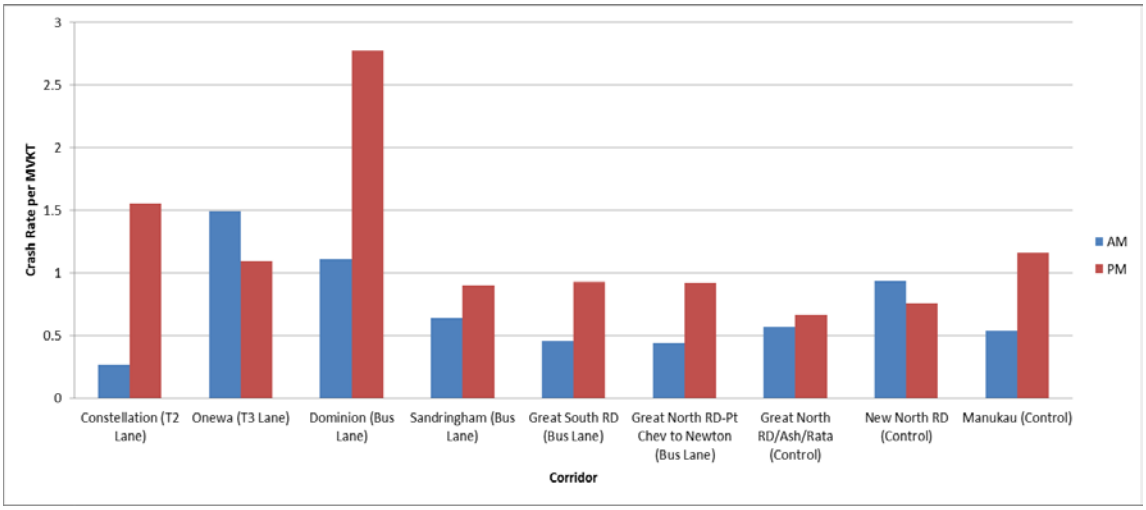


Figure 2.5 Comparison of overtaking/lane changing crash rates

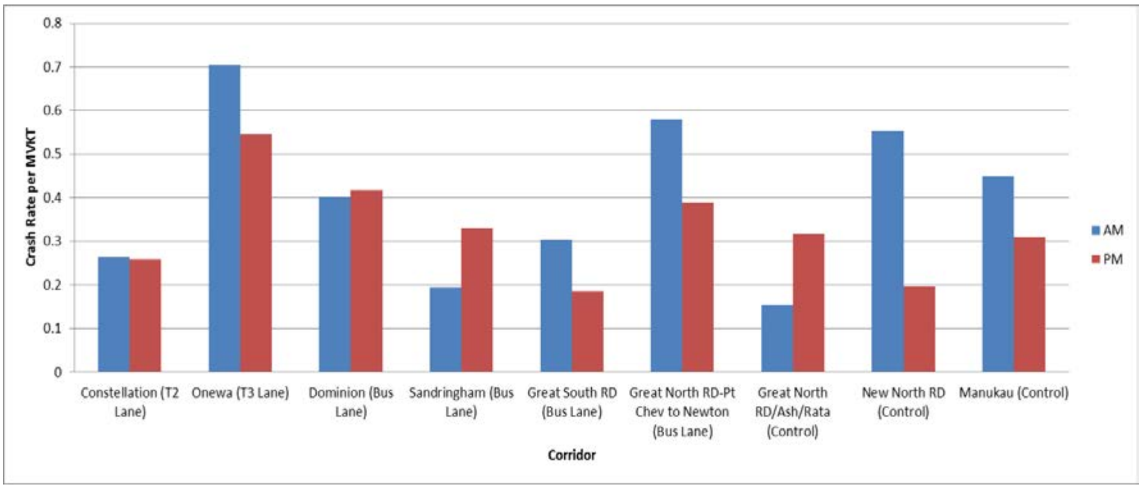
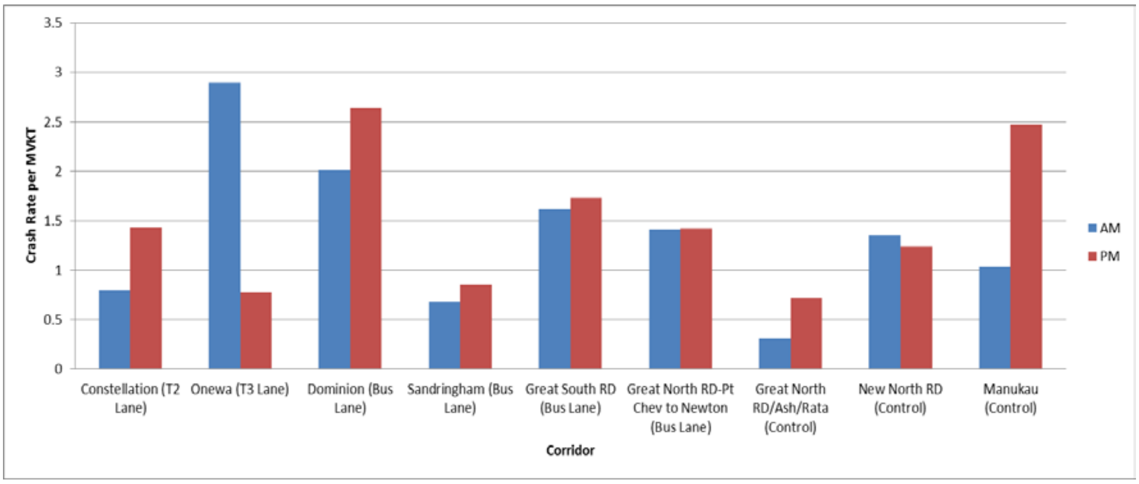


Figure 2.6 Comparison of crossing/turning crash rates



Analysis of the graphs indicates higher crash rates for specific corridors, ie Dominion Road, Onewa Road and Constellation Drive rather than a general difference between corridors with and those without special vehicle lanes. Further analysis would be required to determine whether there is a statistical difference. This would also need to consider expanding the sample size to improve confidence in the results.

While there is an opportunity to further develop the ability to forecast the crash rate to determine whether there are statistical differences between corridors with special vehicle lanes and those with only general traffic lanes, the underlying premise for the implementation of special vehicle lanes is that the crash rate (frequency, severity and type) should not increase as a result of implementing the special vehicle lane.

2.4.1.3 Effects on roadway capacity

The introduction of special vehicle lanes potentially impacts on the operational characteristics of the road as it divides the road space available into separate lanes for special vehicle lane traffic and for general purpose traffic. Differential speeds across the lanes may create side friction in a similar manner to a carriageway with narrow lanes and/or narrow shoulders in reducing capacity and increasing the rate of reduction in speeds with higher traffic flows, therefore giving speed flow curves per lane that are different from those when the traffic can use all available lanes.

Evidence available from overseas

Despite the theoretical basis for the change in operational characteristics, there is very little detailed evidence available on how special vehicle lanes function and their impact on overall highway capacity and performance. What information is available tends to be at a very general level, comparing the observed speeds on special vehicle lanes with general traffic lanes or ensuring the HOV lane achieves a particular target speed (eg PBQD 2004). Typically the introduction of HOV lanes leads to higher speeds for HOVs because the special vehicle lanes carry lower vehicle flows (although higher passenger flows) than if they were available to general traffic. The introduction may also lead to increases in the speeds for general traffic lanes if there is a substantial diversion to HOVs and a reduction in the volumes of traffic remaining on the general traffic lanes. This appears to have been the case for the special vehicle lane along Onewa Road, an arterial route in North Shore City, Auckland (Murray 2003).

However, such a finding may mask any change in the operational characteristics of special vehicle lanes and general traffic lanes. Theory would suggest that dividing the road space available in a particular direction into two separate carriageways for different traffic types would result in some loss of capacity.

The review of the existing literature revealed only two papers which provided detailed comments on the operational characteristics of HOV lanes, both relating to freeway performance in San Francisco. Varaiya (2005) and Kwon and Varaiya (2005) have a common author and the two papers although using slightly different data do have common themes. The conclusion from these papers is that the capacity of a special vehicle lane is approximately 20% less than that of a general traffic lane in a multi-lane road. Introducing special vehicle lanes therefore leads to a loss of vehicular capacity on the route.

Less detailed information is also available from Washington State that confirms this general finding (Nee et al 2002). While not reported in detail, Austroads (2007a) also quotes studies that have found the introduction of HOV lanes could reduce vehicle capacity by between 4% and 7% for five- and three- lane facilities and presumably more for narrower roads.

It does need to be emphasised that this information relates to the introduction of special vehicle lanes on freeways. There appears to have been little or no analysis of the position for arterial routes, for which the measurement of speeds and flows may be more difficult.

Analysis of New Zealand data

Prior to this present study, there was also no information available on New Zealand experience of the capacity effects of introducing special vehicle lanes. However subsequently a review of the position along Onewa Road in the North Shore was undertaken as part of the current research and the findings published in a paper presented at the 2010 IPENZ Conference (Paling and Brown 2010).

This was based on a detailed analysis of automatic traffic count data for Onewa Road, which included flows and speeds for the section of Onewa Road with the special vehicle lane. The data was analysed for the eastbound flows to examine the extent to which the implementation of the special vehicle lane (lane 1) over the morning peak period appeared to affect both its performance and that of the other eastbound lane (lane 2).

The findings from this analysis were that the implementation of a special vehicle lane did lead to some loss of capacity in both the managed and general purpose lanes. In lane 1 (the special vehicle lane) this led to both a reduction in speed and an increase in the extent to which speeds declined with increased traffic flows, and in lane 2 (the general purpose lane) to a reduction in the average speed.

Using the regression equations developed for lane 1, at a flow of 60 vehicles per 15 minutes (240 per hour), the estimated speed would be 43.7km/h as a managed HOV lane or 51.9km/h as a general traffic lane, suggesting a fall in performance of about 15%. For lane 2 at a typical flow of 150 vehicles per 15 minutes (600 per hour) the estimated speeds would be 45.4 when lane 1 was operated as an HOV lane and 49.1 when both were operated as general traffic lanes, suggesting a loss of performance of about 8%. While it is difficult to make exact comparisons these figures appear to be broadly consistent with those quoted from studies elsewhere.

Relevance for research

Although the available data is very limited, the evidence from the US and Australia on special vehicle lanes on freeways and from New Zealand on special vehicle lanes on arterial roads suggests that the introduction of special vehicle lanes, by dividing the carriageway into separate parts results in some reduction in the operational performance of the special vehicle lane. In the case of Onewa Road, the performance of the adjacent general traffic lane also appears to be affected.

To account for the potential loss in capacity and increased rate of reduction in speed under higher flows, the analytical model developed allows the user to specify the increase in ‘side-friction’ considered appropriate.

2.4.1.4 Compliance and enforcement

In New Zealand, the use of a special vehicle lane is governed by the Land Transport (Road User) Rule 2004 (see section 2.1.2), which restricts the use to eligible classes of vehicle and vehicles with more than the number of occupants specified on the signs for a transit lane. This Rule also allows for traffic turning from the roadway to enter the special vehicle lane 50m in advance of the side road. It is illegal for road users to park or stop in special vehicle lanes.

The benefits of providing a special vehicle lane are primarily underpinned by the compliance of the lane. Compliance relies on the combination of drivers’ understanding of the special vehicle lane requirements, the legibility of the design, and enforcement. Illegal users of special vehicle lanes compromise the performance and objectives of the lane, and its benefits could be negated if the illegal use becomes significant.

Enforcement can be effective in two ways:

1. Enforcement by the road controlling authority or Police
2. Self-enforcement through a legible design and education for the travelling public.

Enforcement of the special vehicle lanes in New Zealand is delegated to the road controlling authority, with the exception of state highways, which is undertaken by Police. In Auckland, this activity is undertaken manually with the use of video cameras detecting illegal use of special vehicle lanes, and the enforcement of the ramp signal priority lanes is undertaken by the Police in the enforcement bays provided. In both cases, the enforcement does not impact on the operation of the special vehicle lane.

In practice, the enforcement of transit lanes is more difficult than enforcing bus lanes manually as there is no physical difference in the class of vehicle allowed to use a T2 transit lane or T3 transit lane. The FHWA operational manual (US DoT 1994) identified that difficulties could arise in the following cases:

- monitoring vehicle occupancy in darkness
- observation of vehicles travelling at high speed
- use of tinted windows in vehicles
- difficulty of detecting small passengers/children
- use of ‘dummies’ or false passengers
- lack of enforcement facilities
- lack of enforcement effort
- inappropriate fine structure.

An additional difficulty with enforcing transit lanes on arterial roads is their position on the left-hand kerbside, because the road rules allow for general traffic to use the special vehicle for a length of 50m under certain conditions specified in the Rule (ie to enter or leave the road) as referred to in Austroads (2012) outlining the VicRoads experience.

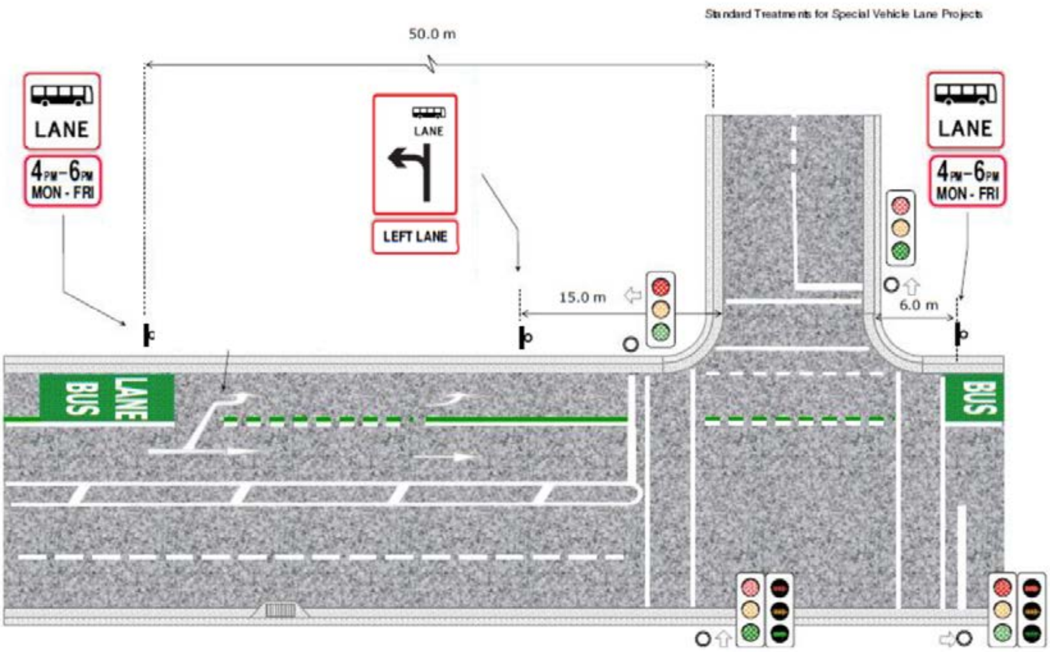
As such, the potential for illegal use is more often higher for transit lanes than for bus lanes. This was found to be the case in Sydney where illegal use of the transit lanes was as high as 75% as presented in figure 2.7. It also shows the general trend of growing illegal usage through a reduction in vehicle occupancy in the transit lanes.

Figure 2.7 Vehicle occupancy for transit lanes in Sydney (Austroads 2007a)

Route	Average vehicle occupancy in transit lane (1992)	Average vehicle occupancy in transit lane (2006)	Illegal usage (2006)
Victoria Road (T3)	1.83	1.59	63%
Military Road (T3)	2.66	2.25	35%
Great Western Highway (T2)	Not supplied	1.55	60%
Epping Road (T3)	1.90	1.50	75%

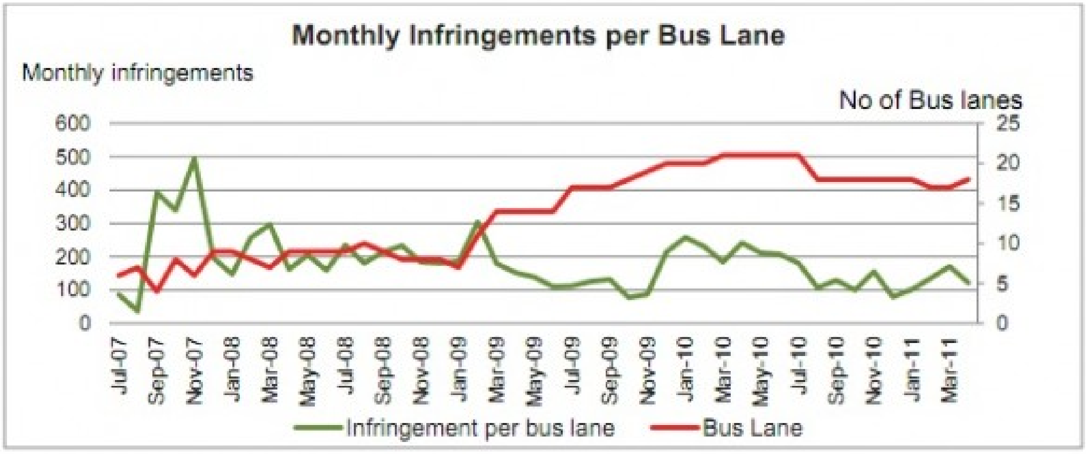
Auckland Transport has been subject to criticism (Dickison 2010) for its enforcement of the special vehicle lanes. The major criticism was that it was not possible for motorists to identify the point at which they could legally enter the special vehicle lane to execute a turning movement. This led Auckland Transport to draw on Australian and UK experience to develop signs and markings that would ensure the lanes were self-enforcing, and remove confusion around the point of entry. These signs and markings (shown in figure 2.8) are now being implemented across the network.

Figure 2.8 Bus lane markings in Auckland (Auckland Transport 2011)



Auckland Transport also undertakes regular enforcement and compliance surveys to ensure that the effectiveness of the special vehicle lanes is being maintained. In 2011, the compliance levels for bus lanes were around 97% and the enforcement regime was adjusted to target those bus lanes with compliance levels lower than 90% (Auckland Transport 2011). Their reporting also indicated a reduction in infringements per bus lane indicating a fairly stable trend in the infringement notices issued (refer to figure 2.9).

Figure 2.9 Bus lane infringements relative to bus lanes



2.4.1.5 Relevance for research

The effectiveness of special vehicle lanes on the corridor performance is affected by the level of illegal usage. When considering the performance (pre-implementation), specifying the level of illegal use provides the opportunity to account for expected driver behaviour, rather than the ideal (fully compliant) driver behaviour. The model developed as part of this research project allows for the user to input the level of illegal use expected in the special vehicle lane, as a function of the total special vehicle lane volume.

2.4.1.6 Effectiveness case study 1: Vancouver, Washington State

At a more specific level for the evaluation of an HOV lane pilot project in Vancouver in Washington State a detailed list of objectives was defined by the State Department of Transportation (Parsons Brinckerhoff 2004). These comprised:

- Goal 1. Move more people per lane in the Vancouver HOV lane during the AM two-hour period than in either of the adjacent general-purpose lanes.
- Goal 2. Reduce peak period travel time for HOV lane users and reduce the average per-person travel time for all users.
- Goal 3. Minimise impacts to other traffic in the corridor and on parallel facilities.
- Goal 4. Increase the use of carpools, vanpools, and transit.
- Goal 5. Maintain safety by not increasing the accident and incident rate in the corridor during HOV lane operating periods.
- Goal 6. Maintain the HOV lane's effectiveness with appropriate enforcement.
- Goal 7. Maintain or improve travel time reliability for carpools, vanpools, and transit.
- Goal 8. Maintain or improve public opinion as to the effectiveness of HOV lanes (PBQD 2004).

The extent to which these goals were achieved was assessed in a set of detailed evaluation reports on observed conditions during the period 2001 to 2004. Evaluation report #6 (PBQD 2004) noted that 'The pilot project is meeting Goals 1, 3, 4, 5, 6, and 7. This is the first time the pilot project has met Goal 1 (note that the HOV lane meets the 2-hour goal, but is still carrying fewer people than either adjacent general purpose lane during the peak hour). Goal 2 contains two components. The pilot project is meeting one of the two components. No recent data has been collected to determine whether Goal 8 is being met'. Critically the component of Goal 2 which was not met was the impact on travel times for all users.

2.4.1.7 Effectiveness case study 2: Caltrans

California Department of Transportation (Caltrans) defined the goal of HOV lanes more specifically as follows:

- Increase the people-moving capacity of the freeway system.
- Reduce overall vehicular congestion and motorist delay by encouraging greater HOV use through carpooling.
- Provide time and commute cost savings to the users of HOV lanes.
- Increase overall efficiency of the system by allowing HOVs to bypass congestion on lanes designed for their use.
- Improve air quality by decreasing vehicular emissions.

However, not all of these are easy to measure and a review of the effectiveness of the HOV lanes which had been established indicated that the impacts of these on carpooling or air quality was unknown (Legislative Analyst's Office California 2000). The challenge of developing an effective suite of objectives lies in the ability to measure the impacts and attribute the results to the implementation of the special vehicle lane.

2.4.1.8 Effectiveness case study 3: Washington State

In Washington State, the 1992 Washington State Freeway HOV system policy report (University of Washington 2010a) gave the objectives of the HOV facilities in the state as threefold:

1 Improve the capability of congested freeway corridors to move more people by increasing the number of people per vehicle.

2 Provide travel time savings and a more reliable trip time to high occupancy vehicles that use the facilities.

3 Provide safe travel options for high occupancy vehicles without unduly affecting the safety of freeway general-purpose mainline.

To help assess the impacts on HOV users standards for speed and reliability were established. These state that any HOV facility 'should maintain or exceed an average speed of 45mph or greater at least 90 percent of the time' during the peak hour. To evaluate the system's effectiveness accurately, the policy also requires an annual HOV system report to document the ongoing impacts of the HOV programme.

In response to this requirement, Washington State Department of Transportation publishes a range of data on the observed characteristics of HOV lanes and the adjacent general traffic lanes (University of Washington 2010b). These include:

- Traffic volumes and person throughput in HOV and general traffic lanes and along the corridor (figure 2.10 provides an example of HOV lanes accounting for 38% to 44% of the persons carried in 18% to 21% of the vehicles).
- Travel times in each lane (figure 2.11 provides an example comparing travel times for users of the HOV and general purpose lanes and indicates the savings achieved by HOV lane users).
- Duration of congestion in HOV and general traffic lanes (figures 2.12 and 2.13 provide examples showing the much higher levels of flow and frequency of congestion for the general traffic lanes compared with the HOV lanes).

Figure 2.10 Example of vehicle and person throughput for HOV traffic in Washington State 2007

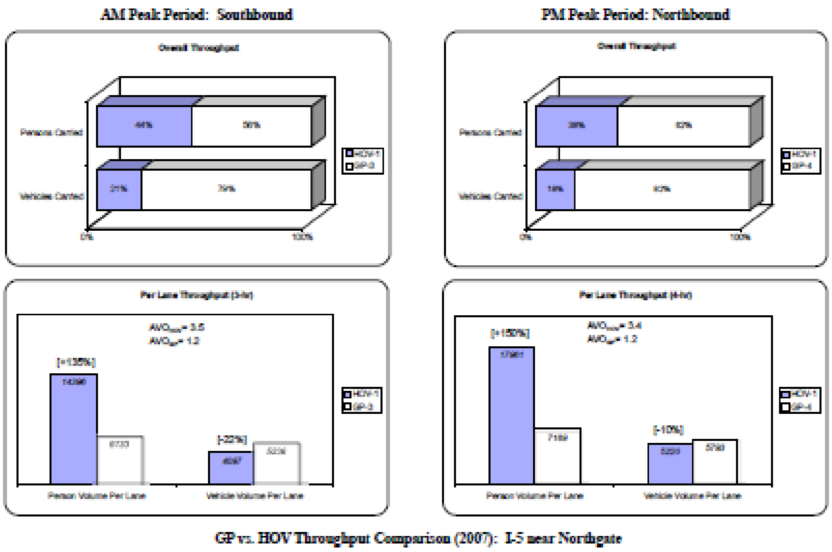


Figure 2.11 Example of travel time savings for HOV traffic in Washington State 2007

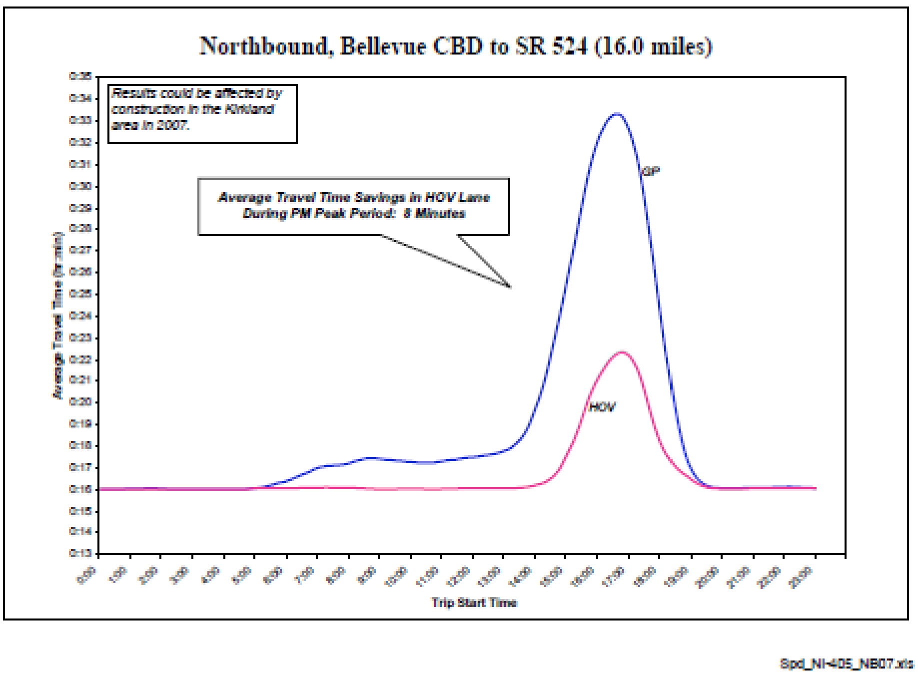


Figure 2.12 Example of speed and congestion measurement (general traffic lanes)

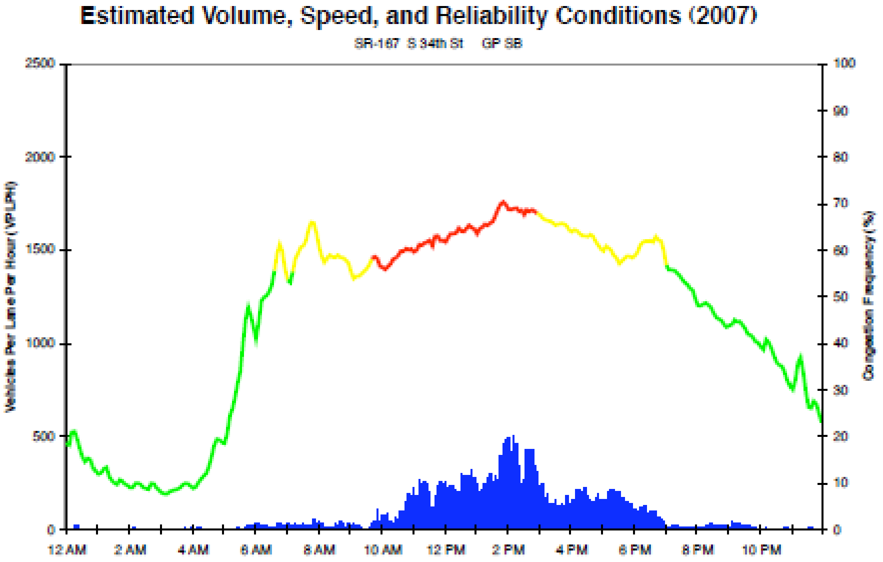
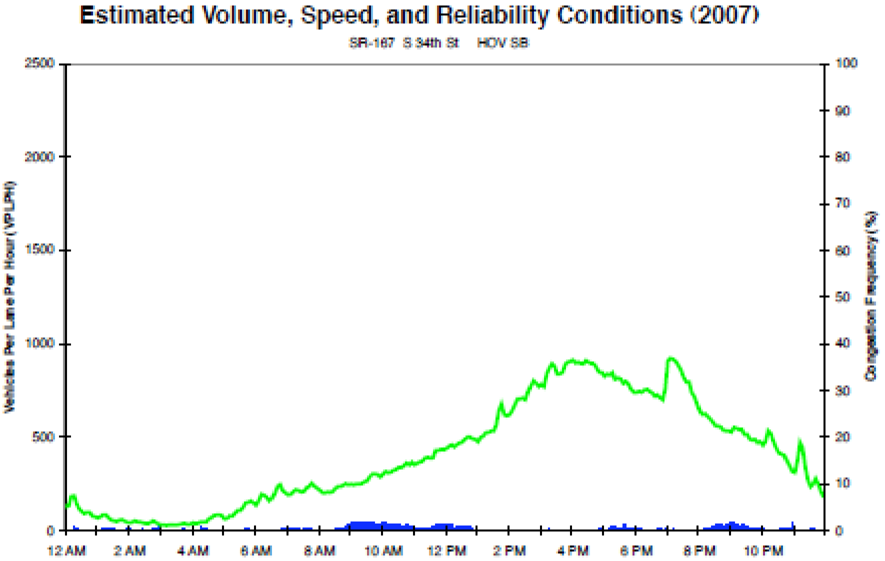


Figure 2.13 Example of speed and congestion measurement (HOV lane)



The earlier objectives have now been refined to comprise a rather broader set of goals:

- To maximise the people-carrying capacity of the freeway system by providing incentives to use buses, vanpools and carpools.
- To provide capacity for future travel growth.
- To help reduce transportation-related pollution and dependency on fossil fuels.[1]

[1] Washington State Freeway HOV system: www.wsdot.wa.gov/HOV/Policy.htm

2.4.1.9 Relevance for research

Goals and measured benefits relating to specific lanes or users do not normally indicate whether their use provides:

- overall benefits to the users within the corridor, or
- overall benefits where the general traffic is able to use the full range of capacity on the highway network.

As a result, there is a degree of debate as to whether satisfying these objectives is sufficient to justify the implementation or continuation of special vehicle lanes as for example in the material issued by the Urban Transport Organisation (Mallinckrodt 2003).

While the performance of the HOV lanes appears to be good, the impact of their introduction on the rest of the traffic flow both along the road affected and in the wider corridor is typically not taken into account and may well be negative. In part this reflects the difficulty of establishing the effects of introducing HOV lanes in a changing traffic environment, especially as the behavioural effects are likely to take some time to emerge. This highlights the importance of an assessment for all users as the lack of a comprehensive case for the implementation of HOV lanes has made the lanes vulnerable to political pressure for their removal, as evidenced in a number of schemes in the USA.

2.4.2 Other measures of effectiveness

2.4.2.1 Economic efficiency

The success of special vehicle lanes can be measured using cost-benefit analysis assessing the changes in travel times for users and any changes in vehicle operating costs along the corridor and balancing these against the costs of providing and operating the special vehicle lanes. However, this approach has been used only very rarely and a range of less comprehensive measures have been developed based on particular observed travel characteristics for traffic in the special vehicle lane or less frequently for the route in general. It is also of note that in general these criteria have been developed for the introduction of special vehicle lanes on freeways and less attention seems to have been paid to the specific performance characteristics of special vehicle lanes on arterial routes.

One example where a more comprehensive cost-benefit analysis was undertaken and the results published was in a KBR (2004) study for the UK Highways Agency. This considered the operation of HOV lanes on a number of motorway sections in the UK. The analysis assumed a standard behavioural response based on experience from overseas (largely reflecting that described in the previous section), but not reflecting the particular characteristics of the schemes being proposed in terms of the potential time savings that might be achieved. On this basis the analysis initially assumed for its central case a 10% reduction in traffic as drivers switched to HOVs, but in subsequent analysis this was reduced to 5% to ensure the HOV lanes did not become more congested than those used by single-occupant vehicles (SOVs). In addition the analysis did not take into account any differences in the operational characteristics of different types of special vehicle lanes.

Substantial benefits from the introduction of HOV routes on motorway routes were identified, especially where these had been added as additional lanes, mainly reflecting the reductions in traffic flows as a result of the behavioural response. However, because of safety concerns no schemes have been implemented.

2.4.2.2 Productivity

Corridor productivity is the measure of the corridor's ability to move people and freight efficiently along a roadway. Corridor productivity is measured in terms of the product of speed and volume compared to road lane optimal vehicle throughput. It demonstrates how effectively the current road network and operational management activities handle peak demand for vehicle movement.

Austroads (2007b) advises that the maximum productivity can be normalised to 31,500 passenger car units-kilometres per hour (pcu-km/h) for an arterial road and 160,000 pcu-km/h for a motorway. Using the Akcelik speed-flow functions, the productivity curves for an urban arterial and motorway have been re-created in figures 2.14 and 2.15. These show that the maximum productivity for a corridor with general traffic lanes is achieved when the volume-capacity ratio is in the order of 80% to 85%. These curves can also be created from actual data such as loop detector data that provides counts, speeds and/or occupancies, and can be developed for individual corridors taking into account the layout and intersection controls.

Figure 2.14 Productivity curve for an urban arterial (900 pcu per hour capacity with a 50km/h speed limit)

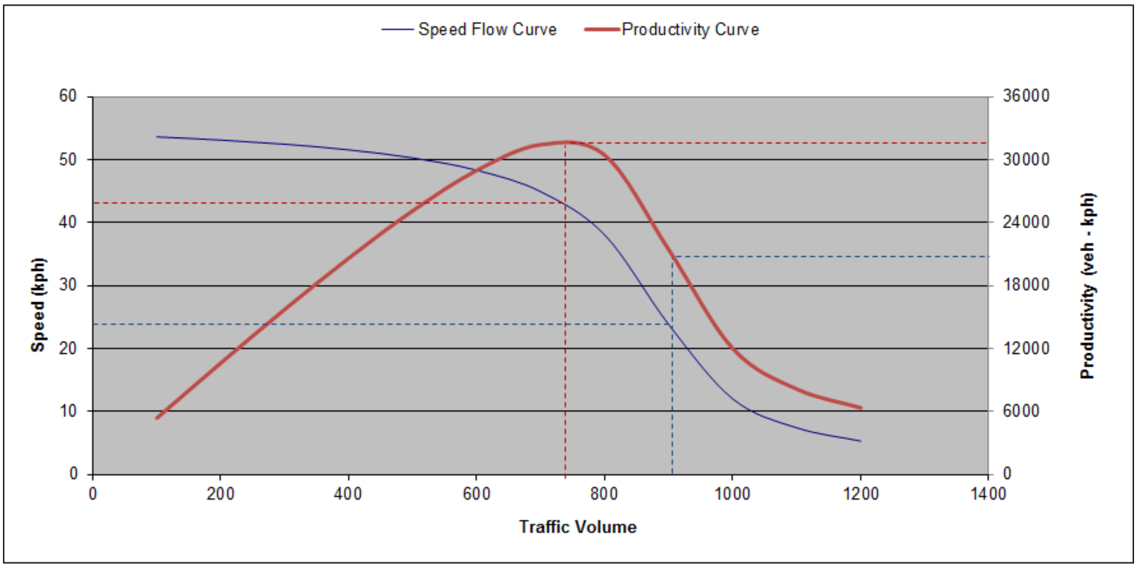
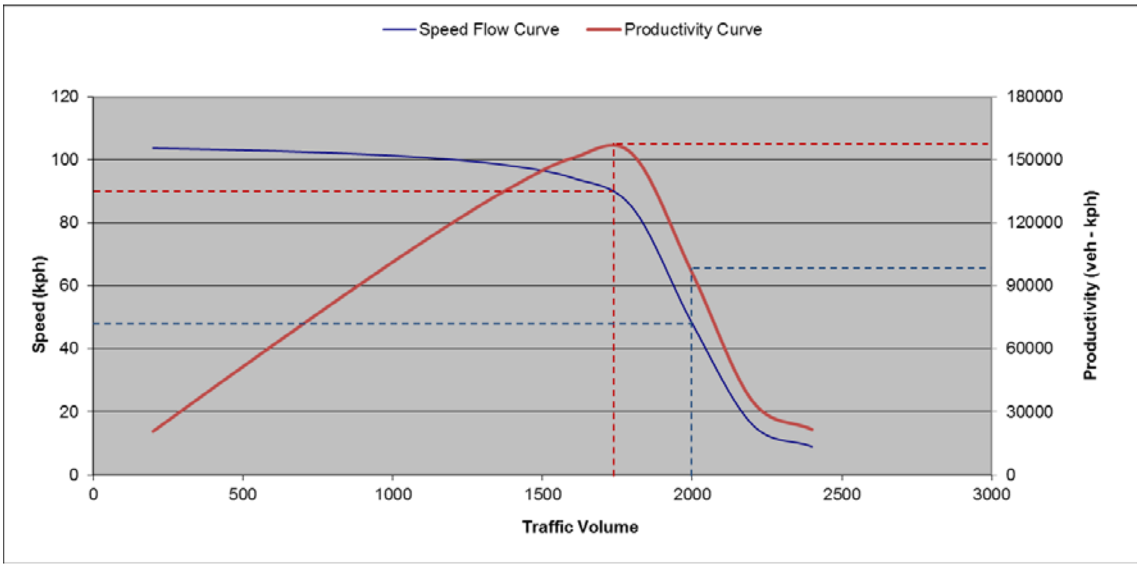


Figure 2.15 Productivity curve for a motorway (2000 pcu per hour capacity with a 100km/h speed limit)



The productivity of the network is a holistic measure in that it is a measure of both demand and capacity, and uses the travel time-related criteria as an input into the measure. The challenge is being able to compare the productivity of a corridor with special vehicle lanes and a corridor with general traffic lanes. For example, a bus lane or transit lane may be able to move people more efficiently than a general traffic lane. Another example is where a truck lane can carry a higher value of travel (in terms of travel times) than a general traffic lane.

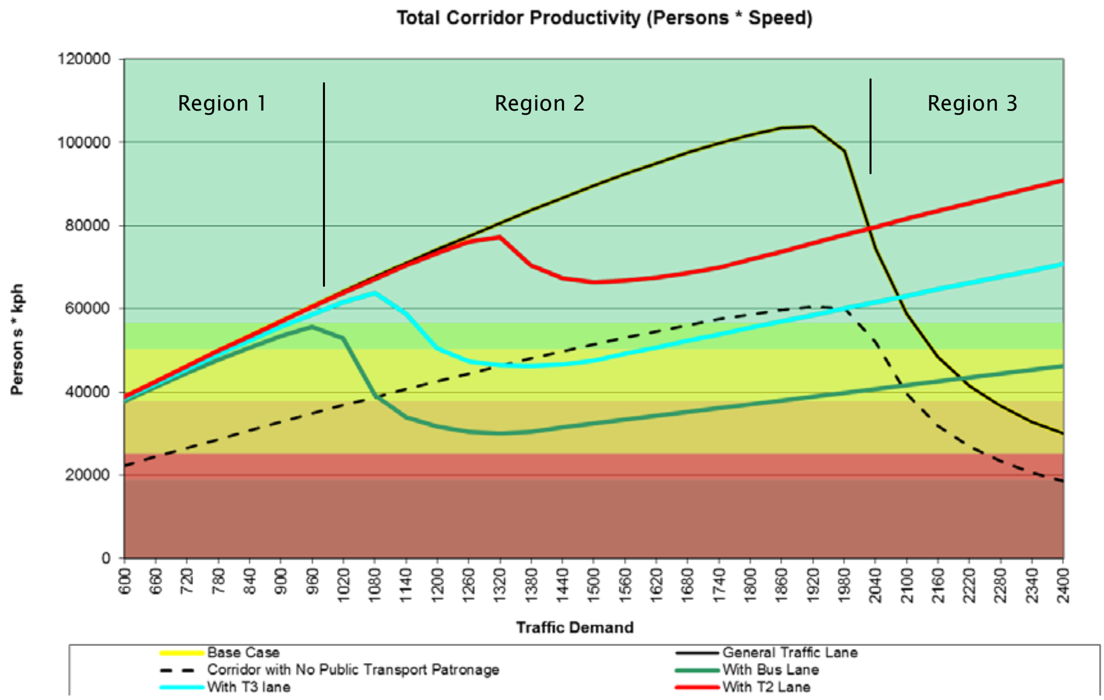
Therefore the productivity measure needs to be weighted to account for the movement of people and freight, not the movement of vehicles. The productivity of the corridor can therefore be represented:

- in absolute terms as the product of speed and person volume (where trucks will not be permitted to use the special vehicle lane), or
- as monetised values taking into account the values of time for different road users (an extremely important measure when considering the economic productivity of the network), or
- in relative terms measured against the benchmark productivity for general vehicles.

Figure 2.16 provides an example of the corridor productivity for general traffic lanes and special vehicles lanes using the analytical tool developed for this research with the following scenario:

- 1km long corridor with two lanes in the direction of travel
- one signalised intersection with 120 second cycle time and 50% green time for the through movement (replicating a capacity of 900 passenger cars per hour per lane)
- 25% public transport, 10% of traffic with three or more occupants, 25% of traffic with two or more occupants and 0% turning traffic
- no mode shift or increase in vehicle occupancy.

Figure 2.16 Example of corridor productivity (persons) where freight is excluded from the special vehicle lane



The black dashed line indicates the corridor productivity with no public transport patronage, highlighting the benefits of public transport patronage on the corridor performance irrespective of the arrangement. The peak of this curve is consistent with the Austroads thresholds. The colour bands represent level of service A through to E/F based on the percentage of productivity relative to the Austroads thresholds.

The bottom of each curve represents the point at which the general traffic lane adjacent to the special vehicle lane becomes so congested no additional traffic volume can be accommodated (in this case it was set at 5km/h – travel on Auckland's worst performing arterials is in the order of 10km/h).

Figure 2.16 demonstrates three different scenarios that could occur when a general traffic lane is converted to a special vehicle lane:

1. Region 1: To the left of the peaks of the curves: uncongested corridor allowing for the implementation of a special vehicle lane without generating significant congestion in the general traffic lanes.
2. Region 2: Between a peak in productivity of the special vehicle lane corridors and a decline in the general traffic corridor. The implementation will be influenced by the ability to meet warrants and the policy direction to accept a drop in productivity in the shorter term until eligibility (either increased vehicle occupancy or growth in public transport patronage) sees the corridor productivity return to pre-special vehicle lane conditions or where the performance with a special vehicle lane is better than the corridor with general traffic lanes only.
3. Region 3: Once the corridor without special vehicle lanes becomes congested, the implementation of a special vehicle lane will improve the productivity of the overall corridor; however, this needs to be offset against the ability of other routes to accommodate displaced traffic if a large enough mode shift or increase in vehicle occupancy is not realised.

Perhaps the critical element in this diagram is the forecasting of future corridor performance to determine whether the corridors without special vehicle lanes are likely to be heavily congested. If this is achieved, there is the potential for early intervention to avoid larger scale impacts. A similar approach can be taken when adding capacity in that the forecast congestion for corridors with general traffic lanes should influence the decision process to implement the additional capacity.

The same philosophies can be applied to special vehicle lanes that allow trucks. Figure 2.17 provides the same example as in figure 2.16, but this time including a 20% proportion of trucks. In this case, the proportion of traffic eligible for a T2/truck lane is greater than 50% of the total traffic volume, therefore this is plotted as being the same as a general traffic lane as there are no travel time benefits in implementing a special vehicle lane.

Figure 2.17 Example of corridor productivity (monetised) where freight is included in the special vehicle lane

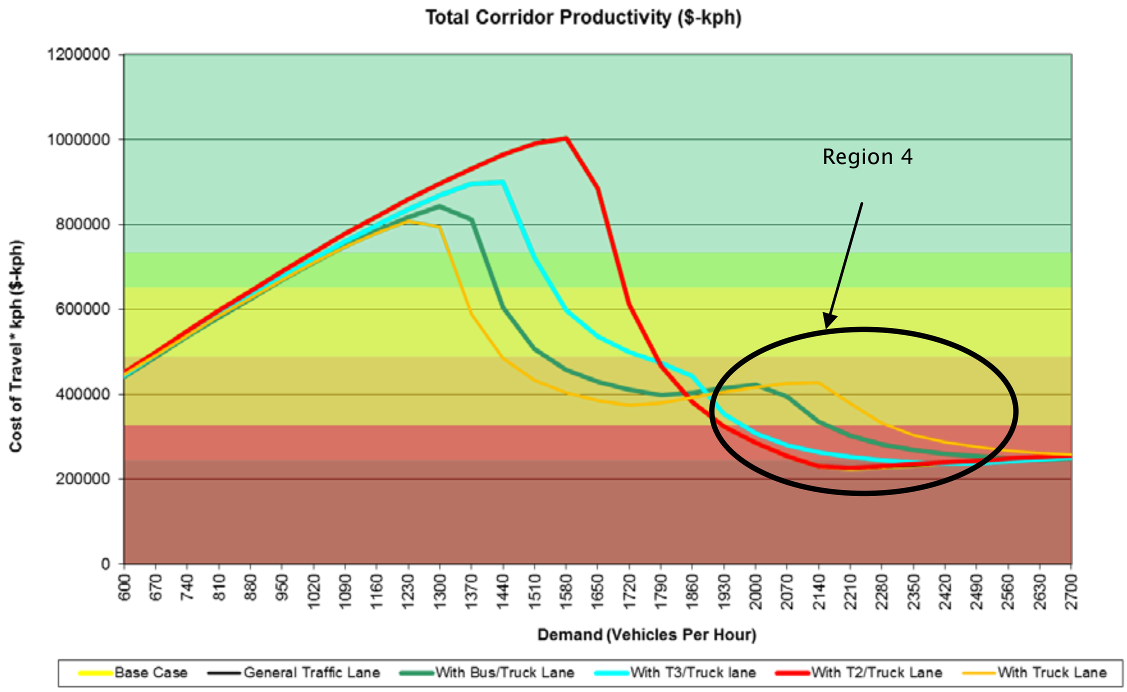


Figure 2.17 again leads to a similar conclusion that, by monetising the cost of travel, corridors with special vehicle lanes can be more efficient than a corridor with congested general traffic lanes. As with the previous example, if congestion caused by non-eligible vehicles entering the special vehicle lane is a key consideration for the road controlling authority, then expanding the level of eligibility is a more likely outcome.

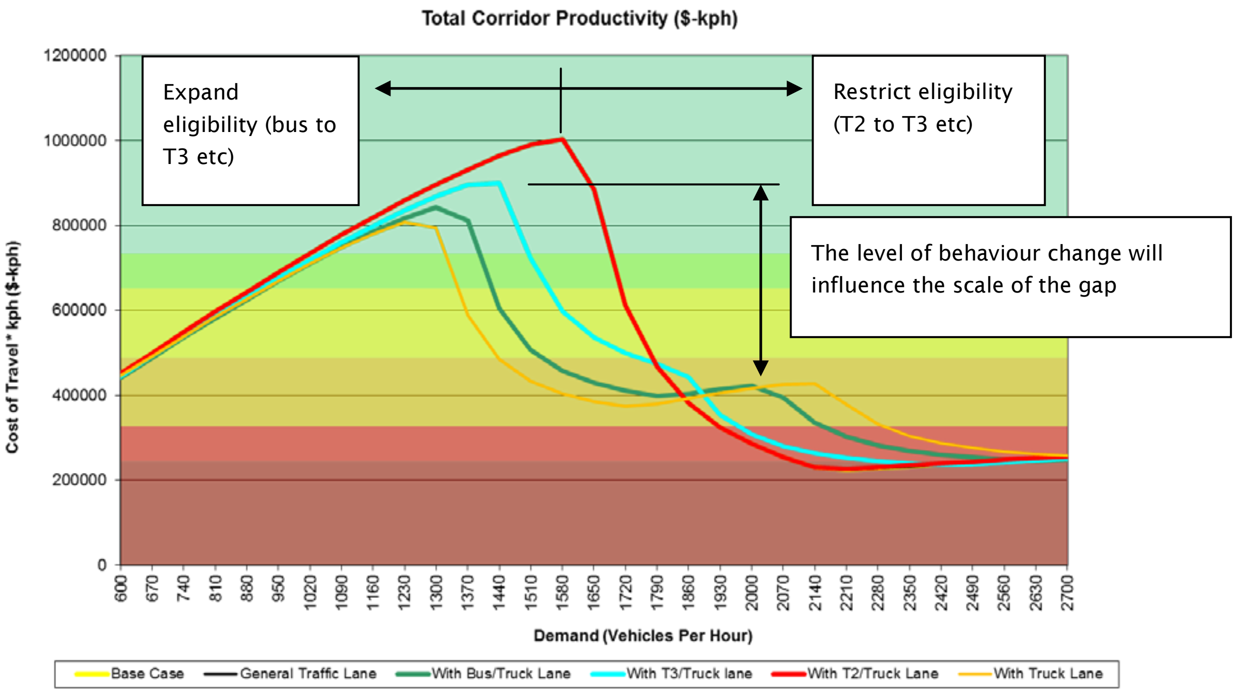
However in figure 2.17 it can be seen the level of eligibility for using the special vehicle lanes is already sufficiently high to cause congestion, as demonstrated by the drop in productivity at the upper end of the traffic demand range (noted in region 4).

This example demonstrates that once the special vehicle lane becomes congested, permission to use it should be further restricted (ie move from T2 to T3 or T3 to bus and/or truck). Once this process has been exhausted, capacity improvements (either physical or through dynamic management) must be considered in order to improve the productivity of the corridor, as there is no time advantage and therefore priority afforded, to eligible users of the special vehicle lane.

Using the example of corridor productivity in monetised terms, the implementation sequence for special vehicle lanes can be considered relative to the peak corridor productivity:

- In adding a lane – the eligibility should be progressively released to have the greatest potential for mode shift or increase in vehicle occupancy, in order to minimise the ‘loss’ in productivity if the need to convert increases the level of eligibility.
- In converting a lane once productivity starts to decline – progressively expand the eligibility to enter the special vehicle lane to minimise the impact on the remainder of the network.

Figure 2.18 Example of corridor productivity (monetised) considering progressive implementation



In planning for special vehicle lanes, a balance may be needed between managing congestion by expanding eligibility and restricting eligibility when the special vehicle lane becomes congested. The aim should be to minimise this gap between the peak productivity prior to the general traffic lane becoming congested and the peak productivity prior to the special vehicle lane becoming congested. It is the level of behaviour change that will influence this gap.

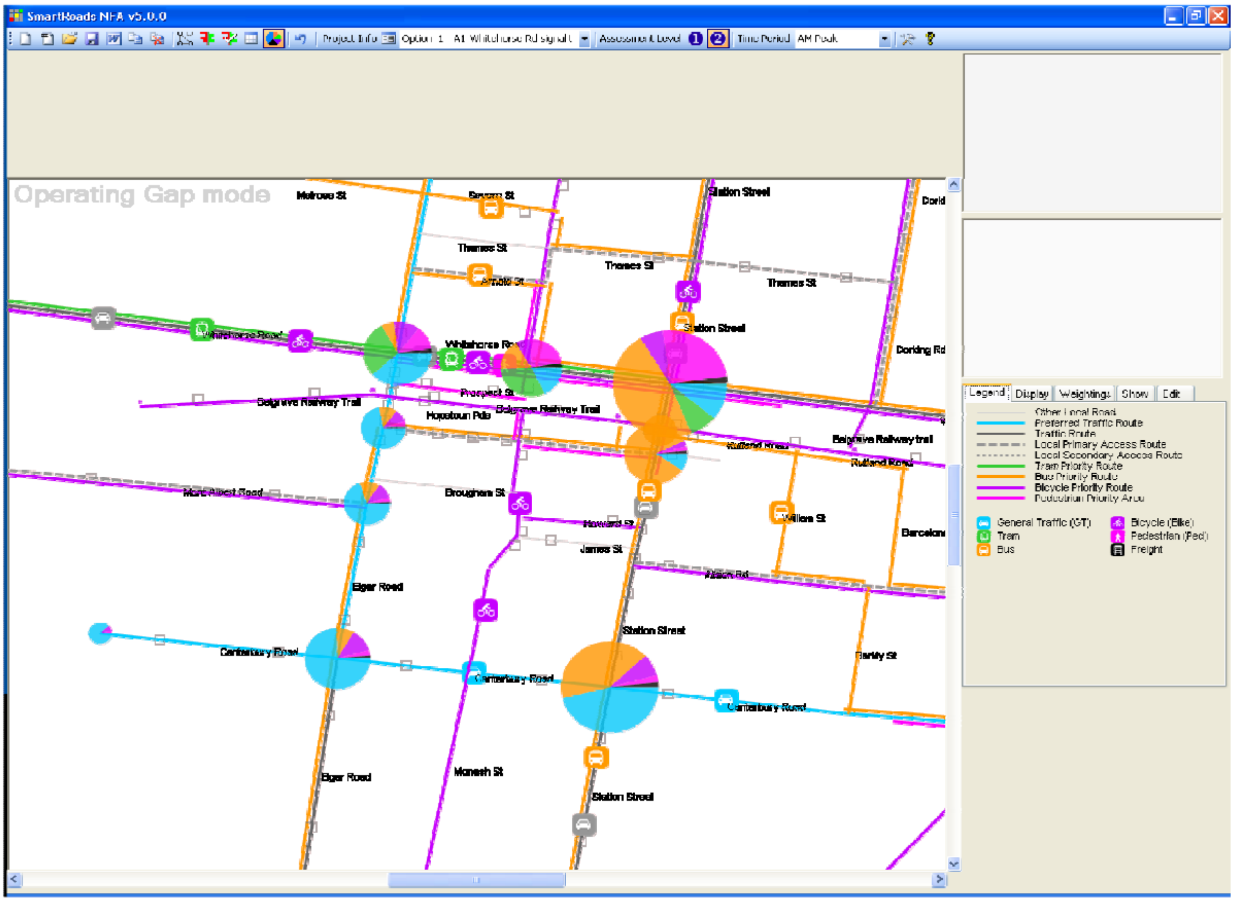
2.4.2.3 SMARTROADS network operating gap

The network operating gap is a measure of effectiveness developed by VicRoads to assess the performance of the network and to assess network improvement projects to determine whether there will be an overall benefit to the efficiency of the network. The network operating gap represents the gap between the observed level of service and the ideal level of service (free flow conditions). It combines the importance of the road for particular users (in the road use hierarchy), the level of service for each user group, the relative efficiency compared with a motorway traffic lane and the cost of travel.

The network fit assessment tool developed by VicRoads presents the network operating gaps as a simple scale that can be used to identify problems and to test proposed treatments, an example of which is provided in figure 2.19.

This measure is also a holistic measure considering all modes of travel; however, it does not consider HOVs (those eligible to use a transit lane) as a specific mode. HOVs would need to be specified as a separately to measure the effectiveness of a transit lane.

Figure 2.19 SMARTROADS operating gap (source: VicRoads 2012)



Source: VicRoads. More information on SMARTROADS and the network operating gap can be found at www.vicroads.vic.gov.au/Home/TrafficAndRoadConditions/HowWeManageTraffic/Smartroads/

2.4.3 Recommended measures of effectiveness

The ability to develop a framework to measure the effectiveness of special vehicle lanes is as critical to their planning as it is to their monitoring. The challenge of developing an effective evaluation framework lies in the ability to:

- measure the objectives (or goals)
- attribute the performance to the implementation of the special vehicle lane
- demonstrate overall benefits to the corridor users
- demonstrate there are more benefits (short or long term) compared with general traffic lanes.

The recommended evaluation criteria link the objectives with those that can be easily measured or predicted. The recommended criteria are provided in table 2.4.

Table 2.4 Recommended evaluation criteria

Policy framework	Suggested special vehicle lane objectives	Recommended measures of effectiveness
• Extract maximum benefit from transport investment – existing and proposed. • Develop more transport mode choices. • Reduce adverse social and environmental effects from transport. • Better access to markets, employment and areas that contribute to economic growth.	• Improving the economic efficiency of urban corridors by improving the travel time efficiency and journey time reliability for people and freight. • Easing of severe urban congestion though increased vehicle occupancy and increased uptake of public transport. • Growth in truck movements and traffic movements on alternative routes is no greater than growth on the corridor under examination. • Ensuring that the downstream network has sufficient capacity to accommodate vehicle traffic. • No net increase in the crash rate along the corridor at an aggregate level, and a mode specific level.	• Cost-benefit analysis • Corridor productivity (monetised) • SMARTROADS network operating gap • Travel times by mode, person and class of vehicle • Coefficient of variation or buffer time index (reliability) by mode and class of vehicle • Corridor demands by mode, person and class of vehicle • Corridor capacity • Average vehicle occupancy. • Crash rates • Violation rates • Public support

2.5 Warrants

Taking into account the objectives and evaluation of special vehicle lanes, warrants for the consideration of special vehicle lanes specify minimum thresholds for their use based on the number of vehicles, people and efficiency. For freight movement, there appears to be only limited literature on warrants. Given that the reason for considering truck lanes is centred on the role of freight in the economy, the warrants related to economic efficiency and lane performance (including reliability) are appropriate.

There are also various approaches to developing warrants for special vehicle lanes considering minimum volumes of eligible vehicles, minimum operating performance for the special vehicle lane and operating level of service in the general purpose traffic lanes.

Table 2.5 outlines the general planning requirements for bus preferential treatments in Kittelson & Associates et al (2003).

Table 2.5 Warrants for bus preferential treatments

Treatment	Minimum one-hour bus volumes	Minimum one-hour passenger volumes	Related land use and transport factors
Bus only street	80 – 100	3,200 – 4,000	Commercially oriented frontage
City centre kerbside lane	50 – 80	2,000 – 3,200	Commercially oriented frontage
Suburban arterial kerbside lane	30 – 40	1,200 – 1,600	At least two lanes available for other traffic in same direction.
Suburban arterial median lane	60 – 90	2,400 – 3,600	At least two lanes available for other traffic in same direction; ability to separate vehicular turn conflicts from buses.
Contraflow bus lanes (short sections)	20 – 30	800 – 1,200	Allow buses to proceed on normal route, turnaround, or bypass congestion on bridge approach.
Contraflow bus lanes (extended segments)	40 – 60	1,600 – 2,400	At least two lanes available for other traffic in opposite direction. Signal spacing greater than (150m) intervals.

Source: Kittelson & Associates et al (2003)

Texas Transportation Institute et al (1998) also includes a minimum threshold of 100–200 vehicles per hour for kerbside transit lanes.

US DoT (1994) provides a series of graphs representing the minimum thresholds for consideration of special vehicle lanes, which have been replicated in PPK (2000). These graphs outline the following:

- The minimum threshold for consideration of a special vehicle lane is the ability to carry more people than a general traffic lane at capacity.

- The maximum threshold is limited to the vehicle (or bus service) capacity of the roadway.

The minimum threshold is much lower than those presented in figure 2.20 and represents a relative measure of the person carrying capacity of a special vehicle lane relative to a general traffic lane.

PPK (2000) provides warrants in four areas:

- Person carrying capacity – the special vehicle lane should carry at least as many people as the adjacent traffic lane. This is irrespective of whether the general purpose lanes are operating at capacity.
- Public transport operations – the eligibility should be restricted to ensure that public transport operations are not unacceptably affected, and operational issues cannot be resolved (such as conflicts with turning traffic and pedestrian volumes).
- Marketing – where minimum criteria cannot be met upon opening, a short-term programme to boost lane usage will be required along with regular performance reporting and monitoring.
- Economic efficiency – the special vehicle lane should have a benefit-cost ratio of 1.0 or greater.

The *SEQ bus priority facilities and warrants* (Bitzios Consulting 2004), updated in 2007, outlined a different approach to whether the bus priority treatment would occur ahead of a need in order to influence mode choice, or whether the treatment would be a reaction to congested conditions on an existing route. Primarily this looked at public transport passengers using a number of criteria:

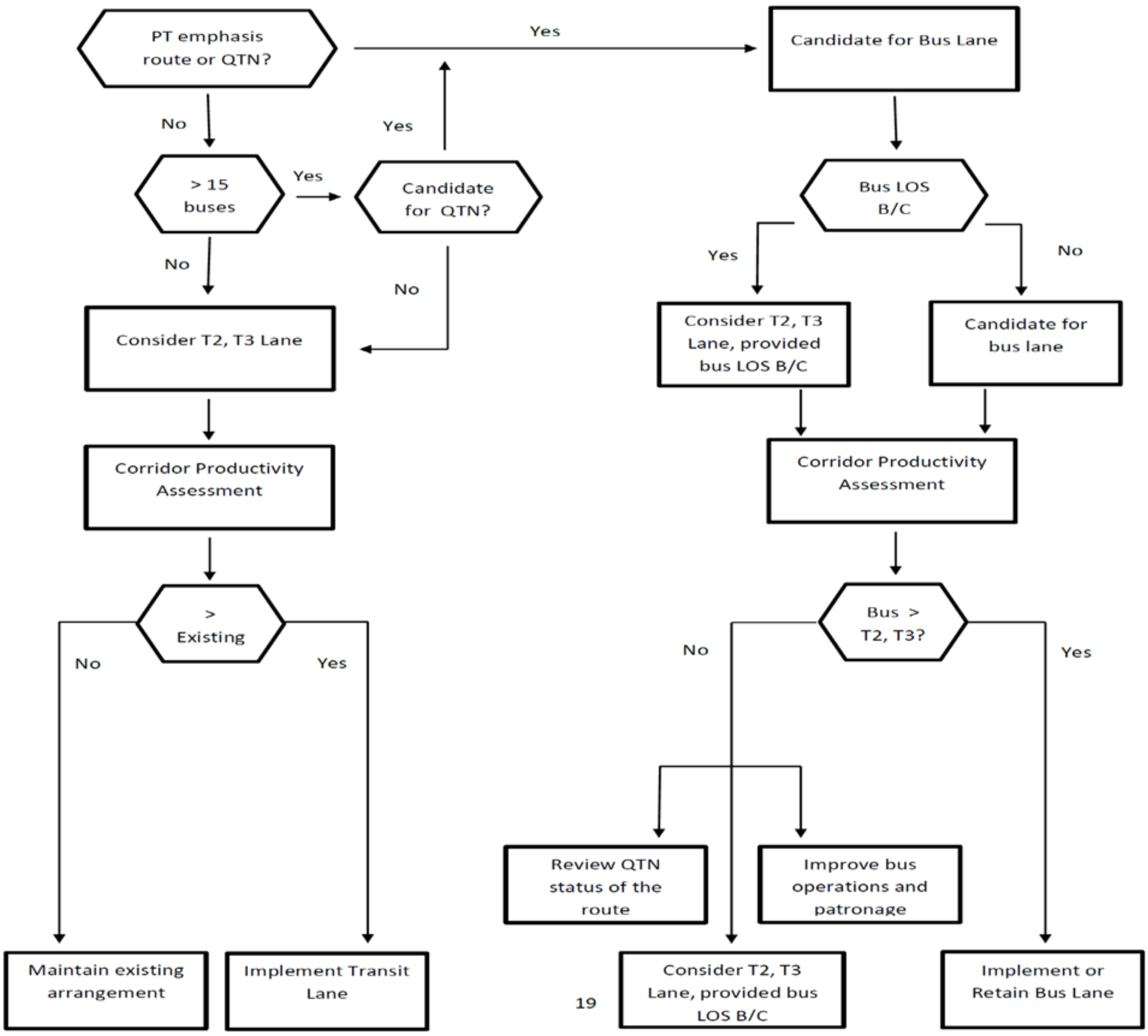
- bus passengers relative to a general traffic lane
- bus frequency
- difference between congested and uncongested travel times
- on-time running.

The consideration of public transport operations is an important one not only to influence mode choice, but also the ability of public transport operators to meet their contractual obligations for service frequency and reliability. A component of people's choice to use public transport is the reliability of the service to be on time (usually within a specified time of scheduled departure). The ability of public transport to run to time is affected by its interaction with other traffic, traffic signal operations and boarding/alighting activities. Timetables can be set to take account of this variability in travel time, but the ability to run to time is difficult for the transport operator to manage or control without dedicated facilities.

2.5.1 Processes

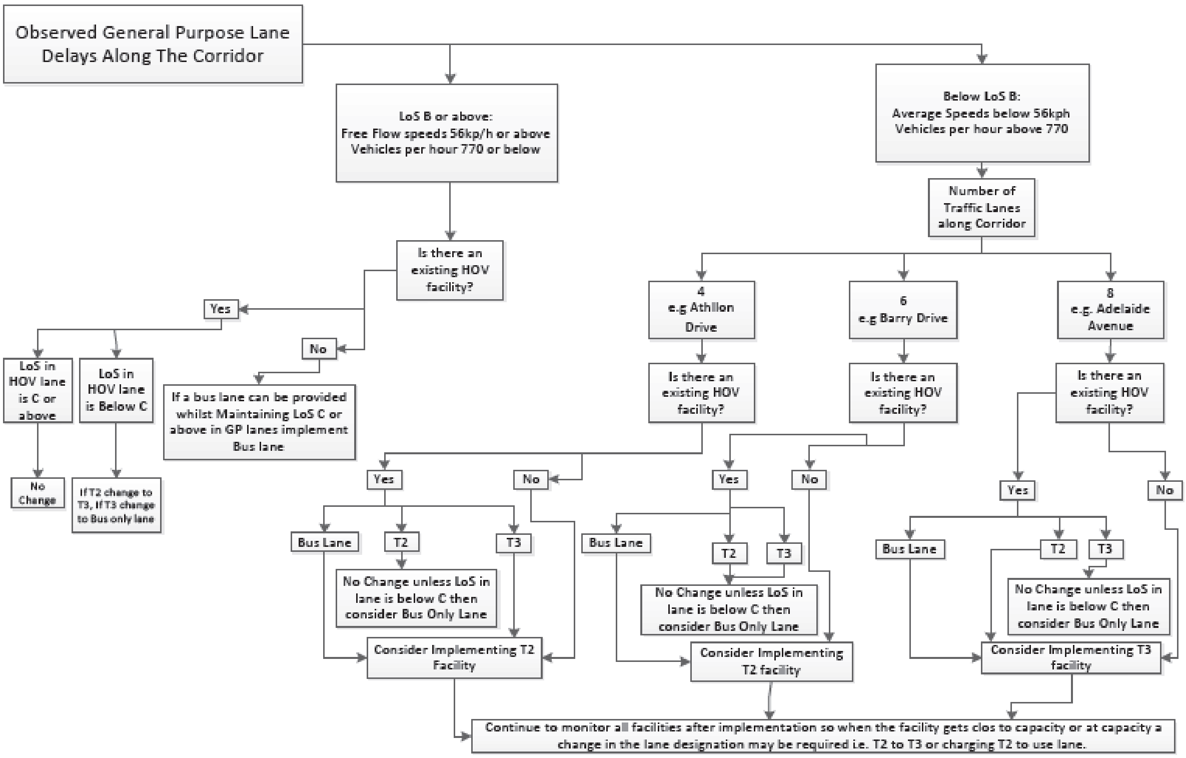
Auckland Transport (2011) developed warrants for special vehicle lanes based on the frequency of public transport services, the hierarchy of the corridor in the public transport network, and the level of service in the special vehicle lane, which strongly aligns with the strategic transport direction for Auckland. However, this process does not adequately consider the impacts where a general traffic lane is converted to a special vehicle lane.

Figure 2.20 Warrant process for special vehicle lanes in Auckland



AECOM (2012) has taken a similar approach to Auckland in setting a minimum operating level of service for a special vehicle lane. However, the difference in their approach is that they first identify the performance of the general purpose lanes, and then evaluate whether a particular type of special vehicle lane would alleviate congestion in the general purpose lanes and maintain the operation of the special vehicle lane above an acceptable level of service.

Figure 2.21 Evaluation criteria for HOV facilities in Australian Capital Territory



Source: AECOM (2012)

2.5.2 Considerations

2.5.2.1 Network planning

Overseas experience suggests that the implementation of special vehicle lanes is likely to be more acceptable if it is part of a system-wide implementation. An example of this was apparent in the history of the Vancouver (Washington State) HOV lanes. Despite their reasonable success in meeting the goals defined for the project, the scheme was discontinued in August 2005.

The press release issued by Washington State Department of Transport stated that 'Perhaps the most significant lesson coming out of this project is that to maximize the effectiveness of an HOV lane in reducing congestion, it must be part of a larger system designed to manage traffic and increase the flow of vehicles during peak traffic hours. We have seen success with HOV lane use in the Central Puget Sound, where the entire traffic management system works in a way that encourages travellers to use more efficient options'. The termination of the apparently successful scheme in Vancouver (at least in terms of meeting its declared objectives) possibly highlights the vulnerability of HOV schemes to political pressure.

In essence, this could mean one of two things (if warrants for HOVs are met and are aligned with transport network objectives):

- HOVs are considered as a mode in their own right, or
- HOVs are considered only where special vehicle lanes are justified by public transport patronage and operations do not warrant bus lanes.

In either case, for the use of HOVs and public transport to be effective, planners need to take into account not only the priority and connectivity provided through the transport system, but also the provision of end of trip facilities and support programmes.

The planning of separate special vehicle and arterial road networks may be impractical due to the space available, the costs and the economic efficiency. It is more likely that the use of special vehicle lanes will be provided as part of the arterial road network or motorway network, with eligibility to use the lanes based on the transport network objectives (such as passenger transport and/or freight priority) and warrants for special vehicle lanes.

Of critical importance to transport network development is the connectivity and reliability that the network provides in order to move people and freight efficiently from their origin to destination. Auckland has a wide range of special vehicle lanes on the road network and spot treatments to provide isolated priority, but there are many gaps in the current network where priority traffic (whether buses, HOVs or freight) mixes with other general traffic.

2.5.2.2 Eligibility

Too much demand

The failure caused by too much demand can be considered on various levels. Auckland Transport (2011) considers operational failure as the mode operating at levels of service worse than the threshold, then considers the operational performance of the lane in terms of corridor productivity.

Failure of a special vehicle lane also occurs when there is very little time advantage for the users of the special vehicle lane over those in the general traffic lane, or the special vehicle lane is congested. When allowing for the widest range of HOVs (ie a T2 lane), a road and transport authority should ensure that significant time advantage over the other general purpose lanes is maintained for users of the special vehicle lane when at maximum demand.

The road controlling authority will also need to consider the ability of the receiving network at the end of the special vehicle lane to be able to accommodate the amount of traffic approaching it. This is relevant where the road controlling authority is adding a lane to the existing roadway and allowing HOVs as well as buses to use it. On the Auckland motorway network the provision of ramp signal priority lanes that allow T2 and freight are becoming congested in their own right, prior to the ramps joining with the mainline.

The analytical model developed for this research sets a maximum threshold for the use of a transit lane, ie if there is no travel time benefit then the particular special vehicle lane is not installed. This is more appropriate to the selection of a T2 lane over a T3 lane, but can be uniformly applied.

Too little demand

The provision of a special vehicle lane that has very low use can result in ‘empty lane syndrome’, whereby pressure is placed on the road controlling authority to widen the eligibility range for the special vehicle lane.

As congestion continues to increase on the urban road network, it can be reasonably inferred that the travelling public will see under-utilised adjacent lanes as a wasted investment. This has become evident in Auckland with the majority of the special vehicle lanes on the North Shore converted from T3 to T2 lanes. The bus lanes on Remuera Road in Auckland have also been converted to T3 lanes in response to public and political pressure. The literature suggests that the minimum threshold to avoid the empty lane syndrome in a transit lane is in the order of 100–150 vehicles.

Unlike the failure caused by too much demand, which has visible impacts (ie congestion), the failure of special vehicle lanes through the perception of the empty lane syndrome requires a robust and transparent framework that can stand up to political scrutiny, so that the overall benefits of restricting eligibility are justified and demonstrated. Section 2.3 outlines the need for the objectives and performance measures to consider the entire roadway, rather than just the performance of the special vehicle lane.

Freight

Allowing freight vehicles to use special vehicle lanes would satisfy two potential objectives by:

- allowing better use to be made of the road space available if there was spare capacity in the special vehicle lane
- supporting the government's objectives set out in the GPS.

Currently the only examples of heavy freight vehicles using special vehicle lanes are associated with access onto motorways (by way of ramp signal priority bypass lanes). These include a number of locations where ramp signalling has been installed on the motorway network in Auckland. Bypass lanes avoiding the use of the ramp signals are available to a range of vehicles including HOVs and freight vehicles.

There has been some investigation of the development of truck-only lanes on freeways in the USA and a number of proposals have been developed. However, the general consensus appears to be that although there could be safety benefits in the segregation of trucks from other types of traffic, there is the potential for a reduction in average travel speeds for road users as a whole compared with where there is no segregation by vehicle type (De Palma et al 2007). As a result, it is understood that no significant truck-only facilities have been implemented.

Austroads (2008) considers that in the interest of economic efficiency, a network of 'high productivity' routes could be considered, such as the over-dimension routes in Melbourne. The use of truck lanes could be considered on motorways and arterials in a similar way to transit lanes. Trucks could be permitted to use transit lanes. However, no specific warrants are cited.

The main potential advantages and disadvantages are considered below:

- **Improvements in travel time for high-value vehicles**: This would allow the relatively high-value freight traffic to take advantage of the faster travel speeds in the special vehicle lanes. As discussed above this would align with the government's objectives for economic efficiency set out in the GPS. However, whether this would lead to an overall reduction in road user costs would depend on the particular conditions in the corridor.
- **Safety:** By segregating traffic there may be some improvement in safety characteristics on the route. Although there is little empirical evidence, it appears that crash rates are higher in mixed light and heavy vehicle traffic than in homogeneous traffic.
- **Choice of lane**: One of the difficulties of allowing trucks to use special vehicle lanes is the choice of location for this lane. The decision to provide the special vehicle lane on the kerbside or in the median needs to consider the conflict with bus operations, the roadside development and amenity and the safety of other users (particularly cyclists and pedestrians).

Cyclists

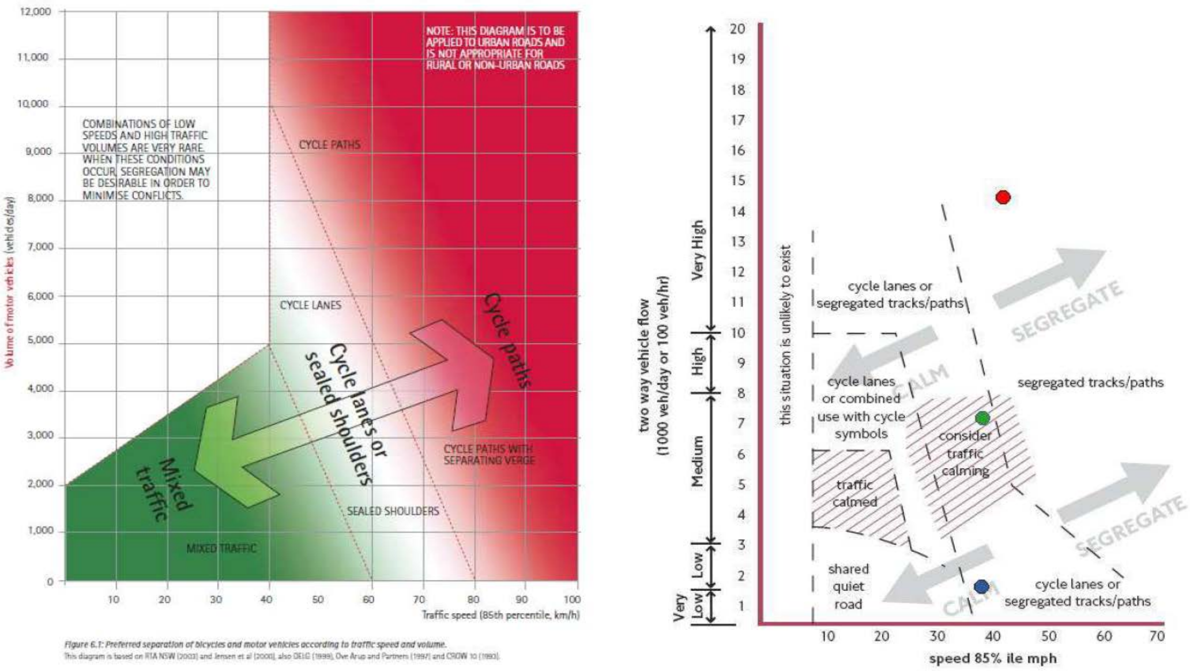
For the purposes of this research project, the publications of several research institutions and sources were examined. These included:

- SUSTRANS – Sustainable Transport Charity – www.sustrans.org.uk
- Bicycle Federation of Australia – www.bfa.asn.au
- Austroads (1993) *Guide to traffic engineering practice*
- Transit NZ (2008) *New Zealand supplement to the Austroads guide to traffic engineering practice, part 14*
- Austroads (2005) *Bus-bike interaction within the road network*
- New Zealand Ministry of Transport – www.mot.govt.nz
- United Kingdom Department for Transport – www.dft.govt.nz
- Vicroads – Victoria's Roads Department – www.vicroads.vic.gov.au

The literature review revealed there is little data available regarding the interaction of bus and cyclists. The majority of information is contained in Austroads (2005). Generally it is considered desirable to keep buses and cyclists separate due to the fact that buses and bicycles are at the opposite end of the spectrum in terms of size, mass and manoeuvrability. This would also extend to allowing trucks to share a special vehicle lane with cyclists.

Volume and speed are key variables in considering the appropriate treatment type. The following correlation charts from the LTSA (2004) and a diagram sourced from Macmillan (2012) which has been adapted and enhanced from the TfL (2005), were also considered.

Figure 2.22 Correlation between volume and speed in cycle treatment selection



Is should be noted, that even if a segregated facility is preferred, the New Zealand legislation permits cyclists to use all forms of special vehicle lane unless excluded by signs. Therefore the design of special vehicle lanes should consider cyclists' requirements. International best practice for the design of bus and transit lanes is largely in agreement with this. In UK practice, where bus lanes are only 3m wide, buses are unable to pass cyclists safely unless they pull out into the 'non-priority' lane; in some cases it may not be possible to do this. With this in mind, bus lanes should be the preferred width of 4m or more wherever possible. This is consistent with observations in Auckland and current Austroads and New Zealand design standards where 4.2m is the recommended minimum for a special vehicle lane in an urban environment. Where bus speeds are higher than 50km/h a minimum width of 4.5 m is recommended and over 60km a minimum width of 5.0m is recommended.

Fundamentally it comes down to a balance between the benefits of installing a bus lane or HOV lane and the safety of cyclists, which is assessed in the analytical model by evaluating the suitability of the corridor for on-road cyclists based on the lane width and the use of special vehicle lane by trucks.

Adding or converting a lane

The road controlling authority should also consider eligibility in the context of adding a lane to an existing roadway, or when converting a general traffic lane to a special vehicle lane. If the road controlling authority is adding a special vehicle lane to an existing carriageway, the travelling public may feel aggrieved that they are not being given the opportunity to access the new roadway capacity (for example, if bus lanes are being added to adjacent traffic lanes).

If the road controlling authority is adding a lane, the negative impact to the existing users of the roadway will be zero or negligible. This scenario allows the road controlling authority to manage the increase in vehicle capacity by managing the eligibility. In doing so, it provides the greatest opportunity to influence driver behaviour and mode choice.

The same cannot be said if the road controlling authority is converting a general traffic lane to a special vehicle lane. The public perception is likely to be that entitlements are being removed. Furthermore, the conversion of a general traffic lane to a special vehicle lane may have impacts on the traffic not eligible to use the special vehicle lane. The term 'may' is used, because the impact is dependent on the level of congestion before and after the conversion of a general traffic lane to a special vehicle lane. The impact on traffic not eligible to use the special vehicle lane becomes a crucial element in determining whether a special vehicle lane is warranted.

For these reasons it is recommended that the provision of a special vehicle lane is aligned with the policy directives outlined in section 2.4.2 to improve the efficiency of corridors and influence travel choice as follows:

- If the road controlling authority is adding a lane, the eligibility of the lane in the short term should be no greater than the recommended eligibility in the long term. For example, if a bus lane is recommended in the medium to longer term, then the road controlling authority should consider a bus lane in the short term subject to the development of the business case for funding. This avoids the situation where vehicle capacity is provided and then removed.
- If the road controlling authority is converting a general traffic lane to a special vehicle lane, the vehicle capacity is gradually decreased over time by allowing a wider range of eligibility, subject to assessing the performance of the corridor with a special vehicle lane. This approach lessens the impact on traffic

not eligible to use the special vehicle lane, and will minimise the impact of traffic reassigning to other corridors.

2.5.3 Recommended warrants

Table 2.6 outlines the suggested warrants for considering a special vehicle lane drawing on local and international literature. The warrants take into consideration the whole of corridor performance, the mode performance, the lane performance and whether the special vehicle lane is added or converted. These warrants have been carried through into the analytical model, and linked back to the evaluation criteria, the objectives and the policy framework.

Table 2.6 Recommended warrants

<table>
<tr><th rowspan="2">Policy framework</th><th rowspan="2">Recommended special vehicle lane objectives</th><th rowspan="2">Recommended measures of effectiveness</th><th colspan="2">Recommended warrant</th></tr>
<tr><th>Where special vehicle lane provides an additional lane in the direction of travel</th><th>Where general traffic lane is converted to a special vehicle lane</th></tr>
<tr><td>• Extract maximum benefit from transport investment – existing and proposed.
• Improve journey time reliability for people and freight.
• Develop more transport mode choices.
• Reduce adverse social and environmental effects from transport.</td><td>• Improving the economic efficiency of urban corridors by improving the travel time efficiency and journey time reliability for people and freight.
• Easing of severe urban congestion though increased vehicle occupancy and increased uptake of public transport.
• Growth in truck movements and traffic movements on alternative routes is no greater than growth on the corridor under examination.
• Ensuring that the downstream network has sufficient capacity to accommodate vehicle traffic.
• No net increase in the crash rate along the corridor at an aggregate level, and a mode specific level.</td><td>• Cost-benefit analysis
• Corridor productivity (monetised)
• SMARTROADS network operating gap
• Travel times by mode, person and class of vehicle
• Coefficient of variation or buffer time index (reliability) by mode and class of vehicle
• Corridor demands by mode, person and class of vehicle
• Corridor capacity
• Average vehicle occupancy
• Crash rates
• Violation rates
• Public support.</td><td>• BCR >1.0.
• Special vehicle lane has higher productivity (monetised) than adjacent general traffic lane.
• Improvement in overall network operating gap.
• Special vehicle lane (excluding truck lane) should carry more people in fewer vehicles than the adjacent traffic lane.
• Special vehicle lane operates at level of service D or better.
• Bus stop volume-capacity ratio should be less than 1 (along bus route as a proxy for reliability).</td><td>• NPV >0.
• Corridor productivity (monetised) is no worse than base case.
• Improvement in overall network operating gap.
• Corridor carries no fewer people along the corridor than currently exist where a general traffic lane is converted.
• General traffic lane operates within the same level of service band or acceptable minimum travel speed.
• Special vehicle lane operates at level of service D or better.
• Bus stop volume-capacity ratio should be less than 1 (along bus route as a proxy for reliability).</td></tr>
</table>

3 Model development

3.1 Overview

An analytical model was developed in Microsoft Excel to assess the relative performance of special vehicles on arterial roads, accounting for the major influential factors in urban corridors, namely:

- intersection performance, spacing and level of coordination
- mid-block lane performance
- on-line or off-line bus stops and bus stopping times
- level of take-up and level of violation
- parking, merging and access
- behavioural response to the implementation of special vehicle lanes.

The model results are presented as a series of tables and figures showing the relative performance of the different types of special vehicle lanes based on the above inputs. The performance measures selected are those outlined earlier in this paper. The model provides an unweighted analysis of the corridor performance, with an additional output to measure the level of service gap relative to the target performance criteria.

The model was designed to allow for the user to specify either observed data or model data, and provide standalone outputs or to feed back into a network assignment model or other assessment processes such as the SMARTROADS network fit assessment tool.

The model can be accessed at www.nzta.govt.nz/resources/research/reports/557.

3.2 Existing modelling techniques

Various modelling and analysis techniques have been used to evaluate the performance of special vehicle lanes:

- Texas Transportation Institute (1998) identifies a number of models that were developed in North America between 1975 and 1994, which use either multinomial logit models or regression models to estimate corridor users by public transport users, drive-alone users and HOV users. Logit models are developed based on the attractiveness of one mode over another and require an intensive amount of user data to calibrate. They consider the whole of the trip and are suited to region-wide model development.
- In New Zealand and Australia, regional models use various forms of logit models to estimate the public transport mode share and the vehicle mode share. The consideration of HOVs has not, to the author's knowledge, been expressly considered as a separate mode of travel within these models, as the conversion of person trips to vehicle trips by trip purpose is undertaken using vehicle occupancy values, either by trip purpose or by time of day.
- FHWA (2004) outlines the process used in developing guidelines for the installation of special vehicle lanes by reducing the analytical processes into a series of graphs based on:

- the signalised intersection capacity along the route
- the bus service capacity for in-lane stops and indented stops
- the conceptual level of public acceptance to avoid the empty lane syndrome.

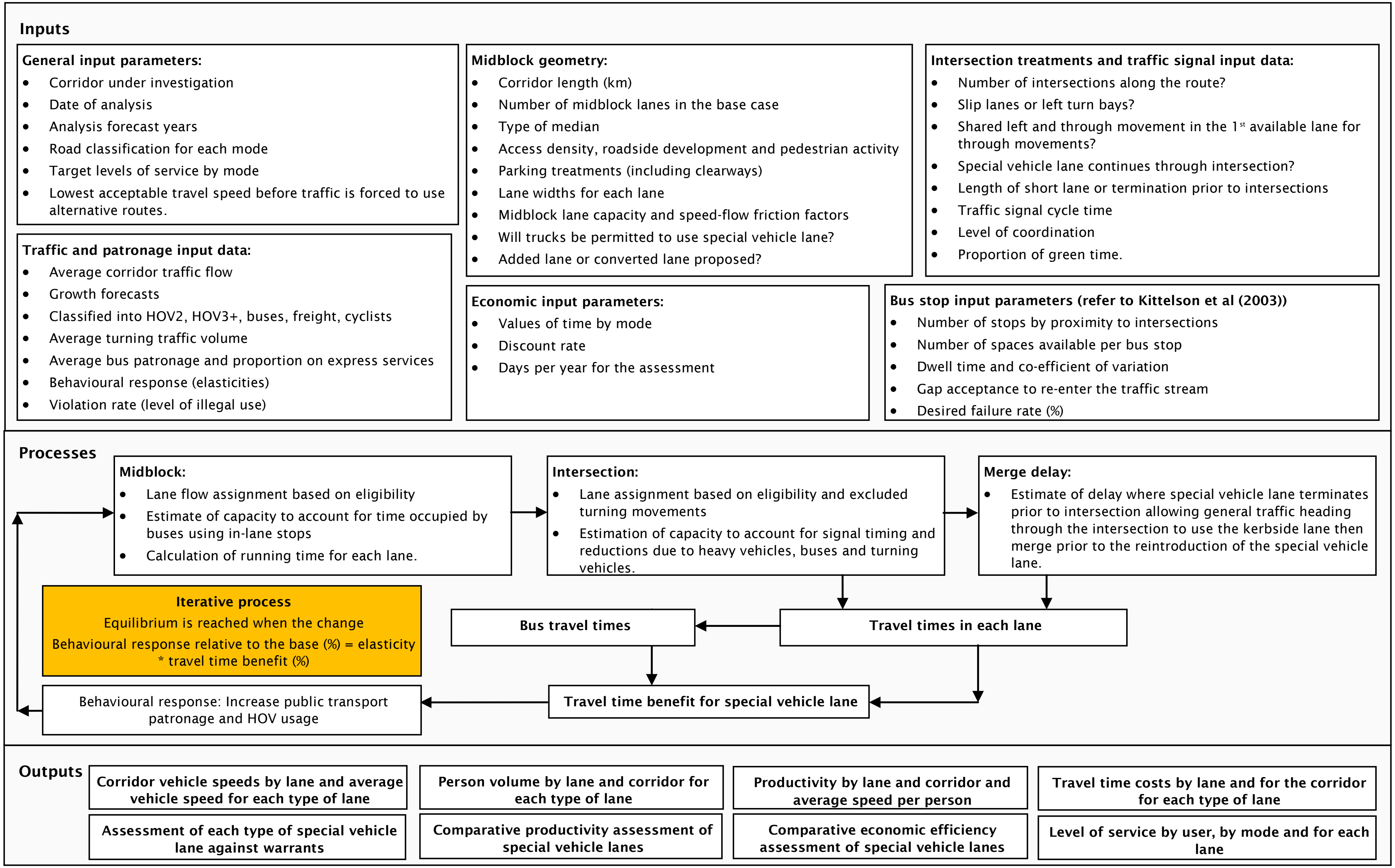
- Austroads (2002) presents an analytical model for estimating the travel time savings for HOVs on a motorway system based on the Akcelik speed flow function. This model does not consider the operation of special vehicle lanes on arterial roads.
- SMARTROADS network fit assessment tool considers multi-modal impacts based on the user inputting the traffic volumes, public transport demands and levels of service. It is not a modelling tool as such but does consider multi-modal level of service. However, it does not include HOVs, and requires the user to input both the demands and performance to determine the 'operating gap'.
- Regional and sub-regional models: Strategic multi-modal models assess public transport patronage and vehicular movement with vehicle occupancy estimated from user surveys (such as household traveller surveys or vehicle occupancy surveys). The modelling of HOV lanes is difficult within these models unless a separate user class (or mode) is established within the models.
- AECOM (2012) has developed a bus priority assessment tool that considers the benefits of special vehicle lanes based on empirical findings, but as far as the author is aware, does not consider the behavioural response to the implementation of transit lanes. The model requires a significant amount of data including turning counts at the signalised intersections, which may not be easily sourced.
- There are various other modelling techniques utilising microsimulation and macroscopic models, requiring the user to input the traffic data required to assess the performance.

With the exception of the logit models developed in the USA, the above models do not account for a change in vehicle occupancy or increase in the proportion of HOVs from implementing a special vehicle lane. As presented in section 2.4.1, there appears to be a relationship between the average vehicle occupancy and travel time savings along the corridor; however, the data set was limited and further research is required to develop this relationship at the corridor and strategic levels for potential use in models.

3.3 Structure of the HOV corridor assessment model

The structure of the model developed as part of this research project is presented in figure 3.1. Further detail on the processes, equations and suggested input values are contained in appendix B and as notes within the analytical models.

Figure 3.1 Model structure



3.3.1 Relevance for the research

The analytical model presented in figure 3.1:

- estimates the behavioural response to the implementation of special vehicle lanes
- evaluates the performance of the corridor in line with the recommended objectives and warrants, including the economic efficiency and the productivity (or effectiveness) reflected in terms of person travel (not vehicle travel)
- considers the performance of mid-block lanes, the intersection delays and the bus travel times using established algorithms
- provides a usable tool requiring data that can be easily sourced
- provides outputs for corridor performance, mode performance and lane performance identifying the best performing special vehicle lane, and whether the relevant criteria meets the targets input by the user.

3.3.2 Advantages of the model

The model:

- is generic and can be applied across New Zealand and Australia
- is highly flexible in the amount of data required to undertake the assessment, therefore is suitable for high-level planning and monitoring where data such as turning counts may not be available or are expensive to collect
- uses established analytical techniques outlined in:
  - *Highway capacity manual* (HCM2010) (TRB 2010) methodologies for urban streets for intersection delays and corridor performance
  - Kittelson & Associates et al (2003) for the calculation of bus service capacity
  - HCM2010 for uninterrupted facilities for the calculation of mid-block travel times on freeways
- allows for an 'elasticity' to be applied, if forecast mode splits and vehicle occupancies are not known. The elasticity used has been derived from the research work presented in section 2.4.1.1 of this report
- can be easily calibrated to observe travel times along the corridor for buses and other traffic
- provides results for performance measures to include corridor performance, lane performance, mode performance and the assessment against warrants
- provides graphical outputs to show the effect of the special vehicle lanes over time
- allows for the impact of buses and bus stops in the kerbside lane on travel times.

3.3.3 Limitations

The current limitations of the model are consistent with the urban street methodologies in HCM2010 including those listed below:

- The model applies only to signalised intersections.
- The model, while not designed to account for changes in layout along the corridor, such as different intersection treatments or changes in the number of mid-block lanes, has revealed that the predicted performance along corridors with different layouts is very close to observed performance.
- The model is designed to assess long corridors rather than short sections of road, although it could be used for short sections without considering behavioural response (ie elasticities).
- The model is intended to be a planning level model and not a detailed evaluation tool.

3.4 Potential for further development

3.4.1 Elasticities

Through the testing of the model, it became apparent that the use of elasticity of vehicle occupancy relative to travel time savings increased HOV mode share beyond what could be considered reasonable. In this version of the model, the level of HOV increase has been limited to 100% (a doubling of eligible HOVs in line with the long-run observations at Onewa Road); however, further research is required into the behaviour response in order to confirm whether the elasticity of vehicle occupancy is the best measure, or whether the eligibility elasticity (the increase in HOVs) is a better measure.

Second, the current version of the model allows for only a single elasticity to be applied. This has the effect of estimating that the response to the implementation of a special vehicle lane will be immediate. The research suggests that long-run elasticities are significantly higher than the short-run elasticities. Therefore there is the potential within the model to allow the user to specify short- and long-run elasticities or to estimate the short-run elasticity based on the user input value. For example the user may specify an elasticity of 0.5. The model could be set up to increase the elasticity over time from a preset proportion (or zero) up to the user-specified value.

3.4.2 Assessment with each intersection

The current form of the model allows for only a 'typical' intersection to be modelled which relies on the user to find the balance between layout and traffic signal parameters that calibrate well with the observed conditions. In future versions of the model, it is anticipated that the user will be able to enter midblock and intersection cross sections, layouts and traffic volumes in order to provide an additional level of detail in the analysis. The development of this level of detail will be more relevant for individual project evaluation rather than the planning level model that has been developed thus far.

3.4.3 Assessment of trip reliability

A useful addition to the model will be the evaluation of trip reliability, or the variability of travel times along the corridor. The process for determining the variability is outlined in the *Economic evaluation* *manual* (EEM) (NZ Transport Agency 2013) and would be beneficial in providing an indication of the ability of public transport providers to meet service level agreements, and also to adjust timetables as necessary.

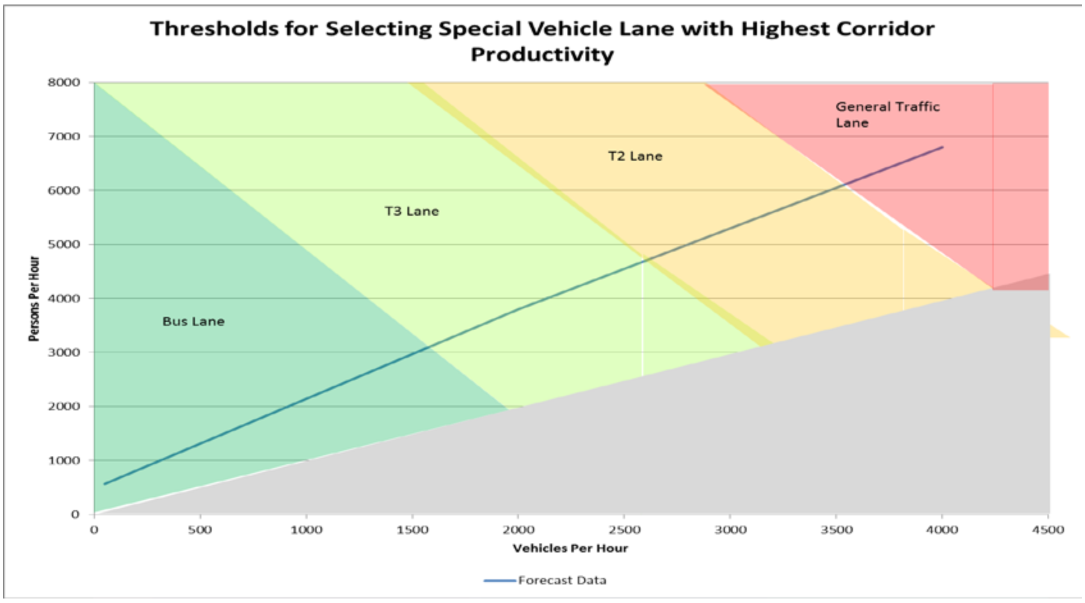
3.4.4 Development of preferred treatment against thresholds

The current form of the model requires the user to enter the demand or observed data and the geometry along the corridor. There is an opportunity, in the next version of the model, to determine the thresholds for each lane to provide the best performance for each criterion based on only the geometry and layout of the corridor.

The advantages of this approach are that the absolute value of the criteria (for example, travel speed per person, or corridor productivity) do not require interpretation to determine which lane is the best performance, and that it will be simple to determine how close or far away the observed data is from the threshold that would result in selecting a different special vehicle lane treatment.

A theoretical example is provided in figure 3.2.

Figure 3.2 Theoretical example of thresholds for highest productivity



3.4.5 Evaluation of multiple layouts

The current form of the model allows only one 'option' layout to be tested which needs to include whether there are left-turn bays and whether the special vehicle lane continues through the intersection. In future versions of the model, it is foreseeable that a single model run will be able to test:

- layouts with and without the special vehicle lane through the intersection (including varying lengths of approach and departure lanes for general traffic)
- layouts with and without left turn bays
- layouts with different forms of pedestrian protection.

This will enable the user to evaluate all possibilities in a single run to determine the preferred way forward.

4 Case studies

The following corridors were assessed using the analytical model developed for this project:

- Onewa Road, North Shore, Auckland (morning peak period)
- Dominion Road, Auckland (morning peak period)
- Dominion Road, Auckland (evening peak period)
- Fanshawe Street, Auckland (morning peak period)
- Albert Street, Auckland (morning and evening peak period)
- Great North Road, Auckland (morning and evening peak periods).

The detailed inputs and outputs for each case study are provided in appendix B. The growth was based on values provided in the EEM. The model was developed so that inputs from higher-level models (eg traffic volume data and public transport patronage) could be added; however, at this stage this data has not been sought.

4.1 Onewa Road, Auckland (morning peak period)

Onewa Road is an urban arterial road running through the southern end of the North Shore in Auckland, and is approximately 2.5km in length.

The analytical model examined two scenarios:

1 The existing layout with a 1.5% growth in public transport patronage and 0% growth in traffic volumes, as the general traffic lane is heavily congested

2 The above scenario but with an elasticity applied.

The surveyed data was compiled from historical traffic count data, the website transportblog.co.nz reporting on the performance of the Onewa Road transit lane, and aa.co.nz for travel time data. This data indicates that the proportion of cars with two occupants is much lower than other corridors across Auckland which is typically in the range of 10% to 15% (cf 4%). Conversely, the proportion of cars with three or more occupants is significantly higher than other corridors across the Auckland region, which is typically in the range of 5% to 10% (cf 14%).

Table 4.1 Onewa Road morning peak period travel data

Vehicle type	Traffic volume	Person volume	Vehicle speed (km/h)
Bus	38	1349	36km/h
HOV3+	221	720	
SOV	1310	1310	9km/h
HOV2	59	118	

The analytical model was calibrated to within 2km/h of the speeds in the general traffic lane, by adjusting the proportion of green time per cycle for through movements along the corridor. No other parameters were adjusted. This provides a good indication that the analytical processes used in the model are able to reflect the corridor performance.

Table 4.2 Onewa Road morning peak period outputs

Case	Preferred treatment		
	Warrants	Productivity	Economic efficiency
Existing layout	T3 or T2 lane with bus lane warranted as public transport patronage grows	T2 lane	T2 lane
Proposed layout with elasticity of 0.3 applied for average vehicle occupancy and public transport patronage	Bus lane, T3 or T2 lane	T3 lane	T3 lane

The key conclusions to be drawn from this assessment are:

- The current low level of cars with two occupants does not affect the performance of the special vehicle lane, hence the recommendation of a T2 lane based on current users.
- When the elasticity is applied, the T3 lane is expected to perform better than a T2 lane, because the number of eligible users in the T2 lane is causing congestion in that lane.

Without an allowance for behavioural response, the analyst would be led to consider that a T2 lane is more appropriate than a T3 lane. This demonstrates the importance of understanding and accounting for behavioural change in the use of the network. The long-running T3 lane has seen a significant increase in the volume of cars with three or more occupants. However, if the lane was to be converted into a T2 lane, there could be three possible responses from road users:

1 The cars that currently have two occupants would use a T2 lane.

2 The cars with single occupants would carry a passenger to use the T2 lane.

3 Cars with two occupants using other corridors would divert to the Onewa Road T2 lane.

Estimating the actual response is highly complex; but allowance is made within the analytical model to test the behavioural response and reassignment scenarios.

4.2 Dominion Road, Auckland (morning peak period)

Dominion Road is an arterial road within the Auckland isthmus and has an established bus lane that is operational between 7am and 9am. The existing layout sees the bus lanes terminating prior to the signalised intersections. This allows general traffic heading through the intersection to use the kerb side lane. Auckland Transport is proposing to extend the bus lanes through the intersection to provide continuity of the special vehicle lane along the corridor.

The analytical model examined four scenarios:

1 The existing layout with growth of 1.5% per annum in line with the default in the EEM

2 The proposed layout with growth of 1.5% per annum in line with the default in the EEM

3 The proposed layout with elasticity and with growth of 1.5% per annum in line with the default in the EEM

4 The proposed layout with elasticity, default growth in public transport patronage and 0% growth in traffic volumes.

The surveyed data provided by Auckland Transport is outlined in table 4.3.

Table 4.3 Dominion Road morning peak period surveyed data

Vehicle type	Traffic volume	Person volume	Vehicle speed (km/h)
Bus	34	1,251	17km/h
SOV	657	657	13km/h
HOV2	164	328	
HOV3+	43	130	

The analytical model was calibrated to within 2km/h of the speeds in the general traffic lane, by adjusting the proportion of green time per cycle for through movements along the corridor. No other parameters were adjusted. This provides a good indication that the analytical processes used in the model are able to reflect the corridor performance.

Table 4.4 Dominion Road morning peak period outputs

Case	Preferred treatment		
	Warrants	Productivity	Economic efficiency
Existing layout (with special vehicle lane stopping short of the intersections)	T2 lane in the short term and bus lane in the longer term	T2 lane in the short term, and T3 in the longer term	T2 lane in the short term, and T3 in the longer term
Proposed layout to continue special vehicle lane through intersections	T2 lane in the short term and bus or T3 lane in the long term	T2 lane	T2 lane
Proposed layout with elasticity of 0.3 applied for average vehicle occupancy and public transport patronage	T3 or T2 lane in the short term transitioning to bus lane in the medium to long term	T2 lane in the short term, and T3 in the longer term	T2 lane in the short term, and T3 in the longer term
As above with 0% growth in vehicle demand (reducing vehicle travel through behavioural response)	T3 lane	T2 lane (but T3 lane is within 5%)	T3 lane

The key conclusions to be drawn from this assessment are:

- It is evident that based on the surveyed data, the selection of a T2 lane is preferred in the short term, but in the medium to long term, a bus lane or T3 lane is preferred.
- It is also evident that the buses are operating near to their seated capacity, with some untapped demand for public transport not realised because of these seating capacity constraints.

- As growth continues, the corridor with a special vehicle lane is more productive than the corridor with general traffic lanes (as shown in the graphical outputs).
- From this evaluation and the data supplied by Auckland Transport, the proposed layout is likely to result in some increases in delay to general traffic, therefore reducing the productivity and efficiency.
- It is evident that as the demand for movement (people and traffic) grows along the corridor, the special vehicle lanes with restricted eligibility will be more productive due to the levels of congestion observed along the corridor.

4.3 Dominion Road, Auckland (evening peak period)

Dominion Road is an arterial road within the Auckland isthmus and has an established bus lane that is operational between 4pm and 6pm. The existing layout sees the bus lanes terminating prior to the signalised intersections. This allows general traffic heading through the intersection to use the kerbside lane. Auckland Transport is proposing to extend the bus lanes through the intersection to provide continuity of the special vehicle lane along the corridor.

The analytical model examined four scenarios:

1 The existing layout with growth of 1.5% per annum in line with the default in the EEM

2 The proposed layout with growth of 1.5% per annum in line with the default in the EEM

3 The proposed layout with elasticity and with growth of 1.5% per annum in line with the default in the EEM

4 The proposed layout with elasticity, default growth in public transport patronage and 0% growth in traffic volumes.

The surveyed data provided by Auckland Transport is outlined in table 4.5.

Table 4.5 Dominion Road evening peak period surveyed data

Vehicle type	Traffic volume	Person volume	Vehicle speed (km/h)
Bus	26	500	22km/h
SOV	683	683	26km/h
HOV2	209	418	
HOV3+	65	196	

The analytical model was calibrated to within 1km/h of the speeds in the general traffic lane, by adjusting the proportion of green time per cycle for through movements along the corridor. No other parameters were adjusted. This provides a good indication that the analytical processes used in the model are able to reflect the corridor performance.

Table 4.6 Dominion Road evening peak period outputs

Case	Preferred treatment		
	Warrants	**Productivity**	**Economic efficiency**
Existing layout	T2 lane	T2 lane	T2 lane
Proposed layout to continue special vehicle lane through intersections	T2 lane	T2 lane	T2 lane
Proposed layout with elasticity of 0.3 applied for average vehicle occupancy and public transport patronage	T2 lane	T3 lane in the short term, and T2 in the longer term	T3 lane in the short term, and T2 in the longer term

The key conclusions to be drawn from this assessment are:

- It is evident that based on the surveyed data, the selection of a T2 lane is preferred.
- As growth continues, the corridor with a special vehicle lane is more productive than the corridor with general traffic lanes (as shown in the graphical outputs).
- From this evaluation and the data supplied by Auckland Transport, the proposed layout is likely to result in some increases in delay to general traffic, therefore reducing the productivity and efficiency.
- It is evident that as the demand for movement (people and traffic) grows along the corridor, the special vehicle lanes with restricted eligibility will be more productive due to the levels of congestion observed along the corridor.

4.4 Fanshawe Street, Auckland (morning peak period)

Fanshawe Street is the main artery connecting people travelling from the North Shore to the city centre via the Northern Motorway. It serves as the major traffic route and is the major bus corridor forming part of the Northern Busway. Fanshawe Street has four through traffic lanes (plus turning lanes on the intersection approaches) plus a bus lane with indented bus stops on both sides of the road. Auckland Transport is currently developing proposals to segregate the bus lanes and provide a busway between Britomart and the Northern Motorway via Fanshawe Street

The analytical model examined two scenarios:

1 The existing layout with growth of 1.5% per annum in line with the default in the EEM

2 As above, but separating the left-turn movements from the bus lanes to simulate a busway – this assumes that the through busway movements are permitted to operate in the same traffic signal phase as the through traffic movements.

The surveyed data provided by Auckland Transport is outlined in table 4.7.

Table 4.7 Dominion Road evening peak period surveyed data

Vehicle type	Traffic volume	Person volume	Vehicle speed (km/h)
Bus	112	4,594	27km/h
SOV	1,063	1,063	35km/h
HOV2	256	512	
HOV3+	40	120	

The analytical model was calibrated to within 1km/h of the speeds in the general traffic lane, by adjusting the proportion of green time per cycle for through movements along the corridor. No other parameters were adjusted. This provides a good indication that the analytical processes used in the model are able to reflect the corridor performance.

Table 4.8 Fanshawe Street evening peak period outputs

Case	Preferred treatment		
	Warrants	Productivity	Economic efficiency
Existing layout	Bus lane	Bus or T3 lane (marginal)	Bus or T3 lane (marginal)
Proposed layout to provide a busway	Bus lane	Bus or T3 lane (marginal)	Bus or T3 lane (marginal)

The key conclusions to be drawn from this assessment are:

- The public transport patronage along this route is more than three times the volume of people transported by private vehicle in the remaining two lanes, hence logically the impact of allowing more traffic into the bus lane is greater than the benefit of having improved traffic flow.
- Interrogation of the results indicates that the bus lane is operating over its capacity, which can be currently observed and is due to the number of buses, the traffic signals and interference from left-turning traffic.
- The analysis indicates that providing an at-grade busway is likely to improve the bus lane capacity by approximately 10% as the improvements are only obtained through the removal of left-turning traffic from the bus lane. This assumes that the through traffic and busway movements run in the same traffic signal phase. As bus numbers continue to grow, consideration will need to be given to skip-stop operation and grade separation.

4.5 Albert Street, Auckland (morning and evening peak period)

Albert Street is the major bus corridor in Auckland's central city for buses serving central-west and west Auckland, and for a large number of services travelling between the central city and the North Shore. It is highly congested in the morning and evening peak periods, and has bus lanes operating during extended periods of the day. The bus stops are predominantly in-lane stops, and there are no left-turn bays provided.

The analytical model examined the existing layout with growth of 1.5% per annum in line with the default in the EEM, and analysed both the morning peak (northbound) and the evening peak (southbound) in the same model given that the bus stop locations and signal timings are similar.

The surveyed data provided by Auckland Transport is outlined in tables 4.9 and 4.10.

Table 4.9 Albert Street (northbound) morning period surveyed data

Vehicle type	Traffic volume	Person volume	Vehicle speed (km/h)
Bus	75	1,573	8km/h
SOV	277	277	14km/h
HOV2	48	96	
HOV3+	14	42	

Table 4.10 Albert Street (southbound) evening peak period surveyed data

Vehicle type	Traffic volume	Person volume	Vehicle speed (km/h)
Bus	74	1,386	8km/h
SOV	428	428	12km/h
HOV2	145	290	
HOV3+	26	78	

The analytical model was calibrated to within 1km/h of the speeds in the general traffic lane, by adjusting the proportion of green time per cycle for through movements along the corridor. No other parameters were adjusted. This provides a good indication that the analytical processes used in the model are able to reflect the corridor performance.

Table 4.11 Albert Street peak period outputs

Case	Preferred treatment		
	Warrants	Productivity	Economic efficiency
Existing layout (morning peak)	Bus lane	Bus lane	T2 lane (marginally)
Existing layout (evening peak)	Bus lane	Bus lane	Bus lane

The key conclusions to be drawn from the assessment are:

- It is evident from interrogating the results that this corridor is a poor-performing corridor in moving people with productivity lower than 30% when measured against the Austroads thresholds.
- It is also evident that neither the special vehicle lane or the adjacent general traffic lane will operate at level of service D or better.

This corridor appears to be a candidate for considerable work to improve its productivity within the space available.

4.6 Great North Road, Auckland (morning peak period)

Great North Road is the major arterial road corridor linking West Auckland and the central city via the town centres of Avondale and New Lynn. It also passes through the neighbourhood centres of Te Atatu, Kelston, Grey Lynn and Point Chevalier. The focus of the analysis is on the section of Great North Road between Avondale and the central city. This part of the corridor is divided into two discrete segments:

1 Avondale – Waterview

2 Waterview – central city.

4.6.1 Avondale – Waterview

The section of Great North Road between Avondale and Waterview is a four-lane arterial with a mix of no median and flush median through to the Waterview Interchange. Along this section there are no special vehicle lanes, and traffic conditions in the morning are heavily congested.

It also serves as the major bus corridor between New Lynn and the central city with a bus approximately every two minutes (12 of those are express services).

The analytical model examined three scenarios:

1 The existing layout with growth of 1.5% per annum in line with the default in the EEM

2 As above but with an elasticity applied

3 As above with an elasticity and no growth in traffic volumes.

The surveyed data was obtained from the Auckland Transport public transport website (maxx.co.nz), the AA traffic website (aa.co.nz) and Auckland Transport for patronage data.

Table 4.12 Great North Road morning peak travel data

Vehicle type	Traffic volume	Person volume	Vehicle speed m/
Bus	28	730	11km/h
SOV	2,156	2,156	
HOV2	504	1,008	
HOV3+	140	420	

The analytical model was calibrated to within 2km/h of the speeds in the general traffic lane, by adjusting the proportion of green time per cycle for through movements along the corridor. No other parameters were adjusted. This provides a good indication that the analytical processes used in the model are able to reflect the corridor performance. The preferred treatments are outlined in table 4.13.

Table 4.13 Great North Road (Avondale – Waterview) morning peak outputs

Case	Preferred treatment		
	Warrants	Productivity	Economic efficiency
Existing layout	T2 lane	T2 lane	T2 lane
Existing layout with behavioural response	T2 lane	T2 lane	T2 lane
Existing layout with no traffic growth and behavioural response	T2 lane	T2 lane	T2 lane

The difficulty in converting a general traffic lane to a special vehicle lane is that it creates a more congested general traffic lane. Without a reduction in traffic volumes through a behavioural response (either increased vehicle occupancy or public transport patronage), this is likely to be the case. Hence a more considered outcome may be to investigate a contra-flow special vehicle lane. This was examined by modelling the special vehicle lane as an added kerbside lane. Scenarios were run for a case with no behavioural response and with a behavioural response. The results are provided in table 4.14.

Table 4.14 Great North Road (Avondale – Waterview) tidal flow morning peak outputs

Case	Preferred treatment		
	Warrants	Productivity	Economic efficiency
Tidal flow (added lane) layout without behavioural response	T2 lane	T2 lane	T2 lane
Tidal flow (added lane) layout with and 0.3 elasticity applied to public transport patronage and average vehicle occupancy	Bus or T3 lane transitioning to a T2 lane in the longer term if traffic volumes grow	T3 lane transitioning to a T2 lane in the longer term if traffic volumes grow	T2 lane

These results are consistent with expectations, and are also aligned with the recommended approach of providing additional road capacity when adding a lane by releasing vehicle capacity in stages in order to maximise the opportunity for people to change their behaviour. However, focusing on only the economic efficiency would lead to the recommendation of providing a T2 lane from the outset.

4.6.2 Point Chevalier – Newton

This section of Great North Road has a dedicated bus lane along its entire length with exceptions at the intersections with St Lukes Road, Williamson Avenue and Bond Street. The number of general lanes varies from two in the western section down to one in the eastern section between St Lukes Interchange and Newton. There are six signalised intersections and four signalised pedestrian crossings along the corridor, with different intersection treatments.

In this case, the analyst would need to decide whether it would be best to model a single corridor, or whether it should be assessed as two corridors. The risk in assessing the corridor in two parts is if the analysis recommends different special vehicle lane treatments for what is effectively a single public transport corridor.

For the purposes of determining the model's suitability in modelling these different characteristics, the corridor was modelled as one segment.

The analytical model examined two scenarios:

1 The existing layout with growth of 1.5% per annum in line with the default in the EEM

2 The existing layout with elasticity and with growth of 1.5% per annum in line with the default in the EEM.

The surveyed data provided by Auckland Transport is outlined in table 4.15.

Table 4.15 Great North Road (Point Chevalier – Newton) morning peak period surveyed data

Vehicle type	Traffic volume	Person volume	Vehicle speed (km/h)
Bus	30	940	26km/h
SOV	850	800	32km/h
HOV2	200	400	
HOV3+	50	150	

Surprisingly, the analytical model was calibrated to within 1km/h of the speeds in the general traffic lane, by adjusting the proportion of green time per cycle for through movements along the corridor. No other parameters were adjusted. In this case, because there are so many changes to a typical treatment along a corridor, the use of the analytical model is best served as a guide for investigating the implementation of treatments in further detail.

Table 4.16 Great North Road (Point Chevalier – Newton) morning peak period outputs

Case	Preferred treatment		
	Warrants	Productivity	Economic efficiency
Existing layout	Bus lane	T3 lane (very little difference between special vehicle lane types)	T3 lane (very little difference between special vehicle lane types)
Existing layout with and 0.3 elasticity applied to public transport patronage and average vehicle occupancy	Bus or T3 lane	T3 lane (very little difference between special vehicle lane types)	T3 lane (very little difference between special vehicle lane types)

From the analysis, the retention of the bus lane is an appropriate recommendation, given that the corridor is not heavily congested, as evidenced through a relatively small difference in productivity and economic efficiency along the corridor with different special vehicle lane types. The author is aware of one location that is heavily congested – the approach to St Lukes Interchange where traffic and buses interact in a single through lane. This is being addressed as part of the upgrade of the interchange, but is not expected to significantly change the recommendations from the assessment, given that the model was intended as a high-level planning and evaluation tool.

4.7 Great North Road, Auckland (evening peak period)

Unlike the citybound direction, the westbound direction on Great North Road has a consistent cross section of one lane plus a bus lane for the majority of its length, with gaps in the bus lanes at the signalised intersections. The intersection with St Lukes Road has a bus queue jump lane although its effectiveness is limited by the left-turn queues blocking access into the lane.

The analytical model examined two scenarios:

1. The existing layout with growth of 1.5% per annum in line with the default in the EEM
2. The existing layout with elasticity and with growth of 1.5% per annum in line with the default in the EEM.

The surveyed data provided by Auckland Transport is outlined in table 4.17.

Table 4.17 Great North Road (Newton – Point Chevalier) evening peak period surveyed data

Vehicle type	Traffic volume	Person volume	Vehicle speed (km/h)
Bus	35	650	25km/h
SOV	590	590	30km/h
HOV2	150	300	
HOV3+	50	150	

The analytical model was calibrated to within 1km/h of the speeds in the general traffic lane, by adjusting the proportion of green time per cycle for through movements along the corridor. No other parameters were adjusted. This provides a good indication that the analytical processes used in the model are able to reflect the corridor performance.

Table 4.18 Great North Road (Newton – Point Chevalier) evening peak period outputs

Case	Preferred treatment		
	Warrants	Productivity	Economic efficiency
Existing layout	Bus lane	T2 lane	T2 lane
Existing layout with 0.3 elasticity applied to public transport patronage and average vehicle occupancy	Bus lane	T2 lane	T3 lane
Layout with continuous bus lanes through the intersections and 0.3 elasticity applied to public transport patronage and average vehicle occupancy	Bus lane (or T3 lane in the longer term)	T3 lane	T3 lane

The key conclusions to be drawn from this assessment are that the level of public transport patronage is not sufficient to support a bus lane. This corridor is a major bus corridor serving the west Auckland region, and surprisingly the data provided indicates that the patronage is approximately two-thirds of the corresponding morning peak period patronage. A sensitivity test using the morning peak period patronage as a proxy revealed no change in the preferred treatment.

In the short term, while the corridor remains relatively free of congestion, the performance of the corridor with a bus lane is comparable to the performance of a corridor with a T2 lane or T3 lane; however, if traffic volumes grow and congestion increases, corridors with a T2 lane or T3 lane will outperform the corridor with a bus lane.

4.8 Summary

The analytical model used for these corridors proved to calibrate very well to the observed travel times along the corridor in the general traffic lanes, which to a degree supports work done to establish the algorithms, which this model has combined. The surprising element was that the calibration typically only required the adjustment of the signal parameters. We therefore consider that the model will be suitable for a high-level planning assessment of the potential for special vehicle lanes.

5 Conclusions

The purposes of the research were to:

- Investigate design, operational and safety issues associated with the introduction of special vehicle lanes, sourcing both local and international evidence.
- Develop warrants for selecting special vehicle lanes with a view to optimising the movement of people and goods along arterial corridors.
- Develop an analytical tool to assess the benefits of special vehicle lanes for the corridor users in motorised vehicles.

The literature review considered three main aspects of the introduction of special vehicle lanes:

- What are the factors used to determine whether the introduction of special vehicle lanes is or will be successful?
- What impact does their introduction have on the effective capacity of the road into which they are introduced?
- What is their longer-term behavioural impact and in particular how is this related to the details of the particular option proposed.

5.1 Keys to success

Typically a range of measures have been determined for HOV schemes but these mainly relate to the performance of the special vehicle lane itself, particularly in relation to the position of the adjacent general traffic lanes. The overall impact on journey times for all users within the corridor is rarely identified and there is also little evidence of any comprehensive cost-benefit analysis of schemes, looking at the overall impacts on users and the costs of introducing, maintaining and enforcing the special vehicle lanes. An example of where a more detailed evaluation was undertaken was for the introduction of special vehicle lanes on a number of particularly congested sections of UK motorways and here a full cost-benefit analysis was undertaken, although not taking account of the operational impacts of special vehicle lanes and using assumed behavioural impacts based on observed results elsewhere.

The lack of a comprehensive framework for measuring the effectiveness of special vehicle lanes linked to the policy objectives means that schemes are vulnerable to pressures for their termination and a number of projects where the specific objectives appear to have been met have been terminated. However, the application of a comprehensive analysis does not necessarily result in schemes being implemented and in the UK where a more comprehensive assessment was undertaken and reasonable returns achieved the proposals were not progressed in the light of concerns about their safety aspects.

Hence, the recommended measures of effectiveness developed as part of this research (and presented in table 2.6) have the following attributes:

- They are closely linked to the policy objectives.

- They consider the whole of corridor performance (eg economic efficiency and corridor productivity) and individual lane performance.
- They are relatively simple to measure, and can be easily reported on using the corridor assessment model.
- They are reflective of the need to consider the operational performance (ie compliance, reliability and level of service by mode) and the user safety.

When looking to implement a special vehicle lane, the road controlling authorities should consider, when evaluating the warrants for a special vehicle lane:

- the role of the corridor in a priority network (general traffic, freight or public transport)
- limiting the eligibility of the special vehicle lane to ensure there is a time advantage over the general traffic lanes
- ensuring that if HOVs are permitted to use the special vehicle lane that the eligibility is sufficient to avoid the ‘empty lane syndrome’
- the benefit and safety of trucks and/or cyclists using the special vehicle lane
- the level of compliance and the ability to enforce the special vehicle lane will directly influence its performance
- recognising that the estimated level of behavioural response in the special vehicle lane is expected to be higher when travel in the corridor represents a higher proportion of the total trip travel time.

This has led to the development of warrants as the minimum performance criteria for considering a special vehicle lane (see table 2.6). The warrants are reflective of the need to compare the special vehicle lane against a general traffic lane as well as the whole of corridor performance.

5.1.1 Impacts on capacity

The introduction of special vehicle lanes is likely to have an impact on the operational characteristics of the road in which they are located (and this factor is recognised in several sources), although there is very little published analysis of the effects in practice. Work in San Francisco identified a loss of capacity in special vehicle lane in a freeway of up to 20%. Analysis of a special vehicle lane on an arterial route in Auckland undertaken as part of this study suggested a reduction of capacity of about 15% on the special vehicle lane and about 8% on the adjacent general traffic lane. Furthermore, there was a steeper degradation in speed when the special vehicle lane was in operation. Both of these are consistent with the theory of ‘side-friction’ in the selection of the appropriate speeds.

Behavioural response

There is rather more information on the longer-term behavioural impacts of average vehicle occupancy in the corridor affected and in general, although not in all cases, these have shown an increase as travellers take advantage of the faster travel times in the special vehicle lane. There is evidence both of the impacts on arterial roads as well as on freeways. In general as might be expected, the increases in average vehicle occupancy are related to the potential journey time savings but these need to be assessed within the context of the overall package offered to HOVs. As an example, a very large increase in average vehicle occupancy was achieved in a case where the time savings were modest but where use of the special vehicle lane was accompanied by employer incentives for carpooling.

5.1.2 Impacts on productivity

A key finding from this research has been the process for managing the impact and benefits of special vehicle lanes using the corridor productivity measure in its monetised form. The justification is provided in figure 2.18 and can be summarised as follows:

1. In adding a lane – the eligibility should be progressively released to have the greatest potential for mode shift or increase in vehicle occupancy, in order to minimise the 'loss' in productivity if the need to convert increases the level of eligibility.
2. In converting a lane once the productivity starts to decline – progressively expand the eligibility to minimise the impact on the remainder of the network in order to maintain access into the special vehicle lanes.

In planning for special vehicle lanes, a balance may be needed between the process to manage congestion by expanding eligibility and the need to restrict eligibility when the special vehicle lane becomes congested. The aim should be to minimise the gap between the peak productivity prior to the general traffic lane becoming congested, and the peak productivity prior to the special vehicle lane becoming congested. It is the level of behaviour change that will influence this gap.

5.1.3 Corridor assessment model

An analytical model created in Microsoft Excel was developed to assess the relative performance of special vehicles on arterial roads, accounting for the major influential factors in urban corridors namely:

- intersection performance, spacing and level of coordination
- mid-block lane performance
- on-line or off-line bus stops and bus stopping times
- level of take-up and level of violation
- parking, merging and access
- behavioural response to the implementation of special vehicle lanes.

The advantages of the model are that it:

- is generic and can be applied across New Zealand and Australia.
- is highly flexible in the amount of data required to undertake the assessment, therefore is suitable for high-level planning and monitoring where data such as turning counts may not be available or are expensive to collect.
- uses established analytical techniques outlined in:
  - HCM (2010) methodologies for urban streets for the intersection delays and corridor performance
  - Kittelson & Associates et al (2003) for the calculation of bus service capacity

- HCM2010 for uninterrupted facilities for the calculation of mid-block travel times on freeways.

- allows for an 'elasticity' to be applied, if forecast mode splits and vehicle occupancies are not known. The elasticity used has been derived from the research work presented earlier in this report
- can be easily calibrated to observed travel times along the corridor for buses and other traffic.

The current limitations of the model are consistent with the urban street methodologies in HCM2010, including those listed below:

- The model applies only to signalised intersections.
- The model, while not designed to account for changes in layout along the corridor such as different intersection treatments or changes in the number of mid-block lanes, has revealed that the predicted performance along corridors with different layouts is very close to observed performance.
- The model is designed to assess long corridors rather than short sections of road, although it could be used for short sections without considering behavioural response (ie elasticities).
- The model is intended to be a planning level model and not a detailed evaluation tool.

The analytical model provides a simple and useful tool to assess the predicted performance of a special vehicle lane and provides a quantifiable estimate of performance, rather than relying on a policy decision for selecting whether a special vehicle lane is desired, and what that should allow.

The key findings from the evaluation of a number of corridors in Auckland with a special vehicle lane are that:

- The established equations to estimate travel times and delays are fairly robust as evidenced by only minor modifications to signal timings to calibrate the models to journey times.
- The evaluation indicates when the corridor becomes congested, the use of special vehicle lanes provides a more efficient outcome in moving more people in a quicker time than for general traffic lanes; however, this is more likely to be through the use of a transit lane than a bus lane.
- The evaluation indicates there is an opportunity to determine the level of public transport patronage that would justify on economic grounds, the use of a bus lane over a transit lane (ie the level of bus patronage is sufficiently high that any increase in vehicle use would lead to a loss in economic performance of the corridor).

6 Recommendations for further investigation and development

While the work has achieved the objectives, there are a number of areas that would benefit from further research:

- The impact of having special vehicle lanes on capacity because of limited data sample. Traffic engineering theory suggests that differential speed and lane widths are two contributing factors to lane capacity and the rate at which the base speeds reduce.
- Impact of transit lanes on mode choice, or choice to carpool – there is very little evidence to either confirm or deny that the choice to carpool is an elastic relationship. The elasticities for mode choice to use car or public transport are well established, but not for HOVs, or for determining whether car passengers are changing to public transport and vice versa. The Fanshawe Street example indicates that a large number of car passengers have switched to bus services demonstrated by a much lower proportion of HOVs compared with other corridors in the Auckland region.
- Safety of special vehicle lanes – there is very little evidence at this stage but there will be a lot of crash data available in New Zealand and probably in Australia as well. There are extensive bus lane and transit lane components in the urban networks in Australia and New Zealand, hence it is foreseeable that the relative safety of special vehicle lanes could be evaluated.
- Refinement of the corridor assessment model to assess multiple layouts in a single run and assess intersection capacities (depending on the data requirements), and to determine the threshold for patronage and vehicle use to justify the type of special vehicle lane rather than relying on a demand analysis.

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Appendix A: Typical treatments

A1 Mid-block treatments

A1.1 Kerbside special vehicle lane

Kerbside special vehicle lanes are the most common form of treatment in New Zealand, but they do not come without challenges. Kerbside special vehicle lanes are most appropriate:

- in spatially constrained urban corridors limiting opportunities for segregated facilities
- where there is a desire or need to provide priority for buses that pick up and drop off passengers along the corridor.

Figure A.1 Examples of kerbside special vehicle lane

Bus lane – Dominion Road, Auckland

T3 lane – Onewa Road, Auckland

A1.1.1 Benefits

The benefits of kerbside special vehicle lanes are that they provide:

- greater ease of bus passenger pick up/drop off without requiring bus passengers to cross traffic lanes to access/egress bus stops
- the ability to make use of the available road space throughout the day by striking a balance between off-peak functions of the corridor (eg parking, turning and stopping)
- the ability to restrict vehicle capacity upstream of congested bottlenecks, by designating the lane to allow only a limited proportion of traffic to use the lane (eg bus lane, T2 lane, T3 lane etc)
- the opportunity to provide a gradual increase or decrease in vehicle capacity depending on whether the special vehicle lane is an added lane to the existing corridor (or new corridor), or converted from an existing general traffic lane.

A1.1.2 Challenges

Some of the issues that can reduce the effectiveness of a kerbside special vehicle lane are:

- loss in lane capacity due to in-lane bus stops for HOVs and express buses using an HOV lane and a bus lane where there is a large volume of buses
- delays for buses re-entering an HOV lane from an indented bus stop
- increased potential for lane changing crashes where vehicles must enter the special vehicle lane to leave the roadway, particularly given the higher speeds in the special vehicle lane
- interference caused by:
    - turning or entering vehicles
    - illegal users of the special vehicle lane (noting that this is common to all special vehicle lanes)
    - stopped vehicles (illegally parked or breakdown)
- safety/visibility for right-turning vehicles crossing a queue of general purpose vehicles and a freely flowing kerbside priority lane
- the safety risk (exposure) for cyclists due to lane width, and eligibility in the lane
- lack of provision of space for off-lane enforcement
- lack of appropriately located bus bays required for efficient movement in lane.

A1.2 Special vehicle lane in the second lane

A special vehicle lane in the second lane is appropriate where there is a high demand for turning and parking movements throughout the day, and there is a bus stop facility as near to the kerb as possible. An example of this application is in shopping precincts where parking bays are provided.

Figure A.2 Special vehicle lane in the second lane

Bus lane – Dominion Road, Auckland

A1.2.1 Benefits

The major benefit of a special vehicle lane in the second lane (or first available through lane) is in the improved efficiency through reduced conflicts between users of the special vehicle lane (including cyclists) and parking, stopping and turning movements. There is also a greater opportunity for manual enforcement of the special vehicle lane.

A1.2.2 Challenges

The challenges of a special vehicle lane in the second lane, over and above those for a kerbside special vehicle lane (refer section A1.1.2), are:

- they can only be implemented where there is a minimum of three lanes in the direction of travel (ie with a kerbside lane used for stopping, turning and parking)
- the kerbside lane needs to be discontinuous (through kerb build-outs or bus boarders) to deter motorists from using it as another traffic lane for through movements
- there are issues associated with general traffic crossing the special vehicle lane to access the kerbside lane for parking, stopping or turning movements
- the lane would require bus boarders for efficient loading and unloading of passengers or a bus stop in the kerbside lane depending on the interference
- drive-in, drive-out parking bays would be required to ensure that vehicles waiting to park are not blocking the special vehicle lane.

A1.3 Median special vehicle lane

Median special vehicle lanes are only suitable where:

- buses using the kerbside lanes to pick up or drop off passengers are not afforded any priority
- there is no requirement to pick up or drop off bus passengers
- the required movements at the end of the segment are either through movements or right-turn movements.

Figure A.3 Examples of a median special vehicle lane

Median bus lane – Wairau Road, Auckland

Median bus lane – Lambton Quay, Wellington

A1.3.1 Benefits

The key benefits of a median special vehicle lane are:

- high-speed traffic (HOVs, express bus services and potentially commercial vehicles) are on the conventional right-hand side (for left-hand drive)
- interference from turning, parking and stopping is minimised for users of the special vehicle lane.

A1.3.2 Challenges

The challenges associated with providing a median special vehicle lane are:

- it is an unconventional location for a special vehicle lane and could lead to driver confusion, particularly for those wishing to turn right
- right-turn bays must be provided to allow for turning traffic to wait clear of special vehicle lane traffic
- it is not suitable for cyclists due to the location being near the centre of the road
- more traffic uses kerbside lanes therefore increasing the exposure for cyclists
- there is reduced vehicle efficiency along the corridor (compared with a kerbside special vehicle lane) due to the general traffic travelling in the kerbside lanes and the losses associated with turning, parking, stopping and local bus services.

A1.4 Segregated special vehicle lanes

Segregated facilities are provided to separate the special vehicle lane from general traffic. These types of facilities are suitable where there are corridors that serve a strategic function for longer distance trips, whether by bus or HOV. In that sense, they are similar in nature to a motorway or rail network. In an urban environment, two-way facilities can be provided in the centre of the road or on one side of the road. Single reversible lanes (where the traffic travels in one direction in one peak period, and the opposite direction in the other peak/s) should be located in the centre of the road to provide safe transitions back to the arterial at the start and end of the lane.

They are typically suited where:

- there is high demand in both directions throughout the day if a two-way facility is under consideration, or a tidal demand where a single reversible lane could be considered.
- a long facility can be provided
- key activity centres and transport interchanges are being linked as part of an integrated network.

Figure A.3 Examples of segregated facilities

Victoria Bridge (South East Busway), Brisbane, Australia

Canal Street bus lanes, New Orleans

A1.4.1 Benefits

The benefits of providing a segregated facility are they:

- eliminate interference caused by turning, stopping and parking between intersections, therefore maximising the benefits for eligible users
- provide consistent travel times for users of the facility throughout the day, therefore maximising the reliability of travel times.
- are typically high-quality facilities which incorporate station-type facilities at greater spacing than on-street facilities, therefore providing a higher-quality level of service for longer-distance passengers.

A1.4.2 Challenges

The challenges of providing a segregated facility are:

- the cost of providing a facility may not be economically viable, even if functionally, it is a preferred treatment
- turning movements, crossing movements and access to the local street network are restricted to controlled points (traffic signals)
- there are large spatial requirements for these facilities, including the need to provide a safe environment for boarding passengers
- there are additional conflicts at the signalised intersections that need to be effectively managed
- the interface to the local network (start and end of the facility) needs to be designed to ensure an efficient and seamless transition to the remainder of the network
- cyclists are typically prohibited from using such facilities, placing them in the general traffic lanes, or requiring a separate off-road facility
- the design requires large intersections, therefore potentially reducing the efficiency of the intersection and public acceptance of the facility.

- single reversible lanes are not suitable for bus operations due to potential confusion for passengers with stopping services using different parts of the road in peak and off-peak conditions.

A1.5 Contraflow lanes

Contraflow lanes allow travel in the opposite direction to the normal flow of traffic. Under two-way operation, contraflow lanes are a form of tidal flow management which is commonly deployed on motorways (which Auckland's Harbour Bridge being a prime example). Special cases of contraflow lanes exist in one-way systems where the special vehicle lane operates in the opposing direction to the general traffic. Contraflow lanes are suitable where:

- there is a high demand for travel in a single direction
- the travel in the off-peak direction is not adversely affected by having a lane 'borrowed' for the contraflow operation on two-way roads
- improved access to constrained networks (eg central business districts) can be provided in one-way systems.

Figure A.4 Examples of tidal flow facilities to allow for kerbside bus lanes

Auckland Harbour Bridge (Northern Motorway), Auckland. Moveable barrier allows kerbside lane to be reserved for buses

Coronation Drive, Brisbane (now removed). Central reversible lane allows kerbside lane to be reserved as a bus lane in peak periods

Figure A.5 Examples of reversible lanes

I-394 Minneapolis (HOV lane)

I-394 Minneapolis (temporary arterial HOV lane)

Figure A.6 Examples of contraflow lanes

Lambton Quay, Wellington

Boulevard PIE-IX, Montreal, Canada

A1.5.1 Benefits

The benefits of using contraflow lanes are they:

- allow better use of the available carriageway under high directional demand conditions
- minimise the impact on congested peak direction general traffic
- minimise priority vehicle delay (if the lanes are provided in the median).

A1.5.2 Challenges

The challenges associated with contraflow lanes are:

- it is difficult to place bus stops on them unless the lane is used for general traffic and the special vehicle lane is provided on the kerbside
- bus stops can only be used if the contraflow lane is on a one-way street, or allocated to the kerbside lane
- the design of these lanes is suited to peak conditions for two-way operation
- there are high operational costs for tidal flow systems on two-way arterials
- the transition between contraflow operations and normal operations needs to be carefully designed and specified
- it requires clear and effective signage and markings to minimise the risk of drivers using the contraflow lane in error
- where the special vehicle lane is in the median, turning and access restrictions will be needed to ensure safe and efficient operation

A2 Intersection treatments

The following sections outline the typical intersection treatments available for providing special vehicle lanes.

A2.1 Queue jump lanes

A queue jump lane is a targeted treatment at intersections to provide priority for eligible users of a special vehicle lane to enable them to proceed ahead of general traffic. Queue jump lanes are typically provided in isolated situations but can also be included as part of a corridor strategy for kerbside lane use. Furthermore, their application is best suited where:

- the level of usage does not warrant a dedicated special vehicle lane
- congestion in the mid-block does not significantly impede the operation of potential users of a special vehicle lane
- spatial constraints preclude the installation of a special vehicle lane as an added lane along the corridor
- conversion of a general traffic lane to a special vehicle lane would result in unacceptable levels of congestion in the general traffic lanes.

The most common form of a queue jump lane is a bus lane, but HOV queue jump lanes could also be provided; however, if an early start is to be provided for the users of the queue jump lane, the rules and legislation governing traffic signals must allow for a traffic signal to reflect HOVs, otherwise it will have to be a separately controlled lane.

Figure A.7 Examples of queue jump lanes

New North Road, Auckland

East Coast Road, Auckland (approach to a roundabout)

A2.1.1 Compatibility

A queue jump lane is compatible with:

- a kerbside special vehicle lane where left-turn bays or slip lanes are provided
- a special vehicle lane in the second lane, or where there is no special vehicle lane in the mid-block but priority is necessary to improve the level of service and performance for eligible users of a special vehicle lane.

A2.1.2 Benefits

The benefits of queue jump lanes are:

- limited amount of physical works are required to provide priority at the intersections – the major source of urban corridor delays
- a bus queue jump lane allows for buses (in conjunction with traffic signal priority) to proceed ahead of the general traffic where there is no special vehicle lane downstream of the intersection
- HOV queue jump lanes are suitable for providing priority where there is a special vehicle lane downstream.

A2.1.3 Challenges

The challenges associated with queue jump lanes are:

- they should be sufficiently long to allow users to queue in the lane without interfering with other traffic
- the intersection approach should be designed to allow unimpeded access into the queue jump lane
- vehicles using the queue jump lane, and arriving in the middle of the green period (common in heavily congested conditions) require a downstream special vehicle lane to avoid merging conflicts within the intersection. If this is not provided, the special vehicle lane needs to be separately controlled resulting in a disbenefit for users
- where a downstream lane is provided for an HOV queue jump lane, merging at the end of the special vehicle lane may negate the benefits of the queue jump lane
- traffic signal priority in allowing special vehicle lane traffic to proceed ahead of general traffic (a 'B' signal) cannot be provided for an HOV queue jump lane unless the lane is physically separated from the general traffic lanes and controlled separately. If the lane is separated, then the lane would face a red signal when the general traffic lanes are operating under a green signal. This may negate the benefits of providing an HOV queue jump lane.

A2.2 Dedicated special vehicle lane

A dedicated special vehicle lane at the intersections is an extension of a mid-block special vehicle lane through the intersections. A recent change in the Traffic Control Devices Rule in New Zealand allows for a special vehicle lane to be designated through intersections rather than terminating prior to intersections.

Figure A.8 Examples of queue jump lanes

Esmonde Road, Auckland

Akoranga Drive, Auckland

A2.2.1 Compatibility

A dedicated special vehicle lane is compatible with any form of mid-block special vehicle lane treatment provided continuity is provided between the mid-block and intersection treatments.

A2.2.2 Benefits

The benefits of a dedicated special vehicle lane at the intersection are:

- they provide continuity of the special vehicle lane along the corridor
- they maximise the benefit of the special vehicle lane along the corridor for the eligible users
- they reduce the amount of conflicting lane changing movements on the intersection approach (when compared to the scenario where a special vehicle lane terminates prior to an intersection)
- the congestion due to merging at the recommencement of a special vehicle lane downstream of an intersection is eliminated.

A2.2.3 Challenges

The challenges associated with a dedicated special vehicle lane at intersections are:

- if left-turn bays are not provided, the eligibility for the special vehicle lane and level of pedestrian protection needs to be carefully considered to ensure the lane does not become congested and outweigh the benefits of providing a special vehicle lane through the intersection. This is particularly relevant in high-pedestrian, high-bus volume environments, where the general traffic lane can be more efficient than the special vehicle lane
- the conversion of the general traffic lane at the intersection may result in unacceptable congestion in the remaining general traffic lanes
- the impact of bus stop location on the operation of the special vehicle lane through the intersection needs to be carefully considered to maximise the efficiency of the lane. In-lane stops on either side of

the intersection will reduce the efficiency of the lane through the intersection, which may have a detrimental effect.

A2.3 Special vehicle lane termination

A special vehicle lane termination is a scenario where the special vehicle lane terminates prior to intersections, and continues as a general traffic lane through the intersections. The legal interpretation in New Zealand prior to the recent change in the Traffic Control Devices Rule was that special vehicle lanes had to terminate prior to the intersections, and recommence downstream of the intersections. This type of treatment favours the movement of vehicles along a corridor more so than the movement of people and goods, as it considers the efficiency of vehicle movements.

A2.3.1 Benefits

The benefits of this treatment are that it:

- provides a balance between priority given to eligible users of the special vehicle lane and congestion experienced by other users at the intersection
- provides some level of priority for eligible users of the special vehicle lane at heavily congested intersections by allowing them to bypass queues in the general traffic lane that extend beyond the point at which the special vehicle lane terminates
- increases the overall efficiency for vehicles at the intersection by maximising the vehicle throughput.

Figure A.9 Examples of special vehicle lane termination

Great North Road, Auckland   Sandringham Road, Auckland

A2.3.2 Challenges

The challenges associated with this treatment are:

- there is a higher frequency of lane changing movement on the approach to the intersection as general traffic changes lanes
- it decreases the attractiveness for cyclists as general traffic occupies the lane on the approach to the intersection, unless a cycle lane is extended through to the intersection

- an additional source of delay is introduced downstream of the intersection where the special vehicle lane recommences and general traffic must rejoin the general traffic lanes
- it reduces the effectiveness of a special vehicle lane in influencing behaviour change and mode shift by reducing the travel time benefits associated with the use of a special vehicle lane
- the combination of pedestrian protection, left-turning traffic and the use of the kerbside lane by other through traffic can negate the benefit of providing a mid-block special vehicle lane.

A2.4 Gating systems

Gating systems are a form of traffic signals installed a short distance upstream of another intersection to allow users of the special vehicle lane to advance to the intersection ahead of the general traffic. The traffic signals operate by detecting a vehicle in the special vehicle lane and terminating the phase for general traffic for a short period of time, therefore allowing the vehicle in the special vehicle lane to continue unimpeded to the intersection. They are similar to the advance traffic signal for buses (a ‘B’ signal) provided in conjunction with a queue jump lane at an intersection, except they are located upstream of the major intersection.

Figure A.10 Examples of traffic signal gating systems

Ann Street, Brisbane

Dixon Street, Wellington

London

A2.4.1 Compatibility

A gating system is compatible with the special vehicle lane termination, and where the users of the special vehicle lane need to cross the general traffic lanes to turn into a side road. They are appropriate where the level of usage in the special vehicle lane is low, so as not to interrupt the general traffic flow too often.

A2.4.2 Benefits

The benefits of a gating system are a combination of the benefits associated with a special vehicle lane termination and a queue jump lane in that the approach to the major intersection is controlled to provide priority for special vehicle lane users but managing the conflicting traffic movements on the approach to the intersection. They can also be used in combination with a signalised pedestrian crossing to provide an additional crossing point in areas with high pedestrian activity.

A2.4.3 Challenges

The challenges associated with a gating system are:

- traffic signals need to be installed at a distance that allows unimpeded access to the major intersection
- the traffic signal design needs to be undertaken in such a way that users of the general traffic lanes are not looking through to the major intersection signals
- traffic signal priority in allowing the special vehicle lane to proceed ahead of general traffic (a 'B' signal) cannot be provided for an HOV lane unless the lane is physically separated from the general traffic lanes and controlled separately. If the lane is separated, then the lane would face a red signal when the general traffic lanes are operating under a green signal. This may negate the benefits of providing an HOV lane.

A2.5 Special vehicle turning lane

A special vehicle turning lane is a lane dedicated to eligible users to turn from the road into a side road. They are suitable for providing priority into a major trip generator or HOV facility (eg park and ride lot, shopping mall, freeway access ramp, ramp meter bypass lane). They can be used in isolation or as part of a broader strategy.

Figure A.11 Examples of queue jump lanes

Fred Taylor Drive, Auckland – access to shopping centre

Te Atatu Road, Auckland – access to motorway

A2.5.1 Compatibility

They can be used in isolation or with:

- a gating system where the mid-block special vehicle lane is in the kerbside lane or second lane
- a median special vehicle lane.

A2.5.2 Benefits

The benefits of providing a special vehicle turning lane are:

- they improve options for HOVs travelling across the network
- they improve bus service reliability where routes leave the corridor, or access major facilities such as bus stations
- they can be easy to enforce on the exit to the intersection
- if used in isolation, the traffic signals could operate on demand depending on the frequency of the turning phase.

A2.5.3 Challenges

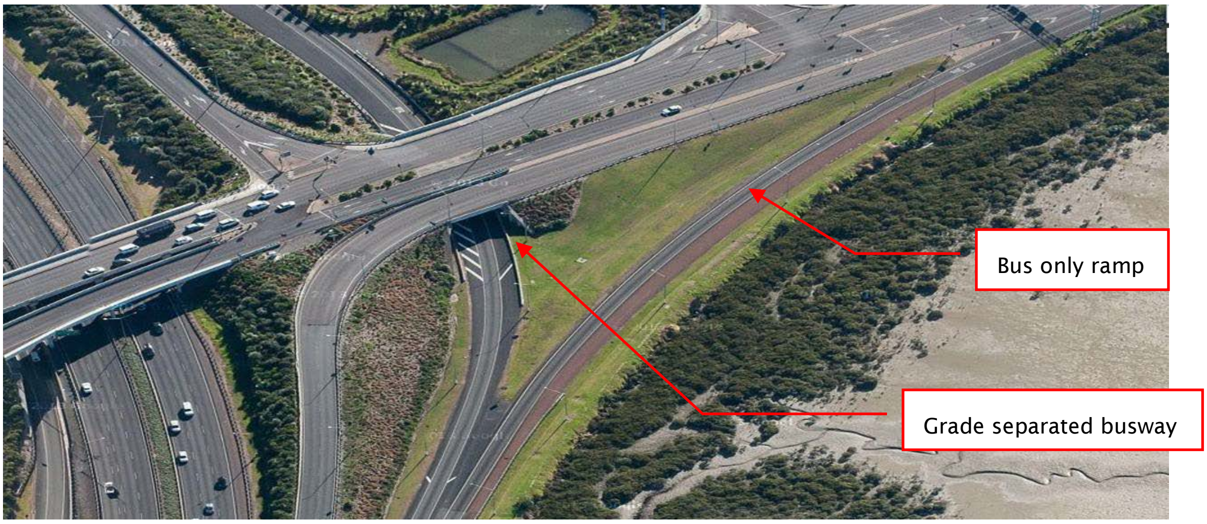
The challenges of providing a special vehicle turning lane are:

- the lanes should be sufficiently long to allow users to queue in the lane without interfering with other traffic
- the intersection approach should be designed to allow unimpeded access into the turn lane
- the lane could be confusing for motorists without clear and effective signage and markings, particularly if the intention is to allow for peak-time operation only
- a dedicated special vehicle lane would be required on the exit leg of the turning movement
- traffic signal priority through an advance signal (a 'B' signal) cannot be easily provided, and is precluded for an HOV lane unless the turn lane is separated from other turning lanes.

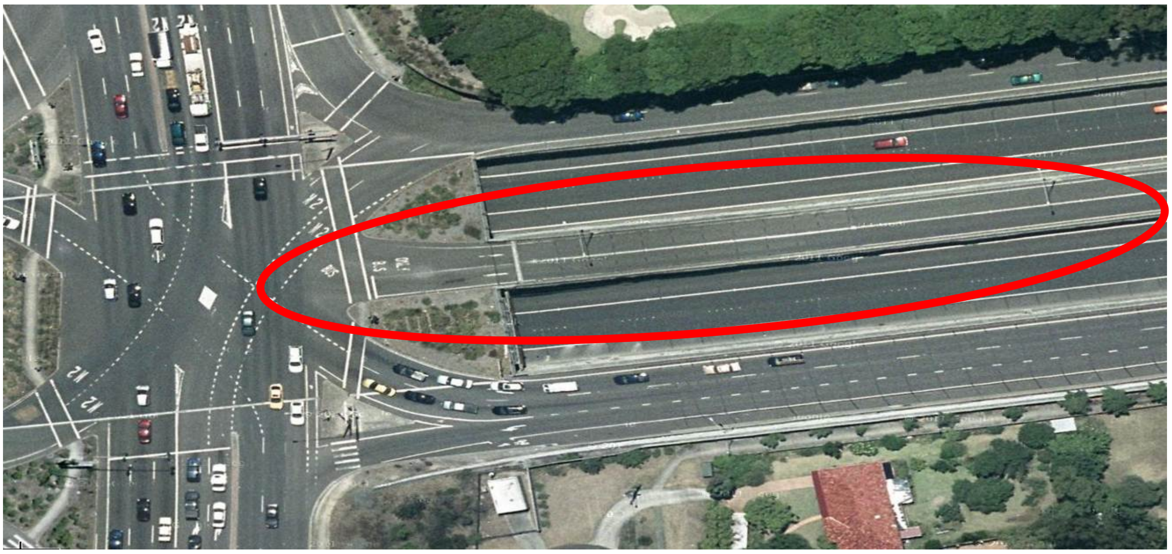
A2.6 Grade separation

Grade separation of special vehicle lanes provides unimpeded movements through urban intersections, but at a high capital cost. They are rare in an urban arterial context but most effective in conjunction with special vehicle lanes over a long length. The development of grade separation options is more common on installations of segregated facilities adjacent to motorway corridors, for example, on Auckland's North Shore and Brisbane's Pacific Motorway.

Figure A.12 Examples of grade separated facilities



Northern Motorway – bus only ramp from Esmonde Road to motorway bus lane



M2 Sydney – bus only ramps to motorway median bus lanes

A2.6.1 Compatibility

This treatment is only compatible with segregated facilities, or where there are no turning movements adjacent from median special vehicle lanes that need servicing.

A2.6.2 Benefits

The benefits of providing grade separating special vehicle lanes along urban corridors, are that delays associated with intersection operation are eliminated, therefore providing the greatest opportunity to influence behaviour change and mode shift.

A2.6.3 Challenges

The challenges associated with grade separation are:

- the intersections need to be designed as urban interchanges

- it requires a high level of use by people (not necessarily vehicles) to be justified
- the cost and space required may outweigh the economic benefits of providing the facility
- it is likely to constrain or preclude further intersection improvements, without considerable expense
- the management of turning movements and access along the corridor needs to be carefully considered
- it is intrusive on an urban environment through severance and aesthetics
- it requires a high level of priority treatment along the corridor to provide a continuous bus or HOV facility.

A3 Guide to the selection of appropriate facilities

There are many other factors to consider, as well as spatial requirements and demand, including:

- intersection spacing and coordination
- roadside development and property access
- the management of road space (ie parking, stopping and turning) throughout different times of the day
- the need to provide kerbside access to a bus stop
- the need to provide priority for turning buses
- the potential for traffic signal priority at the intersections
- the function of the special vehicle lane (eg busway as part of a segregated network versus a bus lane on an arterial road)
- crossfalls and clearances to awnings, signs and footpaths
- the cost of implementation.

The analytical model developed for this research project allows the user to consider the above along the corridor to determine whether:

- an added lane can be provided or whether a converted lane can be provided based on the available road reserve width
- the special vehicle lane is suitable for cyclists based on the lane widths (noting that the decision to provide a separate cyclist facility is also dependent on the volume of traffic)
- a special vehicle lane is suitable for trucks.

Appendix B: Model specification and user guide

B1 Software requirements

The analytical model was developed in Microsoft Excel 2010, and is a macro-enabled workbook (.xlsm). It has not been tested in other versions of Microsoft Excel.

The model can be accessed at www.nzta.govt.nz/resources/research/reports.557.

B2 Running the model

The spreadsheet will open to the inputs page, where the user can enter the required information to run the model.

Once the inputs are complete, the user can press the button at the bottom of the page to run the model. The model will take approximately one minute to run on a high-powered computer.

The model will be saved in the 'default' directory (typically the 'Documents' library) in the Windows operating system. If the user wants to save the model to a different directory, it is recommended to save it to that directory prior to running the model. The file name will be the name of the corridor under investigation. If the file exists in the directory, the user will be prompted to overwrite the existing file.

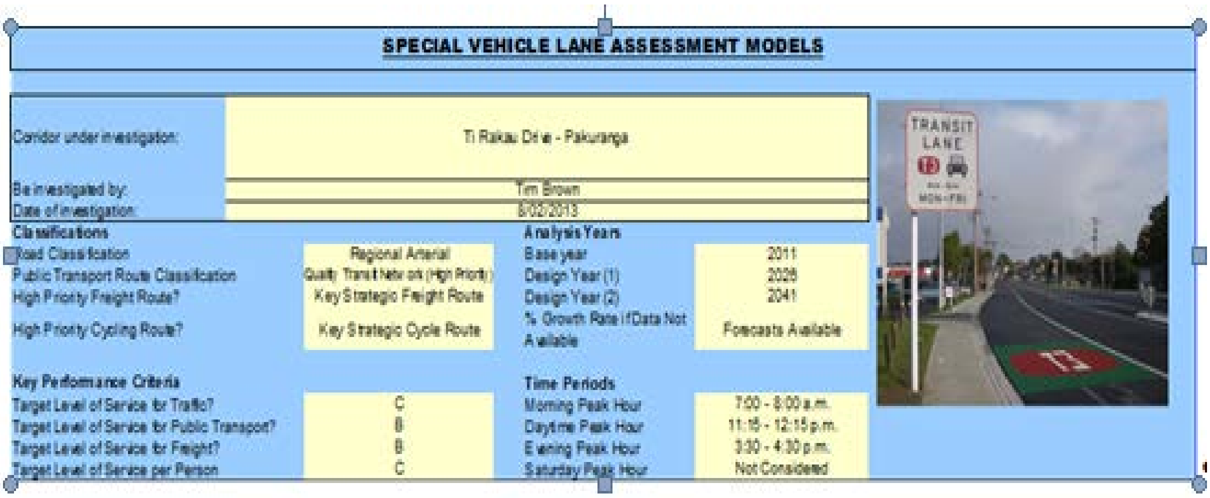
Once the model has completed running, the results will be saved as a PDF in the same location as the model, and then take the user to the 'Outputs – Performance' tab.

B2.1 Inputs

B2.1.1 General information

The user is prompted for general information about the corridor under investigation and the time periods that are to be considered for the evaluation, as outlined in figure B.1. The selected corridor should have a consistent number of lanes in the direction of travel in the mid-block.

Figure B.1 Model inputs page – general information and target levels of service



In this section the user is prompted to enter:

- The corridor under investigation – the corridor name is used as the file name to save the model, and is therefore subject to file name length constraints built into the Windows operating system.
- The road classification within the network hierarchy – motorway, regional arterial, local arterial, collector road or local street. This input is used to determine the class of road (Class I to Class IV) in estimating the free-flow running speed as per the methodology outlined in the *Highway capacity manual* (HCM2010) (TRB 2010) and adapted by Austroads (2009).
- The public transport route classification – rapid transit network, primary route (eg public transport priority routes on arterials), secondary route (eg lower priority routes on arterial roads), local route (eg bus routes on local streets), or not a bus route.
- Whether the route is a key strategic freight route or not.
- Whether the route is a key cycling route or not.

Apart from the road classification input, the remaining inputs provide a guide to the user as to the relative priority that should be given for each mode using the corridor, as well as the facilities that should be provided. As an example, if the user specifies that the route is a key freight route and a key cycling corridor worthy of on-road cycle lanes, the geometry provided in the assessment should consider whether freight should share the special vehicle lane with cyclists.

The user is also prompted to enter the key performance criteria in terms of the desirable, or target, level of service. The classification inputs from above should provide a guide to the corridor's target levels of service. These target levels of service are used directly in the comparative evaluation of the special vehicle lanes.

The levels of service adopted range from A through to F based on:

- for urban corridors – the forecast speed as a percentage of the free-flow speed (or base running speed).
- for a motorway – the density of traffic.

At this stage no formal priority weightings have been adopted, but in specifying a higher level of service for a particular mode gives, in effect, a weighting of level of service band 1 or 20% per band. Further stages of development in the model will adopt the SMARTROADS priority weighting and operating gap assessment.

B2.1.2 Mid-block and traffic signal details

The specification for mid-block details is separated into three parts as outlined in figure B.2, namely:

1. Road classification
2. Geometry and capacity
3. Traffic signal details and the 'lowest acceptable travel speed'.

Figure B.2 Model inputs page – mid-block and traffic signal details

THE ROAD

ROAD CLASSIFICATION	
Length of corridor being investigated (km)	3.000
Corridor width (including berms/verges)	21-30m
Posted speed (kph)	50
Number of "clear" lanes in direction of travel	2
One way road or two-way road	Two Way
Parking and/or shoulder	Parking Allowed
Type of median	Raised Median
No. of traffic signals along route?	4
Roadside Development Intensity	Medium
Pedestrian Activity	High Activity
Frequency of driveway accesses	Moderate
Function Category	Principal - High mobility function
Design Category (score)	15
Design Category	Intermediate
Road Class	Class II
Estimated Free Flow Speed (kph)	60
Estimated Base Running Speed (kph)	56

GEOMETRY	
Mid-block Capacity (through car units per hour per lane)	1,450
Kerbside lane width	3.0m - 3.5m
Kerbside Lane Suitable for on-road cycling (if not a Motorway)?	Not Suitable for on-road cyclists
Kerbside Lane Suitable for on-road cycling with Trucks (if not a Motorway)?	Not Suitable with Trucks
Will Trucks be allowed to use the Special Vehicle Lane?	No
Width of other lanes	3.0m - 3.5m
Speed-flow friction factor	1.0
FRICTION FACTOR UPLIFT FOR PRIORITY LANE	***0%***
Pavement width (Allows for 2.5m median)	15.7
Is there enough space to add a lane along the corridor?	Yes
Added Lane or Converted Lane?	**Added Lane**
TRAFFIC SIGNALS AND MINIMUM ACCEPTABLE CORRIDOR SPEED	
Route Cycle Time	120
Level of Co-ordination	*4 - Favourable Co-ordination*
Green Time Proportion for the Through Movement	75%
Pedestrian Protection	None or SCRAMBLE X-ing
Lowest acceptable travel speed (kph)	**10**

B2.1.3 Road classification

The user is prompted to enter details about the corridor that will enable the calculation of the base running speeds, which is then used in the calculations of mid-block travel speed and travel time in the kerbside lane and the other traffic lanes.

The road classification details are essentially the primary level information needed for the model to determine:

- base running speeds – this is estimated using the methodology outlined in the HCManual2010, and the *Economic evaluation manual* (EEM) (NZ Transport Agency 2013). This base running speed is used as the free-flow speed for the estimation of the level of service and is the free-flow speed input for determining the mid-block speed using ART3 model speed flow curves
- number of lanes used for the assignment of traffic flows in the mid-block
- number of intersections to apply the calculated intersection delay and merge (bottleneck) delay where the user specifies that the special vehicle lane terminates prior to the intersections and recommences downstream of the intersections.

B2.1.4 Mid-block geometry

The user is prompted to enter the details of the mid-block geometry – the mid-block capacity and speed-flow friction factors (the J-parameter) – which are used to:

- calculate mid-block running speeds – typical values for mid-block capacity are provided in table B.1, and have been used in the ART3 model.
- provide guidance on whether the kerbside lane width is a) suitable for cyclists if trucks are not permitted to use the special vehicle lane, and b) suitable for cyclists if trucks are permitted to use the special vehicle lane
- decide whether trucks should be allowed in the special vehicle lane, giving consideration to the needs of cyclists
- determine if there is sufficient space along the corridor to provide an 'added lane' in each direction without land acquisition

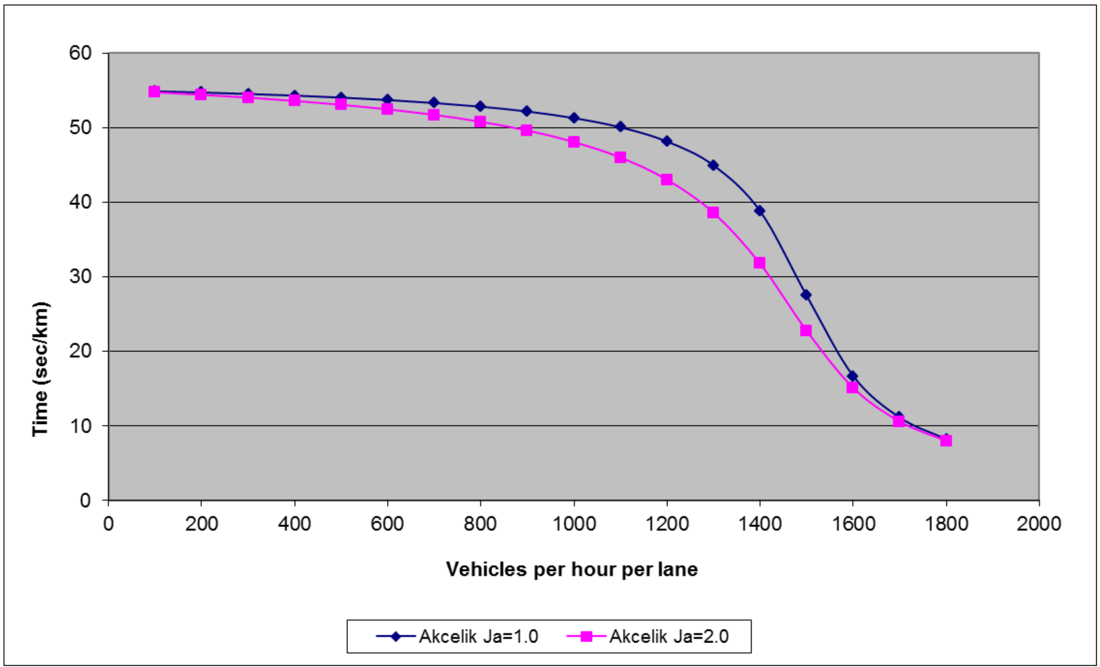
- decide whether the special vehicle lane will be an added lane next to the existing general traffic lanes, or whether one of the existing general traffic lanes will be converted to a special vehicle lane.

Table B.1 Typical mid-block capacity and friction factors

Road classification	Typical mid-block capacity	Typical friction factor (J-parameter)
Motorway	1,800 to 2,200 vehicles per lane per hour	0.4
Regional arterial	1,200 to 1,500 vehicles per lane per hour	0.6
Local arterial	900 to 1,200 vehicles per hour per lane	0.8
Collector road	600 to 900 vehicles per hour per lane	1.0
Local street	300 to 600 vehicles per hour per lane	1.2

The user is also prompted to specify an uplift in the friction factor to allow for effect that the differential speed across the lanes has on the operation of the special vehicle lane. Figure B.3 presents the impact of a higher friction factor on the mid-block running speeds for a 50km/h free-flow speed and 1,500 vehicles per hour capacity.

Figure B.3 Effect of friction factor on mid-block speed



As presented in section 2.4.3, there appears to be a reduction in capacity and a deterioration in travel speeds with increasing traffic volumes in a special vehicle lane. Traffic engineering theory would suggest that this is due to side friction. There is limited information to suggest that cross-section widths and distance to obstructions confirm this to be the case for a special vehicle lane. However, to provide some level of account for the deterioration of performance, table B.2 provides some suggested figures for an uplift to the typical friction factors used in the calculation of mid-block travel times. This is a parameter that can be refined with further investigation.

Table B.2 Typical mid-block capacity and friction factors

Lane width and separation	Suggested friction factor uplift
>4.5m or buffer separated	20%
3.5 – 4.5m	50%
<=3.5m	80%

B2.1.5 Traffic signal data

The user is prompted to enter in basic traffic signal data, namely:

- the corridor cycle time (typically 90–150 seconds
- the level of coordination for the corridor in the direction of travel (outline the table)
- the level of pedestrian protection applied at the intersections – this reduces the capacity of the kerbside lane by the proportion of green time lost in the phase due to pedestrian protection (if left-turn traffic is shared with through traffic or special vehicle lane traffic). The assumption for the application of capacity loss is that there will be a left-turn vehicle that blocks the through movement for the duration of the pedestrian protection.

B2.1.6 Minimum acceptable travel speed

The user is prompted to consider the lowest travel speed that motorists will tolerate before they choose a different route (if one is available), or time their travel differently. The model will use this input to determine the maximum traffic volume per lane to be evaluated. If the user has specified traffic volumes that significantly exceed the capacity of the corridor, the estimated speeds along the corridor can reduce to below walking speed. In practice this will not occur as motorists will either choose an alternative route or time their travel differently. The example provided in figure B.4 highlights the performance of a traffic lane under increasing traffic flows with:

- a 1km corridor length
- a cycle time of 120 seconds
- 50% green time for the corridor through movement
- one signalised intersection.

Figure B.4 Lane performance 'minimum acceptable travel speed' of 5km/h

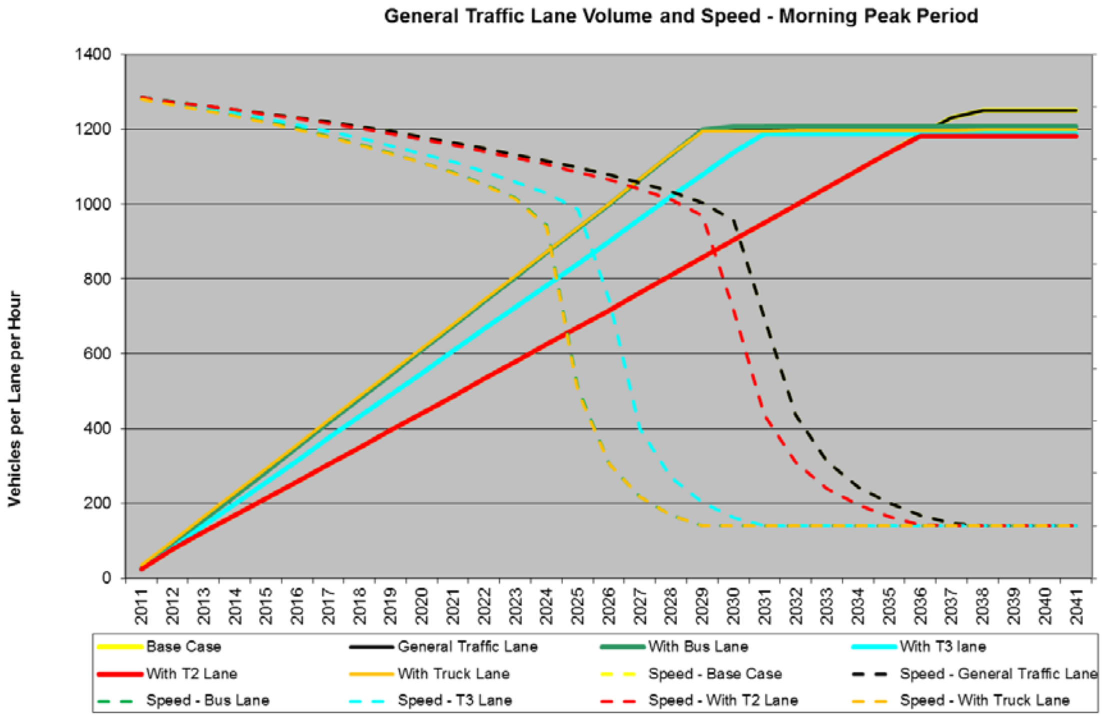
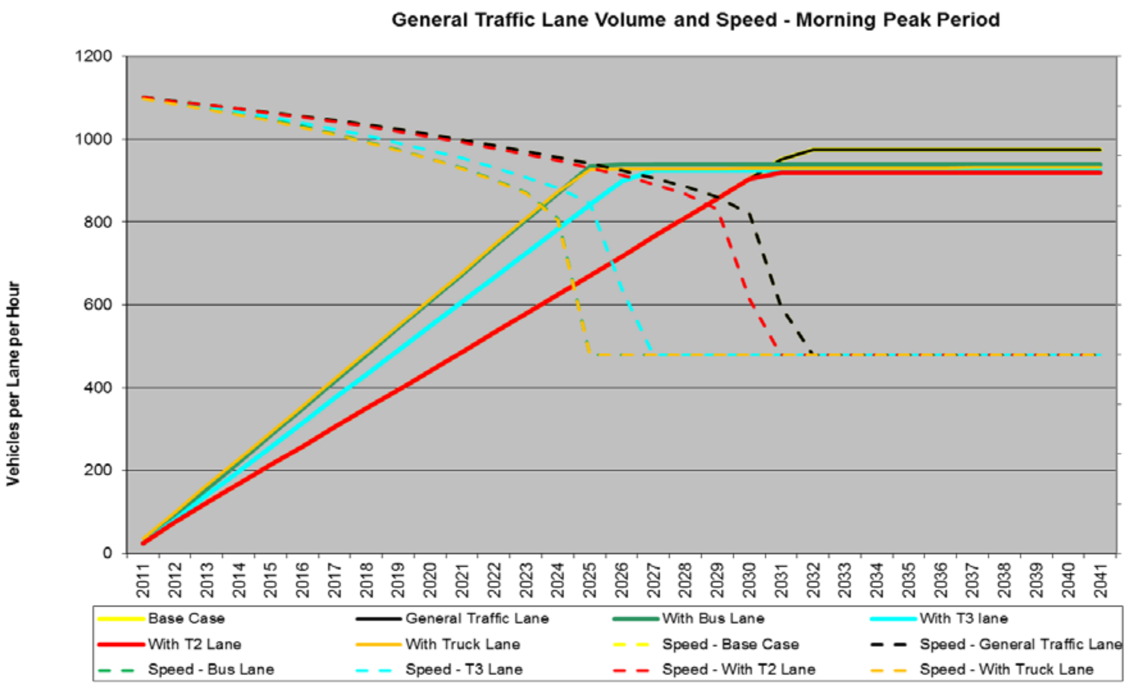


Figure B.5 Lane performance with 'minimum acceptable travel speed' of 20km/h



This input is a subjective input and should be based on local data and experience. In the absence of reliable data the user is recommended to adopt the threshold speed equating to a level of service 'F'. This is particularly important if considering the effects of converting a lane as it is likely that motorists will divert away from the corridor under examination if it becomes too congested. It is important both to report on the corridor performance and to highlight in the outputs that the results are affected by the limiting criteria.

B2.1.7 Intersection layouts

It is typically the intersections that govern the performance of an urban corridor. In order to analyse the effectiveness of a special vehicle lane, the user is prompted to provide information about the typical intersections along the corridor. At this stage of model development, each individual intersection is not examined, although this could easily be done by running one model per intersection and aggregating the results. It is anticipated that further stages of the model's development will allow the user to specify the details of each intersection along the corridor.

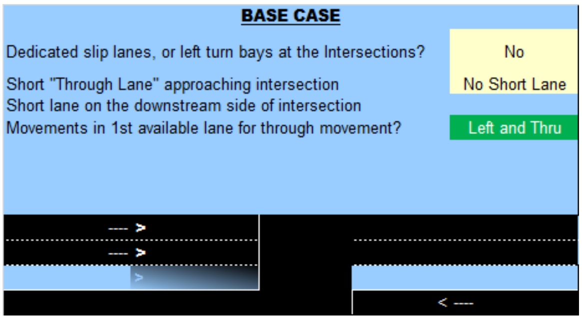
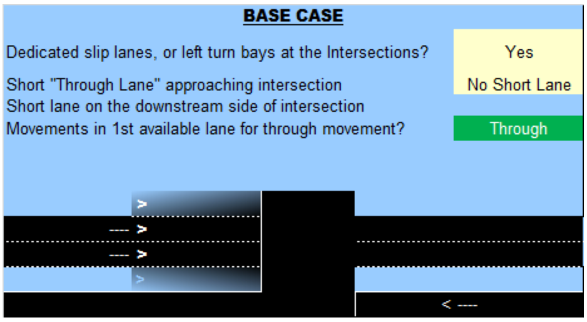
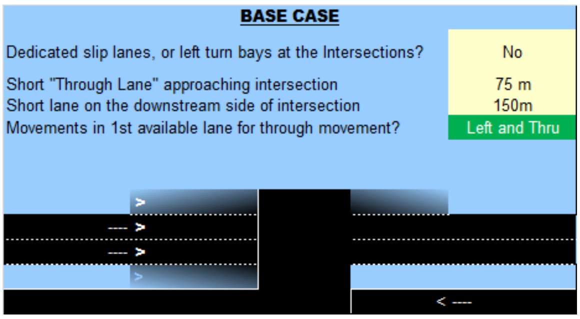
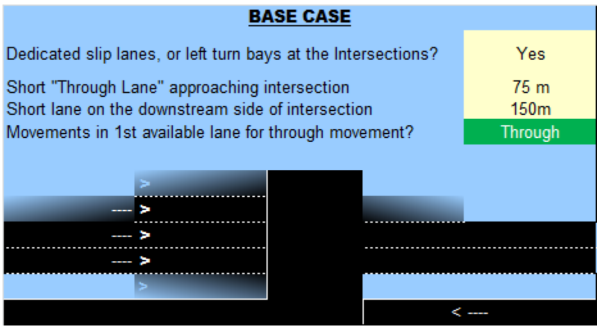
The model is designed to analyse the typical intersection layout along the corridor, and assumes that right-turn bays are provided. Shared through-right lanes cannot be analysed in this model.

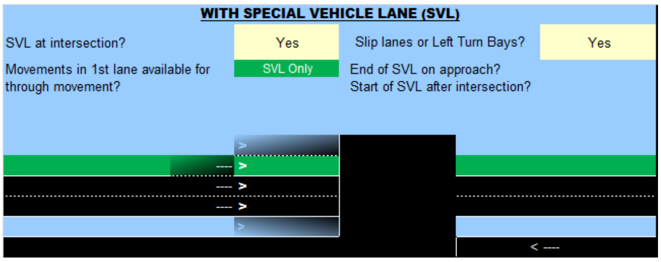
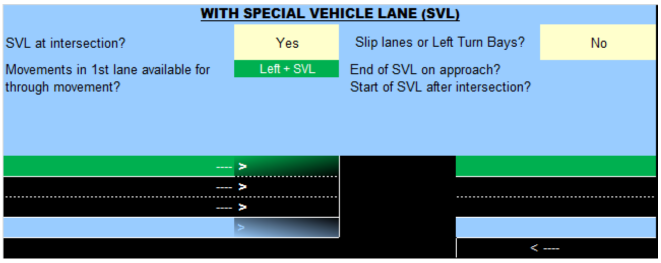
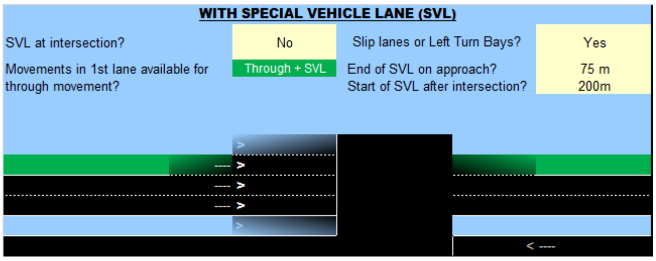
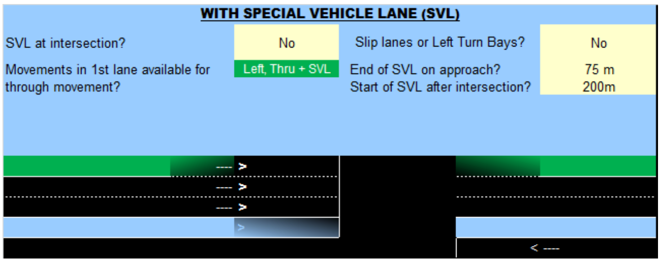
The user is prompted to enter the details for the base case and the proposed layout under consideration. The model allows for the user to specify the following:

1. Whether there are left-turn lanes or slip lanes that allow for left-turning traffic to be separated from the through movements.
2. Whether there is a short lane upstream and downstream in the base case that provides additional intersection capacity (including the length of short lane). At this stage the effect of the downstream merge length has not been considered in the intersection capacity. SIDRA, a software package to assess the performance of intersections, adjusts the lane utilisation on a pro-rata basis from 0% for no downstream short lane to 100% where the downstream short lane is greater than 200m).
3. Whether the special vehicle lane continues through the intersection, or whether it terminates short of the intersection and restarts after the intersection. Where the user specifies that the special vehicle lane continues through the intersection, the model will allow for left-turn traffic to use the special vehicle lane, if the user has specified there are no left-turn bays or slip lanes adjacent to the slip lane.
4. Where the user has specified that the special vehicle lane terminates prior to the intersection, the user is prompted to enter how far upstream and downstream the special vehicle lane terminates and recommences respectively. The model treats the portion of traffic lane between the termination of the special vehicle lane and the intersection as a general traffic lane, and assigns the lane flows accordingly.
5. The user can specify the movements permitted in the first available through-lane in order to determine the amount of 'through movement' traffic that can use the first lane available for through movements. For the section 'With special vehicle lane', the reference to SVL (special vehicle lane) is traffic that is eligible to use the special vehicle lane between intersections, and 'Thru' or 'Through' is available where the user has specified that the special vehicle lane terminates prior to the intersection to indicate that general traffic can use the lane on the approach to the intersection. If there are no left-turn movements at the signalised intersections (left-turn bans, or T-junctions with an arm on the right-hand side) this can be specified in this section, or by entering 0% for left-turn traffic when specifying the traffic volume composition. When the user specifies movements that are not feasible with the selected intersection layout, the cell will be highlighted in red.

Table B.3 outlines the eight layout options that users of the model are permitted to specify. The key assumption for the layouts is that right-turn bays are provided to separate right-turning traffic from through traffic.

Table B.3 Layout options for the signalised intersections

Case	Illustration
Case 1: Base case – no left-turn bays and no short lane	
Case 2: Base case – left-turn bays and no short lane	
Case 3: Base case – short lane with no left-turn bays	
Case 4: Base case – short lane with left-turn bays	

Case	Illustration
Case 5: Option – left-turn bays with special vehicle lane carried through the intersection	
Case 6: Option – no left-turn bays with special vehicle lane carried through the intersection	
Case 7: Option – left-turn bays with special vehicle lane terminating prior to the intersection	
Case 8: Option – no left-turn bays with special vehicle lane terminating prior to the intersection	

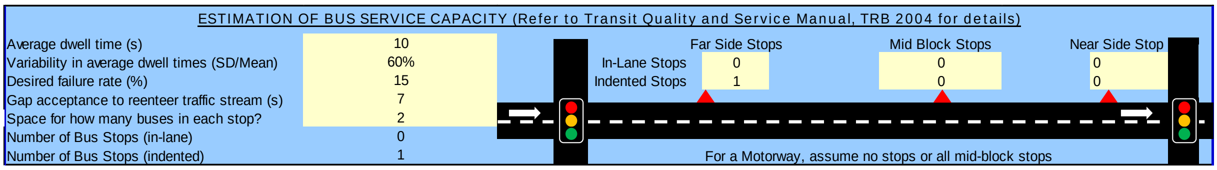
B2.1.8 Bus infrastructure

The model was developed to estimate the bus travel times for express services and all-stops bus services using the corridor, and the capacity of the lane the buses are running in (kerbside lane for all lanes other than a truck lane or motorway). The estimation of the capacity was developed using the procedures defined in the *Transit capacity and quality of service manual* (Kittelson & Associates et al 2003), which considers the effect of:

- bus stop location
- bus dwell time
- number of loading bays available at the critical stop

- whether the stops are indented or on-line stops
- the effect of left turn traffic at the intersections
- the effect of buses running in general traffic lanes or HOV lanes.

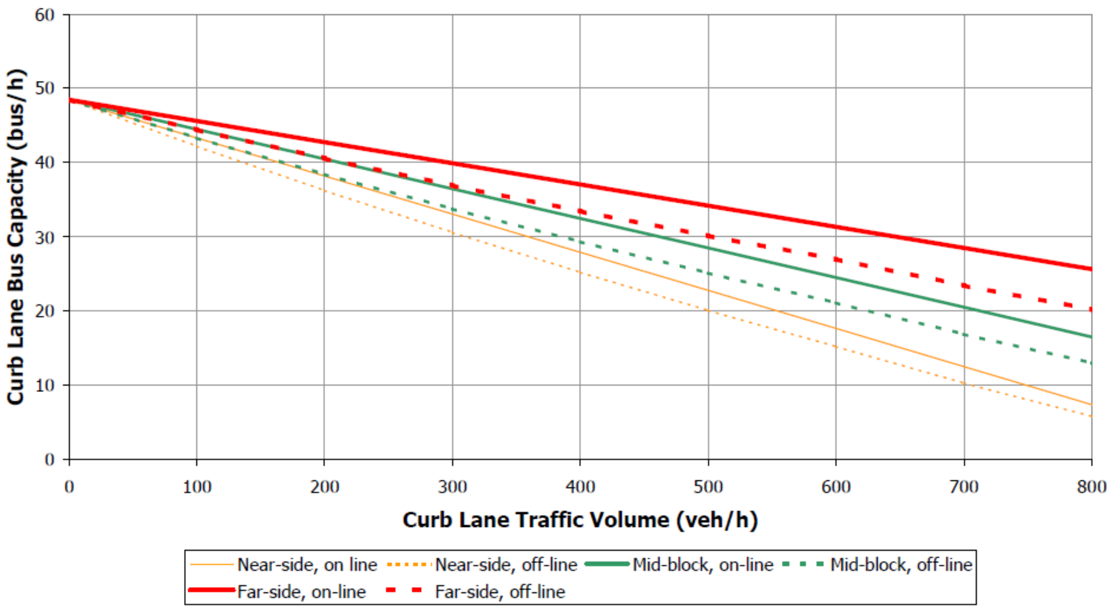
Figure B.6 Model inputs page – bus stop infrastructure



Source: Kittelson & Associates et al (2003)

The user is prompted to enter details of the operating characteristics of the bus and bus stop details as highlighted in figure B.6. The model will then, combined with the traffic and bus services data, calculate the critical bus stop capacity which is then adopted as the bus service capacity of the kerbside lane. This is calculated for each type of lane investigated (general traffic lane, bus lane, T3 lane and T2 lane).

Figure B.7 Impact of traffic volume on bus stop capacity



NOTE: Assumes a Type 2 lane, one linear loading area per stop, *g/C* = 0.5, 30-second dwell time, 25% failure rate, and 60% coefficient of variation.

Source: Transportation Research Board (2003)

B2.1.9 Behavioural response

The user will be required to enter the behavioural response parameters in the model. There are three main inputs:

1 The impact of behavioural response on traffic volumes – the user has the following choices:

   a Case 1: Reduce traffic volumes through behavioural response – this case retains the forecast number of people travelling along the corridor and moves them in fewer vehicles. It enables the relative efficiency of the different special vehicles lane to be measured, but does not consider the potential for reassignment from other corridors.

b Case 2: Retain forecast traffic volumes – this case retains the traffic volumes that are input by the user, whether specified as a growth rate, or specified for the forecast years. This essentially indicates there will be some reassignment from other corridors in response to the improved efficiency of providing a special vehicle lane, but not beyond initial traffic volume forecasts.

c Case 3: Allow for reassignment from other corridors – this case is an extension from case 2 with the exception that the underlying assumption is that the spare capacity afforded by implementing a special vehicle lane will be absorbed by traffic from other corridors .

2 The elasticities to be applied for behavioural response. There are two main inputs:

a Increase in bus patronage – the percentage increase in bus patronage compared with the benefit in travel time afforded by the special vehicle lane. Elasticities are typically applied at a whole of trip, rather than for a specific corridor. The user should therefore consider the time travelled along the corridor as a proportion of the total journey time. Typical values are in the order of 0.1–0.7 with 0.4 recommended in Australia and 0.3 used in Auckland. However if the travel time in the general traffic lanes along the corridor represented only 50% of the total journey time, the elasticity could be reduced by this proportion as the remaining travel time within the trip is likely to remain unchanged.

b Increase in vehicle occupancy – the percentage increase in vehicle occupancy compared with the benefit in travel time afforded by the special vehicle lane. As reported in section 2.4.1 there appears to be a relationship between the percentage increase of average vehicle occupancy and the number of minutes saved along the corridor. In the case of Onewa Road, the percentage change in vehicle occupancy is 40% with the percentage change in travel time undefined. From the data obtained from the Automobile Association website (www.aa.co.nz), the ideal travel time (or uncongested time) is in the order of five minutes, therefore the time saving equates to 80% and the elasticity in vehicle occupancy is 0.5 with respect to the travel time difference. Data from the Victoria Transport Policy Institute (2013) indicates elasticities in the order of 0.2 for an increase in car passengers with respect to fuel price increases, and a similar elasticity for public transport patronage with respect to fuel price. Most elasticity research for HOV lanes has recently been on price-elasticity of HOT lanes which shows a wide range of elasticities related to increased use of the special vehicle lane with respect to the price. The evaluation of the MnPass express lanes indicated a positive relationship between the toll price and usage (ranging between 0.03 and 0.85), indicating people were willing to pay a higher amount for a greater (perceived or actual) travel time saving. Care must be taken when applying the elasticities in relation to the length of corridor being examined, as this affects the proportion of the total trip that will benefit from a special vehicle lane. The model was developed to use a traditional elasticity, but initial versions of the model used the percentage behavioural response which resulted in a dynamic elasticity – and a much greater change over time in response to increased congestion. In the absence of further research, any elasticities in the model should not be greater than for public transport elasticities.

3 The level of illegal usage in the special vehicle lanes – the literature review suggests there may be a relationship between the level of eligibility (the traffic volume) and the level of illegal usage. Auckland Transport has reported a high level of compliance in bus lanes; however, anecdotal evidence for the ramp signal priority bypass lanes suggests that up to 50% of traffic using the lanes are illegal users. Ranges between 5% and 30% are considered appropriate in the absence of available data.

Figure B.8 Model inputs page – mode shift behaviour and traffic reassignment

THE USERS		Morning	Daytime	Evening	Saturday
Behavioural Response	Consider reassignment from other corridors or reduction in traffic due to mode shift and increased vehicle occupancy?	Reassignment from other corridors (move more people and more traffic)			
	Vehicle occupancy elasticity	0%	0%	0%	
	Bus patronage elasticity	0%	0%	0%	
	Level of illegal usage (Cars using SVL as a proportion of total SVL volume)	0%	20%	20%	

B2.1.10 Traffic volume composition

The user will be prompted to enter classified traffic count information and growth forecasts for each of the periods being analysed. The following parameters are required:

- traffic volumes – the average traffic volume travelling along the corridor (excluding buses)
- average proportion of traffic turning left and right at the intersection.
- bus patronage – the average bus patronage travelling along the corridor
- bus services – the total number of buses travelling along the corridor in the base year
- express services – the number of buses that are express services and do not stop along the corridor
- the proportion of public transport patronage using the express services
- the proportion of traffic volume with two or more occupants (HOV 2+)
- the proportion of traffic volume with three or more occupants (HOV 3+)
- the proportion of trucks in the total traffic volume
- the proportion of motorcyclists in the total traffic volume
- the number of cyclists along the corridor.

Figure B.9 Model inputs page – traffic composition

THE USERS		Morning	Daytime	Evening	Saturday
Traffic Volumes	2011 Traffic Volume in the Direction being analysed	2500	1200	1440	
	2026 Traffic Volume in the Direction being analysed	2500	2200	2640	
	2041 Traffic Volume in the Direction being analysed	2500	2400	2880	
	Estimated % Turning Left	0%	10%	12%	
	Estimated % Turning Right	0%	5%	6%	
Public Transport	2011 Bus Patronage in the Direction being analysed	400	800	960	
	2026 Bus Patronage in the Direction being analysed	1000	1100	1320	
	2041 Bus Patronage in the Direction being analysed	1200	1200	1440	
	Total Number of bus services using the route	20	43	51.6	
	Number of express services using the route	0	10	12	
	Proportion of passengers on express services (if known - default = 0%)	0%	20%	20%	
Light Vehicles (includes cars, 4WD, SUV, Utes and people movers)	% of light vehicles with 2 or more occupants (HOV2+)	10%	55%	66%	
	% of light vehicles with 3 or more occupants (HOV3+)	5%	10%	12%	
	Average vehicle occupancy for HOV3+	3.30	3	3.6	
Heavy Vehicles (include trucks > 3.5t)	% of Heavy Vehicles (includes rigid and articulated)	3%	2%	2%	
Motorcycles	% of total traffic is motorcyclists	3%	2%	2%	
Cyclists	Number of cyclists that use the corridor	55			

B2.1.11 Economic parameters

A key consideration for the evaluation of special vehicle lanes is the economic performance of the corridor when compared with other special vehicle lanes and a general traffic lane. To undertake an economic assessment, the values of time must be disaggregated in order to evaluate the cost per person and vehicle, rather than aggregated to an average cost per vehicle.

The user is therefore prompted to enter the values of time and the operating cost per vehicle, as outlined in figure B.10. The user is also prompted to enter the parameters for the economic evaluation including:

- the discount rate – the default rate in the EEM is 6%; however, sensitivity assessments using 4% and 8% are currently being used in the evaluation of projects across the Auckland region
- the number of hours that traffic conditions remain at a similar level throughout the nominated peak period for assessment
- the number of days per annum that the assessment should apply – for a weekday assessment the default number of days is 245 for working days and 120 for other days in accordance with the EEM.

Figure B.10 Model inputs page – economic parameters

ECONOMIC EVALUATION PARAMETERS					
Standard Parameters	Discount Rate	8%	Evaluation Period (Years)		30
	Number of Hours for Each Time Period to accrue benefits	1.00	1.00	1.00	
	Number of Typical Days per Year to accrue benefits	245	245	245	
Values of Time (refer to Economic Evaluation Manual)					
	Bus Passenger	$ 4.70	$ 4.70	$ 4.70	
	Bus Vehicle	$ 17.10	$ 17.10	$ 17.10	
	Car Driver	$ 7.80	$ 7.80	$ 7.80	
	Car Passenger	$ 5.85	$ 5.85	$ 5.85	
	Car Vehicle	$ 0.50	$ 0.50	$ 0.50	
	Commercial Vehicle Driver	$ 20.10	$ 20.10	$ 20.10	
	Commercial Vehicle	$ 28.10	$ 28.10	$ 28.10	
	Motorcyclist	$ 7.80	$ 7.80	$ 7.80	
	Motorcycle	$ 0.50	$ 0.50	$ 0.50	

B2.2 Process

B2.2.1 Mid-block capacity and delays

General functions

The mid-block delays use the Ackelic function for mid-block running time as outlined below:

$$t_{mid} = L * t_0 * \left\{ 1 + 0.25 r_f * \left[\left(x - 1 + \sqrt{(x-1)^2 + \frac{8 * J_A * (1 + J_f) * x}{Q * t_0 * r_f}} \right) \right] \right\} \quad \text{(Equation B.1)}$$

Where:

t_{mid} = average travel time (in seconds)

L = corridor length (km)

t_o = travel time at base running speed (seconds per km)

J_A = friction factor (curve parameter)

J_f = friction factor uplift for special vehicle lane due to side friction along facilities that are not segregated from the other traffic lane/s (%)

Q = mid-block lane capacity (passenger car units per lane per hour)

x = degree of saturation (q/Q)

q = traffic volume in the lane (passenger car units per hour)

r_f = ratio of analysis period to minimum travel time (the analysis period is taken as one hour in the model, therefore $t_0 * r_f = 1$).

B2.3 Capacity reduction in special vehicle lane due to in-lane bus stops

The presence of in-lane bus stops reduces the capacity of the lane due to the time spent in decelerating, allowing for board and alighting and then accelerating back to the base running speed. In practice, traffic following buses that have stopped will attempt to merge into other traffic lanes if there is an acceptable gap. This is an area that is difficult to incorporate into an analytical model, and a simulation model would better reflect this. The model was developed to provide planning level support for the proposed treatments, therefore a reduction in lane capacity should be considered while recognising that some vehicles would change lanes in practice.

Kittelson & Associates et al (2003) define the concept of 'clearance time' which is the time start up and travel its own length plus re-entry delay if the bus stop is indented. This concept is applied when considering the bus stop capacity, rather than considering the proportion of time lost in the lane used by buses for in-lane bus stops.

The reduction in mid-block lane capacity (Q_{SVL}) has been estimated using the following equation:

$$Q_{SVL} = Q_i * \left[(3600 - (a - b - c) * N)\right] / 3600 \qquad \text{(Equation B.2)}$$

Where:

Q_i = user input capacity per lane (passenger car units per hour)

a = time for bus to decelerate to zero at an deceleration rate of $2.0 m/s^2$ (seconds)

b = user input time for passengers to board and alight (dwell time) (seconds)

c = time for bus to accelerate to the base running time at an acceleration rate of $1.0 m/s^2$ (seconds)

N = number of all-stops buses along the route, assuming that all-stops buses will stop to allow passengers to board and alight.

B2.3.1 Lane flow assignment

Use the following steps to assign the traffic volumes to the appropriate lanes:

Step 1 Determine the traffic volume eligible to use the special vehicle lane based on the type of lane (bus lane, HOV lane with two occupants, HOV lane with three or more occupants, truck lane, general traffic lane, noting that in New Zealand, motorcyclists are permitted to use bus lanes and transit lanes).

Step 2 Determine the amount of traffic using the other lanes, which is the total traffic volume for the given year less the traffic volume eligible to use the special vehicle lane.

Step 3 Convert these traffic volumes to passenger car units per hour based on the following factors:

- cars = 1 passenger car unit
- buses = 2 passenger car units
- trucks = 2.5 passenger car units
- motorcycles = 0.7 passenger car units

Step 4 Calculate the traffic volume in passenger car units that would result in lanes that have equal degree of saturation using the following equation:

$$q_x = [(q_{SVL} * Q_{SVL} + q_{other} * Qi * (N-1)]/\left(Q_{SVL} + Q_i * (N-1)\right) \quad \text{(Equation B.3)}$$

Where:

q_x = traffic volume in special vehicle lane that would provide equal degree of saturation across the lanes

q_e = traffic eligible to use special vehicle lane (passenger car units per lane per hour)

q_{other} = total traffic volume less the traffic eligible to use the special vehicle lane

Q_{SVL} = mid-block capacity of the special vehicle lane (passenger car units per lane per hour)

Q_i = user input mid-block capacity per lane (passenger car units per lane per hour)

N = user input number of lanes in the mid-block.

Step 5 Determine from steps 2 and 3, whether the level of traffic eligible to use the special vehicle lane, is higher than the threshold calculated for the equal degree of saturation in the special vehicle lane. The assumption here is that if the traffic volumes eligible to use the special vehicle lane are higher than the threshold for an equal degree of saturation, there is no time advantage for eligible users, therefore a proportion of eligible users would use the general traffic lanes.

$$q_{SVL} = \min\left(q_e, q_x\right) \quad \text{(Equation B.4)}$$

Step 6: Recalculate the traffic volumes in the other lane/s as the difference between the traffic volumes calculated in step 5.

Step 7: Convert traffic volumes from steps 5 and 6 from passenger car units per hour to vehicles per hour using the following equation.

$$V_n = q_n * \left[\frac{Bus_n + Truck_n + Motorcycle_n + (q_n - Bus_n - Truck_n - Motorcycle_n)}{Bus_n * 2 + Truck_n * 2.5 + Motorcycle_n * 0.7 + (q_n - Bus_n - Truck_n - Motorcycle_n)} \right] \quad \text{(Equation B.5)}$$

Where the inputs are outlined in table B.4.

Table B.4 Inputs for the conversion of passenger car units per hour to vehicles per hour

Variable	Description	Value – special vehicle lane	Value – other general traffic lanes
N	Lane being considered (special vehicle lane or other general traffic lane/s)		
V_n	Traffic volume (vehicles per hour)		
q_n	Traffic volume (passenger car units per hour)	q_{SVL}	q_{other}
Bus_n	Number of buses in lane under consideration	Buses eligible to use special vehicle lane.	Buses not eligible to use special vehicle lane divided by the number of lanes that are not special vehicle lanes (assumed to be 0 for all except a truck lane)
$Truck_n$	Number of trucks in lane under consideration	Trucks eligible to use special vehicle lane. Where qSVL = qx, the number of trucks in special vehicle lane is equal to ratio of the special vehicle lane capacity to the total mid-block capacity.	Trucks not eligible to use special vehicle lane divided by the number of lanes that are not special vehicle lanes
$Motorcycle_n$	Number of trucks in lane under consideration	Motorcyclists eligible to use special vehicle lane. Where qSVL = qx, the number of trucks in special vehicle lane is equal to ratio of the special vehicle lane capacity to the total mid-block capacity.	Motorcycles not eligible to use special vehicle lane divided by the number of lanes that are not special vehicle lanes

B2.3.2 Intersection capacity and delays

General functions

The calculation of the intersection delays uses the equations presented in the HCM2010, as outlined in the following equations. The HCM2010 methodologies consider an incremental analysis over the peak period under consideration; however, the model does not go into this level of detail and considers the peak hour as a single assessment period.

$$d_{\text{int}} = d_1 + d_2 + d_3 \qquad \text{(Equation B.6)}$$

Where:

d_{int} = control delay (seconds per vehicle)

d_1 = uniform delay (seconds per vehicle)

d_2 = incremental delay (seconds per vehicle)

$$d_1 = \frac{0.5 * C * (1 - g/C)^2}{1 - [\min(1, x) * g/C]} \qquad \text{(Equation B.7)}$$

Where:

C = user specified cycle time (seconds)

g/C = effective green split for the lane (%)

x = degree of saturation for the lane (q_n/S_n)

$$d_2 = 900 * T * \left[(x-1) + \sqrt{(x-1)^2 + \frac{8*k*I*x}{C*T}} \right]$$ (Equation B.8)

Where:

T = analysis period (the analysis period is taken as one hour)

x = degree of saturation for the lane (q_n/S_n)

C = user specified cycle time (seconds)

g/C = effective green split for the lane (%)

q_n = traffic flow for the lane under consideration (passenger car units per hour)

S_n = saturation flow for the lane under consideration (passenger car units per hour)

k = incremental delay factor – it is assumed that the traffic signals are operating with little flexibility in phase splits in the peak periods therefore simulating fixed time operation. Under these conditions k = 0.5 (refer to chapter 18 of the HCM2010)

I = upstream filtering adjustment factor – the HCM2010 defines the degree of saturation (x) as the weighted degree of saturation for all movements contributing to the movement group. In the context for modelling the special vehicle lane, and the other general traffic lanes separately, it is assumed that the degree of saturation (x) will be that of the corresponding lane upstream. In New Zealand, the traffic signal operating system (SCATS) seeks to provide an equal degree of saturation for the movements under signal control at the intersections, and then co-ordinates the corridors based on operator inputs. With this type of operation, it is considered reasonable that using the corresponding lane upstream is a fair representation of the degree of saturation for the other movements available the intersections.

$$I = 1 - 0.91 * x^{2.68}$$ (Equation B.9)

Capacity reduction due to left-turn traffic and pedestrian protection

A major source of delay for users of special vehicle lanes occurs where:

- turning traffic executes the movement from the lane designated as the special vehicle lane
- pedestrian protection requirements result in the turning vehicle waiting to proceed
- the special vehicle lane terminates prior to the intersection to allow general traffic and turning traffic to use the lane on the intersection approach.

The third point above is treated as a design scenario in the model, allowing the user to specify the intersection treatment. The capacity reduction due to turning movements and pedestrian protection is determined based on user inputs for pedestrian protection and proportion of turning traffic.

The process is undertaken in two parts:

Step 1 Determine stop line capacity due to the presence of left-turn vehicles

Step 2 Reduce the stop line capacity to account for the usable green time during the phase in which the through movement will operate.

The capacity of the first lane available is based on a saturation flow for turning vehicles of 1,650 passenger car units per hour and 1,800 passenger car units per hour for through movements.

$$Q_1 = [q_l * 1{,}650 + (1 - q_l) * 1800] / 1800 * [g * C * (1 - P)] / g$$ (Equation B.10)

Where:

Q_1 = stop line capacity of 1st lane available for through movements (passenger car units per hour)

q_l = proportion of the overall traffic volume turning left in the first lane available for through movements converted to passenger car units (%)

g = green time proportion specified by the user (%)

C = cycle time specified by the user (seconds)

P = level of pedestrian protection specified by the user (seconds).

Lane flow assignment

The process for assigning the traffic volumes to the appropriate lanes in undertaken using the following steps:

Step 1 Determine the traffic volume eligible to use the first lane available for through movements based on the type of lane (bus lane, HOV lane with two occupants, HOV lane with three or more occupants, truck lane, general traffic lane) and the intersection treatment:

$$q_1 = q_e + q_l + q_s$$ (Equation B.11)

Where:

q_1 = eligible vehicles in the first lane available for through movements (passenger car units per hour)

q_l = traffic volume turning left in the first lane available for through movements converted to passenger car units

q_e = mid-block traffic volumes using the lane allocated as a special vehicle lane (or general traffic lane if that is being considered) (passenger car units per hour)

q_s = additional traffic that can use the first lane available for through movements either due to a short lane in the base case, or where the special vehicle lane terminates prior to the intersection. q_s is calculated using equation B.12. The assumption in this equation is that the space available is occupied by the traffic eligible to use the special vehicle lane in the mid-block plus the left-turning traffic eligible to use the lane, so that any available capacity remaining based on the length of short lane available is then occupied by through traffic.

$$q_s = L / 7m * 3600 / C - q_e - q_l$$ (Equation B.12)

Where:

L = length of lane available to general traffic approaching the intersection

7m represented space occupied per passenger car unit.

Step 2 Determine the amount of traffic using the other lanes, which is the total traffic volume for the given year less the traffic volume eligible to use the first available through lane and turning traffic.

Step 3 Convert these traffic volumes to passenger car units per hour based on the same factors as those used for the mid-block conversion from passenger car units per hour to vehicles per hour.

Step 4 Calculate the traffic volume in passenger car units that would result in lanes that have equal degree of saturation using equation B.13.

$$q_x = [(q_1 * Q_1 + q_{other} * 1{,}800 * (N-1)] / \left(Q_1 + Q_i * (N-1)\right) \quad \text{(Equation B.13)}$$

Where:

q_x = traffic volume in the first available through lane that would provide equal degree of saturation across the lanes

q_1 = traffic eligible to use the first available through lane calculated from step 3 (passenger car units per lane per hour)

q_{other} = total traffic volume less the traffic eligible to use the first available through lane

Q_1 = stop line capacity of first available through lane (passenger car units per lane per hour)

$Q_i = g*C*1800$ (passenger car units per lane per hour)

g = green time proportion specified by the user (%)

C = cycle time specified by the user (seconds)

N = user input number of lanes in the mid-block.

Step 5 Determine from steps 2 and 3 whether the level of traffic eligible to use the special vehicle lane is higher than the threshold calculated for the equal degree of saturation in the special vehicle lane. The assumption here is that if the traffic volumes eligible to use the special vehicle lane are higher than the threshold for an equal degree of saturation, there is no time advantage for eligible users, therefore a proportion of eligible users would use the general traffic lanes.

$$q_{SVL} = \min\left(q_e, q_x\right) \quad \text{(Equation B.14)}$$

Step 6 Recalculate the traffic volumes in the other lane/s as the difference between the traffic volumes calculated in step 5.

Step 7 Convert traffic volumes from steps 5 and 6 from passenger car units per hour to vehicles per hour using equation B.15:

$$V_n = q_n * \left[\frac{Bus_n + Truck_n + Motorcycle_n + (q_n - Bus_n - Truck_n - Motorcycle_n)}{Bus_n * 2 + Truck_n * 2.5 + Motorcycle_n * 0.7 + (q_n - Bus_n - Truck_n - Motorcycle_n)} \right] \quad \text{(Equation B.15)}$$

Where the inputs are outlined in table B.5.

Table B.5 Inputs for the conversion of passenger car units per hour to vehicles per hour

Variable	Description	Value – special vehicle lane	Value – other general traffic lanes
n	Lane being considered (special vehicle lane or other general traffic lane/s)		
V_n	Traffic volume (vehicles per hour)		
q_n	Traffic volume (passenger car units per hour)	q_{SVL}	q_{other}
Bus_n	Number of buses in lane under consideration	Buses eligible to use special vehicle lane.	Buses not eligible to use special vehicle lane divided by the number of lanes that are not special vehicle lanes (assumed to be 0 for all except a truck lane)
$Truck_n$	Number of trucks in lane under consideration	Trucks eligible to use special vehicle lane. Where qSVL = qx, trucks in special vehicle lane is equal to ratio of the special vehicle lane capacity to the total mid-block capacity.	Trucks not eligible to use special vehicle lane divided by the number of lanes that are not special vehicle lanes
$Motorcycle_n$	Number of trucks in lane under consideration	Motorcyclists eligible to use special vehicle lane. Where qSVL = qx, trucks in special vehicle lane is equal to ratio of the special vehicle lane capacity to the total mid-block capacity.	Motorcycles not eligible to use special vehicle lane divided by the number of lanes that are not special vehicle lanes

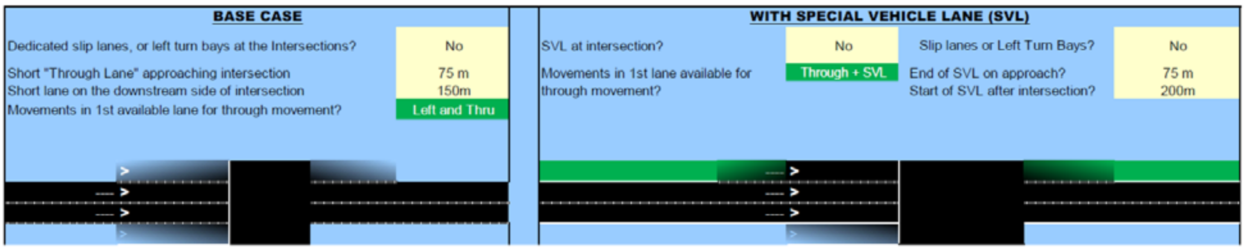
Merging delays

The impact of merging downstream of an intersection is addressed when the user specifies:

- a short lane is available for through movements in the 'base case'
- the special vehicle lane terminates prior to the intersection and recommences at a distance downstream of the intersection. This treatment is consistent with the legal interpretation of the implementation of special vehicle lanes prior to the amendment to the Traffic Control Devices Rule in 2010.

Figure B.11 illustrates these two cases as they appear in the 'Inputs' tab in the model.

Figure B.11 Cases where merge delays downstream of intersection are addressed



Merging delays are rarely addressed when undertaking the analysis of intersections, but are a major source of delay if consideration is being given to terminating the special vehicle lane upstream of the intersection and recommencing the lane downstream of the intersection, as traffic not eligible to use a special vehicle lane must merge back into the general traffic lanes.

Merging delays typically form and dissipate with each traffic signal cycle. The location of the merge downstream of the intersection can lead to queuing that extends back through the intersection, reducing the amount of traffic that can pass through the traffic signals. The model does not consider this effect, but does consider the delay from the traffic signals and the merging delay as two discrete sources of delay. This method assumes that the merge downstream of the intersection does not affect the efficiency of the traffic signals.

The process for estimating the merge delay uses a simple bottleneck model derived from the process outlined in A3.19 of the EEM and defined as:

$$d_{merge} = GT * (q_u - q_d) / 2 * s / Q \qquad \text{(Equation B.16)}$$

Where:

M = merge delay (seconds per vehicle)

t_{sat} = duration of the green time that is under saturated conditions from the traffic signals (seconds)

Q_u = total traffic flow approaching the merge area per cycle (vehicles)

Q_d = amount of traffic that can be discharged through the merge area during time, t (vehicles)

s = saturation flow of a through lane at the traffic signals – this is assumed to be 1,800 passenger car units per hour per lane

Q = midblock capacity per lane (passenger car units per hour per lane)

t_{sat} is defined as:

$$t_{sat} = Min\left(g * C, g * C * x_o\right) \qquad \text{(Equation B.17)}$$

Where:

$g*C$ = green time for the lanes other than the first lane is available for the through movements

x_o = maximum degree of saturation

qu is defined in equation B.18 as:

$$q_u = \frac{q_o * (L-1) * Min(x_o, 1) + q_t * Min(x_t, 1)}{3600 / C} \qquad \text{(Equation B.18)}$$

Qd is defined in equation B.19 as:

$$q_d = Q * L * t + q_e \qquad \text{(Equation B.19)}$$

Where:

Q = user specified mid-block capacity per lane (passenger car units per hour per lane)

L = number of lanes that are not special vehicle lanes in the mid-block

Qe = traffic eligible to use a special vehicle lane in the midblock.

Figure B.12 illustrates the merging delay per intersection for a three-lane arterial with a green time of 60% and a cycle time of 120 seconds. This represents a significant component of delay when considering whether to allow a special vehicle lane to continue through an intersection, or whether to terminate the special vehicle lane prior to the intersection.

Figure B.12 Merging delay as a function of mid-block traffic volumes

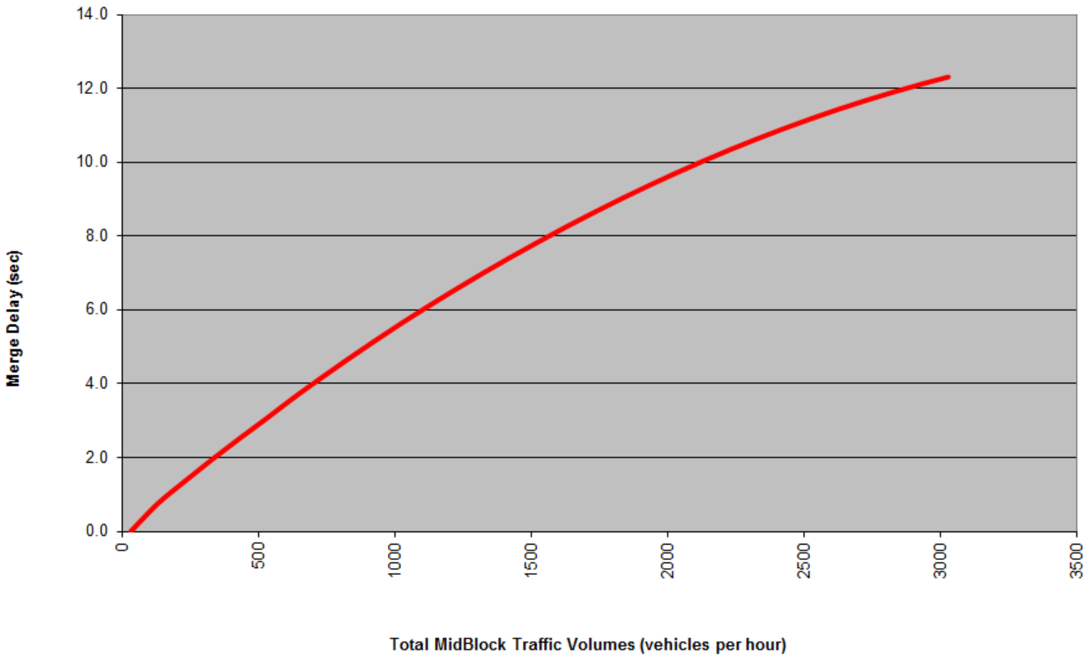
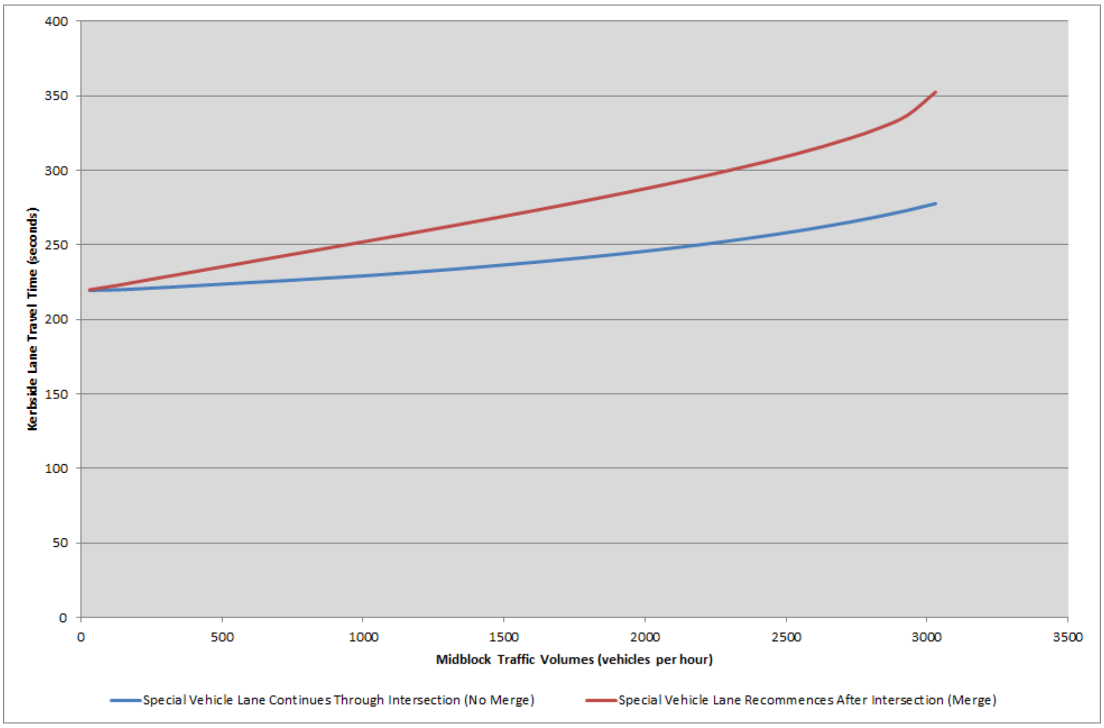


Figure B.13 provides an indication of the impact that merging has on the kerbside lane travel time when a special vehicle lane terminates prior to an intersection. The scenario considered has the following parameters:

- 3km corridor
- four signalised intersections
- 60% green time
- 120 second cycle time
- no pedestrian protection
- no left-turning traffic.

Figure B.13 Comparison of kerbside lane travel times



In this example, the effect of the merging delay on the kerbside travel time represents up to a 25% increase in travel times as the intersections approach capacity where the special vehicle lane recommences downstream of the signalised intersections. This highlights the importance of including merging delays when considering the preferred intersection layouts along the corridor.

Bus stop capacity

The capacity of the bus stops and the re-entry delay have been calculated using the procedures outlined in Kittelson & Associates et al (2003). The relevant extracts from this manual are provided below (noting that references to right-turn adjustment factors also relate to left-turn adjustment factors.

The capacity of a bus stop in buses per hour, B_s, is:(R36)

$$B_s = N_{el} B_l = \frac{3{,}600(g/C)}{t_c + t_d(g/C) + Z c_v t_d}$$

where:

B_s = bus stop bus capacity (bus/h);
B_l = individual loading area bus capacity (bus/h);
N_{el} = number of effective loading areas, from Exhibit 4-12;

Kittelson & Associates et al (2003) provide indications of typical dwell times based on passenger loading times. In the absence of local data, dwell times in the order of 15–30 seconds for urban areas and 30–60 seconds in central city areas are considered to be reasonable. The user is able to adjust these as necessary.

$$B = B_l N_{el} f_m$$

where:

B = mixed traffic bus capacity (bus/h);
B_l = bus loading area capacity at the critical bus stop (bus/h);
N_{el} = number of effective loading areas at the critical bus stop; and
f_m = capacity adjustment factor for mixed traffic interference at the critical bus stop.

The effects of right turns on bus lane vehicle capacity can be estimated by multiplying the bus lane vehicle capacity *without* right turns by an adjustment factor. The values of this adjustment factor, f_r, may be estimated from Equation 4-10:[R36]

$$f_r = 1 - f_l\left(\frac{v_r}{c_r}\right)$$

where:

f_r = right-turn adjustment factor;
f_l = bus stop location factor, from Exhibit 4-51;
v_r = volume of right turns at specific intersection (veh/h); and
c_r = capacity of right turns at specific intersection (veh/h).

$$f_m = 1 - f_l\left(\frac{v}{c}\right)$$

where:

f_m = mixed traffic adjustment factor;
f_l = bus stop location factor, from Exhibit 4-51;
v = curb lane volume at a specific intersection; and
c = curb lane capacity at a specific intersection.

Source: Kittelson & Associates et al (2003)

B2.3.3 Behavioural response

The behavioural response is undertaken by repeating the following steps until equilibrium is reached when the travel time benefit in successive iterations is the same:

Step 1: Calculate the travel time in the special vehicle lane and the other traffic lanes as follows:

$$t_i = t_{mid} + \left(d_{\text{int}} + t_{merge}\right) * Number.of.Intersections \quad \text{(Equation B.20)}$$

Where:

t_i = travel time in lane being examined

t_{mid} = midblock travel time

d_{int} = intersection delay

t_{merge} = merging delay.

Step 2 Calculate the travel time benefit for the special vehicle lane as a proportion of the general traffic lane travel time:

$$t_b = \frac{t_{General} - t_{SVL}}{t_{General}}$$ (Equation B.21)

Where:

t_b = travel time benefit in the special vehicle lane as a proportion of general traffic lane travel time

$t_{general}$ = corridor travel time in the general traffic lane

t_{SVL} = corridor travel time in the special vehicle lane.

Step 3 Calculate the percentage change in baseline average vehicle occupancy as follows:

$$\Delta AVO = E_{AVO} * t_b$$ (Equation B.22

Where:

ΔAVO = percentage change in average vehicle occupancy

E_{AVO} = user input elasticity represented as the percentage change in average vehicle occupancy per 1% benefit in travel time for using a special vehicle lane

t_b = travel time benefit in the special vehicle lane as a proportion of general traffic lane travel time.

Step 4 Calculate the revised average vehicle occupancy:

$$AVO_{\mathrm{Re}\,vised} = (1 + E_{AVO} * t_b) * AVO_{base}$$ (Equation B.23)

Where:

$AVO_{\mathrm{Re}\,vised}$ = revised average vehicle occupancy

E_{AVO} = user input elasticity represented as the percentage change in average vehicle occupancy per 1% benefit in travel time for using a special vehicle lane

t_b = travel time benefit in the special vehicle lane as a proportion of general traffic lane travel time

AVO_{base} = average vehicle occupancy from user input data for traffic volume and proportion of HOV 2+ and HOV 3+.

Step 5 Calculate the increase in HOVs as follows:

If the lane is a T2 lane then:

$$\Delta HOVs = \frac{(AVO_{\mathrm{Re}\,vised} - 1)}{(AVO_{HOV2+} - 1)} * (\frac{1}{HOV2+}) - 1$$ (Equation B.24)

If the lane is a T3 lane then:

$$\Delta HOVs = \frac{(AVO_{\mathrm{Re}\,vised} - 1 - HOV2+)}{(AVO_{HOV3+} - 2)} * (\frac{1}{HOV3+}) - 1$$ (Equation B.25)

Where:

$\Delta HOVs$ = increase in eligible HOVs for the special vehicle lane

$AVO_{\mathrm{Re}vised}$ = revised average vehicle occupancy

AVO_{HOV2+} = average vehicle occupancy for vehicles with two or more occupants

AVO_{HOV3+} = user input average vehicle occupancy for vehicles with three or more occupants

HOV_{2+} = proportion of traffic volume with two or more occupants per vehicle

HOV_{3+} = proportion of traffic volume with two or more occupants per vehicle

Step 6 Calculate the revised public transport patronage:

$$PT_{\mathrm{Re}vised} = \left(1 + E_{PT} * t_b\right) * PT_{base} \quad \text{(Equation B.26)}$$

Where:

$PT_{\mathrm{Re}vised}$ = revised public transport patronage

E_{PT}= user input elasticity represented as the percentage change in average vehicle occupancy per 1% benefit in travel time for using a special vehicle lane

t_b = travel time benefit in the special vehicle lane as a proportion of general traffic lane travel time

PT_{base} = baseline public transport patronage.

Step 7 Calculate the change in traffic volumes:

If the user has specified 'Case 1: Reduce traffic volumes for mode shift (move same people with less traffic)', the traffic volume is reduced by the number of people moved from the traffic not eligible to use the special vehicle lane to those that are eligible to use the special vehicle lane. The simplifying assumption is that the reduction in the number of vehicles equals the reduction in the number of people divided by the difference in the average vehicle occupancy as outlined below.

$$\Delta Q = \left(People_{Base} - PT_{Base}\right) * \left(\frac{1}{AVO_{\mathrm{Re}vised}} - \frac{1}{AVO_{Base}}\right) - \left(\frac{\Delta PT}{AVO_{\mathrm{Re}vised}}\right) \quad \text{(Equation B.27)}$$

Where:

ΔQ = reduction in traffic volumes

ΔPT = increase in public transport patronage

PT_{base} = baseline public transport patronage

$People_{base}$ = baseline number of people travelling along the corridor

AVO_{base} = baseline average vehicle occupancy

$AVO_{revised}$ = revised average vehicle occupancy

If the user has specified 'Case 2: Retain forecast traffic volumes' there is no change in the average traffic volume along the corridor, therefore the increase in HOVs represents an increased proportion of the 'fixed' traffic volume.

If the user has specified 'Case 3: Increase traffic volumes to allow reassignment from other corridors (move more people and more traffic)' the increase in total traffic volumes along the corridor is equal to the traffic volume eligible to use a special vehicle lane where an added lane is proposed. Where a converted lane is proposed the change in traffic volumes equals zero, as the implementation of a special vehicle lane would be more likely to move traffic away from the corridor. This is accounted for in the model by restricting the traffic volumes in each lane to the threshold volume calculated for the user-input lowest acceptable travel speed.

Speeds and productivity

Speeds are calculated for:

- average speed per vehicle in each lane
- average speed for all-stops buses
- average speed per vehicle
- average speed per person

The average speed for each lane is calculated as follows:

$$S_i = \frac{CorridorLength}{t_i / 3600}$$ (Equation B.28)

Where:

S_i = speed (km/h) in lane under investigation

t_i = travel time (seconds) in lane under investigation

The average speed for the all-stops buses is calculated for each lane as follows:

$$S_b = \frac{CorridorLength * 3600}{t_i + d_r * No.of.Bus.Stops}$$ (Equation B.29)

Where:

S_b = speed (km/h) for all-stops buses

t_i = travel time (seconds) in lane that buses travel in

d_r = re-entry delay for buses entering the traffic stream from indented bus bays.

The average speed per vehicle is calculated as follows:

$$S = \frac{P_{SVL} + P_{other}}{Q}$$ (Equation B.30)

$$P_{q,SVL} = (Min(q_{m,SVL}, q_{t,SVL}) - q_{buses}) * S_{SVL} + q_{buses} * S_b + 3600 * CorridorLength * \frac{Max(0, q_{m,SVL} - q_{t,SVL})}{(t_{mid,SVL} + (d_{\text{int},other} + d_{merge}))}$$ (Equation B.31)

$$P_{q,Other} = (Min(q_{m,other}, q_{t,other}) - q_{buses}) * S_{other} + q_{buses} * S_b + 3600 * CorridorLength * \frac{Max(0, q_{m,other} - q_{t,other})}{(t_{mid,other} + (d_{int,SVL} + d_{merge}))}$$ (Equation B.32)

$$Q = \frac{P_{SVL} * \frac{t_{SVL}}{S_{SVL}} + P_{other} * \frac{t_{other}}{S_{other}}}{t_{SVL} + t_{other}}$$ (Equation B.33)

Where:

$P_{q,SVL}$ = productivity for vehicle travel in the kerbside lane (base case and corridor with general traffic lanes) or the special vehicle lane, (accounting for vehicles that change from the special vehicle lane to another lane to achieve an equal degree of saturation through the intersections)

$P_{q,other}$ = productivity for vehicle travel in the other general traffic lane/s (accounting for vehicles that change from the special vehicle lane to another lane to achieve equal degree of saturation through the intersections)

$q_{m,SVL}$ = mid-block traffic volume in the kerbside lane (base case and corridor with general traffic lanes) or the special vehicle lane

$q_{t,SVL}$ = through-traffic volume in the first lane available for through movements (base case and corridor with general traffic lanes) or the special vehicle lane

$q_{m,other}$ = mid-block traffic volume in other general traffic lanes

$q_{t,other}$ = through traffic volume in other general traffic lanes

q_{buses} = all-stops buses eligible to use the lane (noting that for a truck lane buses would use the other general traffic lanes and not the truck lane)

S_{SVL} = average speed in the kerbside lane or special vehicle lane

S_{other} = average speed in other general traffic lanes

S_b = average speed of all-stops buses using the given lane

t_{SVL} = corridor travel time in the kerbside lane or special vehicle lane

t_{other} = corridor travel time in other general traffic lanes.

The average speed per person is calculated in the same manner as the average speed per vehicle except that the number of people replaces the number of vehicles as outlined in table B.5:

Table B.5 Equivalent person input to calculation of productivity

Input in calculating average speed per vehicle	Input in calculating average speed per person
$q_{m,SVL}$	$q_{m,SVL} * AVO_{SVL} + PT_{revised} * \% PT_{express}$
$q_{t,SVL}$	$q_{t,SVL} * AVO_{SVL} + PT_{revised} * \% PT_{express}$
$q_{m,other}$	$q_{m,other} * AVO_{other} + PT_{revised} * \% PT_{express}$
$q_{t,other}$	$q_{t,other} * AVO_{other} + PT_{revised} * \% PT_{express}$
q_{buses}	$PT_{revised} * (1- \% PT_{express})$

Where:

AVO_{SVL} = average vehicle occupancy in the special vehicle lane

AVO_{other} = average vehicle occupancy in other general traffic lanes

$\% PT_{express}$ = user-input proportion of public transport patronage on express services

$PT_{revised}$ = revised public transport patronage after the behavioural response.

Costs

The undiscounted travel costs for each year are calculated by multiplying each component of the productivity calculations for both vehicles and people by the unit cost per person (or vehicle). The calculations include the number of car drivers, car passengers, public transport all-stops, public transport express, motorcyclists and truck drivers travelling in each lane (mid-block and through the intersections) in order to determine the cost of through travel along the corridor. Turning traffic is not included in this assessment.

The cost per vehicle using lane *i* (kerbside or other lanes) in section *j* (either the mid-block or through traffic at the intersections) is:

$$C_{j,motos,i} = q_{j,i} * \%Motorcyclist * ValueofTime(Motorcyclist + Motorcycle)$$ (Equation B.34)

$$C_{j,trucks,i} = q_{j,i} * \%Trucks * ValueofTime(TruckDriver + Truck)$$

$$C_{PT,i} = PT * ValueofTime(PT)$$

$$C_{j,car,i} = q_{j,i} * (1 - \%Motos - \%Trucks) * [(ValueofTime_{driver} + ValueofTime_{vehicle}) + (AVO_i - 1) * ValueofTime_{passenger}$$

The costs are then discounted at the user-specified discount rate, and multiplied by the user-input number of hours per day, and days per year that the assessment is applied, to produce the net-present value of the travel costs of the proposal. The net-present value of the benefits is the difference between the net-present value of the travel time costs for the special vehicle lane type and the base case.

The cost per user is also calculated by dividing the total cost by the number of people travelling along the corridor.

B2.3.4 Model outputs – output summary

The output summary is presented in three parts, comprising:

1 The evaluation against the warrants

2 The evaluation of productivity and economic efficiency

3 The evaluation against user-specified level of service criteria.

In almost all cases, the recommended special vehicle lane will differ across the three series of outputs and it is up to the analyst to determine which should be more heavily weighted. The purpose of providing these outputs is to provide transparency in the analysis.

Evaluation against warrants

This summary examines the results and determines, first, whether the corridor is a candidate for a special vehicle lane based on its relative public transport and freight priority, and whether the corridor is likely to become congested in the future. This stage will determine whether the special vehicle lane would be installed in response to congestion or in anticipation of it.

The second stage of the assessment determines which of the special vehicle lanes (bus lane, transit lane, truck lane) meets operational warrants namely where:

- the number of buses required is less than bus capacity
- in an added lane, a special vehicle lane will carry more people than a general traffic lane, or in a converted lane, maintain the same flow of people
- a special vehicle lane has a higher productivity than a general traffic lane for an added lane, or has a higher productivity than the base case for a converted lane
- a special vehicle lane is uncongested
- general traffic lanes operate at speeds better than the lowest acceptable travel speed (the test of congestion on other users)
- a special vehicle lane is restricted to a class of vehicle (bus lane or truck lane), or has a sufficient number of HOVs (set at 100) to avoid the empty lane syndrome
- a special vehicle lane will carry few vehicles and have a faster running speed than a general traffic lane (ie the eligibility is not too strict to prevent it operating as a general traffic lane).

The preferred special vehicle lane is one that meets the number of warrants, noting that this could be more than one lane. The user may need to determine whether any or all of these warrants are 'fatal flaws' and whether a special vehicle lane has to meet all the warrants. In practice, this may not be possible.

An example is provided in figure B.14.

Figure B.14 Evaluation against warrants

Bus Priority Route or Freight Priority Route?	Bus and Freight Priority Route		
Congested Corridor (Level of Service E or F) or Corridor operating below Person and/or Freight Level of Service Target?	No	Yes	Yes
Merit in proceeding to the next stage of assessment?	**Consider Proactive Implementation of Bus, Transit and/or Truck Lane**		
Special Vehicle Lane that provides Bus Capacity Sufficient for Number of Public Transport Services Required?	Bus, T3 or T2 Lane	Bus, T3 or T2 Lane	Bus or T3 Lane
Special Vehicle Lane carries more people than adjacent general traffic lane?	Bus, T3 or T2 Lane	T3 or T2 Lane	No Special Vehicle Lanes
Special Vehicle Lane that has higher productivity than a general traffic lane (proactive implementation)?	Bus, T3 or T2 Lane	Bus, T3 or T2 Lane	Bus, T3 or T2 Lane
Special Vehicle Lane that remains uncongested (Level of Service D or better)	Bus, T3 or T2 Lane	Bus, T3 or T2 Lane	Bus, T3 or T2 Lane
Special Vehicle Lane that keeps general traffic lane operating above Lowest Acceptable Operating Speed (10 kph) - the test of impact for general traffic	Bus, T3 or T2 Lane	T3 or T2 Lane	No Special Vehicle Lanes
Special Vehicle Lane that is restricted to classes of vehicle only or has 100 HOV's to avoid "empty lane syndrome"	Bus Lane	Bus, T3 or T2 Lane	Bus, T3 or T2 Lane
Special Vehicle Lane that carries fewer vehicles than adjacent general traffic lane (i.e. will the level of eligibility be too great to provide a travel time saving)	No Special Vehicle Lanes	Bus, T3 or T2 Lane	Bus, T3 or T2 Lane
SPECIAL VEHICLE LANE THAT SATISFIES MEETS MOST WARRANTS FOR FURTHER CONSIDERATION	**Bus Lane Without Trucks**	**T3 or T2 Lane Without Trucks**	**Bus or T3 Lane Without Trucks**

The theoretical example highlights various scenarios which the user will be required to interpret. The first is highlighted vertically. The results indicate that the corridor is not yet congested, so:

- there are not enough HOVs to warrant a transit lane hence a bus lane is the only one to meet the warrant to avoid the empty lane syndrome
- there is no special vehicle lane that could restrict the eligibility to the point at which it would operate better than the adjacent general traffic lane, because there is no congestion in the general traffic lane.

The second relates to the special vehicle lane carrying more people than a general traffic lane. In this example, the public transport patronage was set to decline over the analysis period, therefore in the longer term none of the special vehicle lanes would carry more people than a general traffic lane.

The third relates to the level of congestion in the general traffic lanes. Logically, as traffic volumes grow, congestion increases to the point where it cannot be sustained above the lowest acceptable travel speed. In this example, in the longer term, there are two warrants that none of the special vehicle lanes can meet, and it is the bus capacity that ends up determining which is the preferred lane. In these situations, the user is directed to consider the economic efficiency and whether there is a positive net present value to determine the viability of a special vehicle lane.

The assessment of truck lanes is not expressly considered as part of these warrants, but is included as a requirement in the preferred special vehicle lane if the user has specified that trucks are permitted to use this lane and the corridor under investigation is identified as a freight priority route.

Evaluation of productivity and economic efficiency

The model provides outputs that evaluate the performance of the corridor with a special vehicle lane by using three measures:

1. Corridor productivity – measured as the number of people moved multiplied by the average speed per person expressed as a percentage of the ideal productivity. As congestion increases, the productivity also increases to a point where the speed declines faster than the growth in traffic. Under further traffic growth the productivity also declines. The ideal productivity can be defined in five ways, which the user is prompted to specify, as follows:
    a. using the benchmarks specified in Austroads (2009)
    b. modifying the Austroads benchmarks to reflect the intersection capacity or input mid-block capacity if examining a motorway
    c. calculating the highest achievable productivity based on the user input parameters, without traffic signal control
    d. calculating the highest achievable productivity based on the user input parameters, with traffic signal control
    e. calculating the highest achievable productivity for the class of arterial road (and the maximum number of traffic signals) determined from the user inputs (in accordance with the methodology outlined in the HCM2010).
2. Economic efficiency – measured as the lowest travel time cost per user based on the travel times calculated by the model and the values of time input by the user. The lowest cost per user is a normalised measure to account for the different cases allowed for when estimating the behavioural response.
3. Economic efficiency – measured as the net present value of the benefits comparing the total cost of travel for the corridor with a special vehicle lane to the total travel costs for the base case.

These results are colour coded to correspond with the ideal through to the poorest corridor performance, consistent with the concept of levels of service.

An example of these outputs is provided in figure B.15.

Figure B.15 Evaluation of productivity and economic efficiency

CORRIDOR OPERATIONAL PERFORMANCE (PRODUCTIVITY)				
Colour Ratings	Near Optimal Productivity	High Productivity (underutilised capacity)		
Method of Productivity Assessment (Choose one)	Method 5: Max for the Road Class	Morning		
		2013	2026	2041
Corridor with Added Kerbside Lane to provide a Bus Lane		46%	46%	37%
Corridor with Added Kerbside Lane to provide a T3 Lane		46%	68%	61%
Corridor with Added Kerbside Lane to provide a T2 Lane		46%	70%	54%
Corridor with Added Kerbside Lane to provide a Truck Lane		48%	35%	31%
CORRIDOR WITH SPECIAL VEHICLE LANE THAT HAS THE HIGHEST PRODUCTIVITY RELATIVE TO OPTIMUM		Bus Lane Without Trucks	T2 Lane Without Trucks	T3 Lane Without Trucks

CORRIDOR ECONOMIC PERFORMANCE (COST PER PERSON USING THE CORRIDOR (UNDISCOUNTED))				
Colour Ratings	Low Cost	Low-Moderate Cost		
		Morning		
		2013	2026	2041
Corridor with Added Kerbside Lane to provide a Bus Lane		$ 0.825	$ 1.890	$ 2.112
Corridor with Added Kerbside Lane to provide a T3 Lane		$ 0.824	$ 1.023	$ 1.706
Corridor with Added Kerbside Lane to provide a T2 Lane		$ 0.831	$ 1.032	$ 1.869
Corridor with Added Kerbside Lane to provide a Truck Lane		$ 0.791	$ 2.197	$ 2.210
CORRIDOR WITH SPECIAL VEHICLE LANE THAT HAS LOWEST PER USER COST		T3 Lane Without Trucks	T3 Lane Without Trucks	T3 Lane Without Trucks

ECONOMIC PERFORMANCE - NPV OF BENEFITS			
	1st Year	2013-2026	2013-2041
Corridor with Added Kerbside Lane to provide a Bus Lane	$ 5,737	$ 998,524	$ 1,467,908
Corridor with Added Kerbside Lane to provide a T3 Lane	$ 5,940	$ 1,497,632	$ 2,140,333
Corridor with Added Kerbside Lane to provide a T2 Lane	$ 1,711	$ 1,331,105	$ 1,873,191
Corridor with Added Kerbside Lane to provide a Truck Lane	$ 15,641	$ 1,331,105	$ 1,873,191
HIGHEST NPV BENEFITS WITH A POSITIVE NPV	T3 Lane Without Trucks	T3 Lane Without Trucks	T3 Lane Without Trucks

Evaluation against levels of service

The levels of service are traditional traffic engineering measures ranging from A through to F for:

- urban corridors – the level of service is directly related to the forecast speed as a percentage of the free-flow speed (or base running speed) as defined in Austroads (2009)
- motorways – these levels of service are based on the density of traffic and defined in the HCM2010.

The model provides outputs that evaluate the performance of the corridor with a special vehicle lane using three measures:

1 Mode performance – categorised into general traffic, eligible HOVs, all-stops public transport, express (or non-stop public transport) and freight, and compared against the target level of service specified by the user. If the user has not selected a target level of service, no results will be displayed. The preferred special vehicle lane treatment is determined by calculating the gap between the level of

service provided and the target level of service defined by the user. The lane with the lowest level of service gap is the preferred lane. More than one lane can have the same level of service gap.

2 Lane performance – level of service for the special vehicle lane and the general traffic lanes.

3 User performance – categorised into people and freight, and compared against the target level of service specified by the user. If the user has not selected a target level of service, no results will be displayed.

An example is provided in figure B.16. It is evident that in the short term, as with the assessment against the warrants, that all lanes are equally valid in uncongested conditions as they all have the same level of service gap. A point to note is that unlike the SMARTROADS assessment the level of service gap is not weighted by volume or travel time cost at this stage, nor is it weighted according to any priority. The specification of a target level of service does provide some weighting as these levels of service are related performance.

In the example provided in figure B.16, in the short term, the general traffic and HOVs target level of service is 'D' and operating at a level of service 'B'. The level of service gap for general traffic and HOVs is +2 for each (operating at 2 levels of service better than the target). The freight and public transport target level of service is 'B' and operating at a level of service 'B' for freight and express public transport, but operating at a level of service 'D' for all-stops public transport. The level of service gap for freight and express services is 0 for each and -2 for all-stops public transport (operating at two levels of service below than the target). Total level of service gap is the total of the individual model levels of service, in this case +2.

Figure B.16 Evaluation against level of service

MODE PERFORMANCE

Colour ratings		Exceeds target LoS		
		Morning		
		2013	2026	2041
Corridor - Base Case	**Target LoS**			
Level of Service for Public Transport (All Stops)	B	D	F	F
Level of Service for Public Transport (Express)	B	B	F	F
Level of Service for Freight	B	B	F	F
Level of Service for HOV's	D	B	F	F
Level of Service for General Traffic	D	B	F	F
Corridor - General Traffic Lanes	**Target LoS**			
Level of Service for Public Transport (All Stops)	B	D	D	F
Level of Service for Public Transport (Express)	B	B	C	F
Level of Service for Freight	B	B	C	F
Level of Service for HOV's	D	B	C	F
Level of Service for General Traffic	D	B	C	F
Corridor with Added Kerbside Lane to provide a Bus Lane	**Target LoS**			
Level of Service for Public Transport (All Stops)	B	D	D	D
Level of Service for Public Transport (Express)	B	B	C	C
Level of Service for Freight	B	B	F	F
Level of Service for HOV's	D	B	F	F
Level of Service for General Traffic	D	B	F	F
Corridor with Added Kerbside Lane to provide a T3 Lane	**Target LoS**			
Level of Service for Public Transport (All Stops)	B	D	D	E
Level of Service for Public Transport (Express)	B	B	C	C
Level of Service for Freight	B	B	D	F
Level of Service for HOV's	D	B	C	C
Level of Service for General Traffic	D	B	D	F
Corridor with Added Kerbside Lane to provide a T2 Lane	**Target LoS**			
Level of Service for Public Transport (All Stops)	B	D	D	E
Level of Service for Public Transport (Express)	B	B	C	D
Level of Service for Freight	B	B	C	F
Level of Service for HOV's	D	B	C	D
Level of Service for General Traffic	D	B	C	F
Corridor with Added Kerbside Lane to provide a Truck Lane	**Target LoS**			
Level of Service for Public Transport (All Stops)	B	D	F	F
Level of Service for Public Transport (Express)	B	B	F	F
Level of Service for Freight	B	B	C	C
Level of Service for HOV's	D	B	F	F
Level of Service for General Traffic	D	B	F	F
PREFERRED SPECIAL VEHICLE LANE - DIFFERENCE BETWEEN TARGET LOS AND EVALUATED LOS		All Lanes	T2 or General Traffic Lane	T3 Lane

LANE PERFORMANCE

Colour Ratings	Level of Service A	Level of Service B		
		Morning		
		2013	2026	2041
Base Case - General Traffic Lane		B	F	F
Corridor with General Traffic Lanes		B	C	F
Corridor with Added Kerbside Lane to provide a Bus Lane				
Bus Lane		B	C	C
Other Lanes		B	F	F
Corridor with Added Kerbside Lane to provide a T3 Lane				
T3 Lane		B	C	C
Other Lanes		B	D	F
Corridor with Added Kerbside Lane to provide a T2 Lane				
T2 Lane		B	C	D
Other Lanes		B	C	F
Corridor with Added Kerbside Lane to provide a Truck Lane				
Truck Lane		B	C	C
Other Lanes		B	F	F

USER PERFORMANCE

Colour ratings		Exceeds target LoS		
		Morning		
		2013	2026	2041
Level of Service per Person	**Target LoS**			
Corridor with Added Kerbside Lane to provide a General Traffic Lane	C	C	C	F
Corridor with Added Kerbside Lane to provide a Bus Lane	C	C	E	E
Corridor with Added Kerbside Lane to provide a T3 Lane	C	C	C	D
Corridor with Added Kerbside Lane to provide a T2 Lane	C	C	C	E
Corridor with Added Kerbside Lane to provide a Truck Lane	C	C	F	E
Level of Service for Freight	**Target LoS**			
Corridor with Added Kerbside Lane to provide a General Traffic Lane	B	B	C	F
Corridor with Added Kerbside Lane to provide a Bus Lane	B	B	F	F
Corridor with Added Kerbside Lane to provide a T3 Lane	B	B	D	F
Corridor with Added Kerbside Lane to provide a T2 Lane	B	B	C	F
Corridor with Added Kerbside Lane to provide a Truck Lane	B	B	C	C

B2.3.5 Model outputs – graphical

The analytical model outputs a series of graphs that demonstrate the performance of the base case, a scenario with a general traffic lane and a special vehicle lane to show how the performance changes over time. Examples are provided in figures B17 to B.24.

Graphs are provided for:

- kerbside lane (or special vehicle lane) traffic volumes and speeds
- general traffic lanes (or special vehicle lane) traffic volumes and speeds
- changes in traffic volumes and public transport patronage through behavioural response
- buses using kerbside lane versus the bus service capacity
- corridor productivity with level of service bands
- travel speed per vehicle (including all-services buses) with level of service bands
- travel speed per person with level of service bands
- undiscounted travel costs

Figure B.17 Example of kerbside lane performance

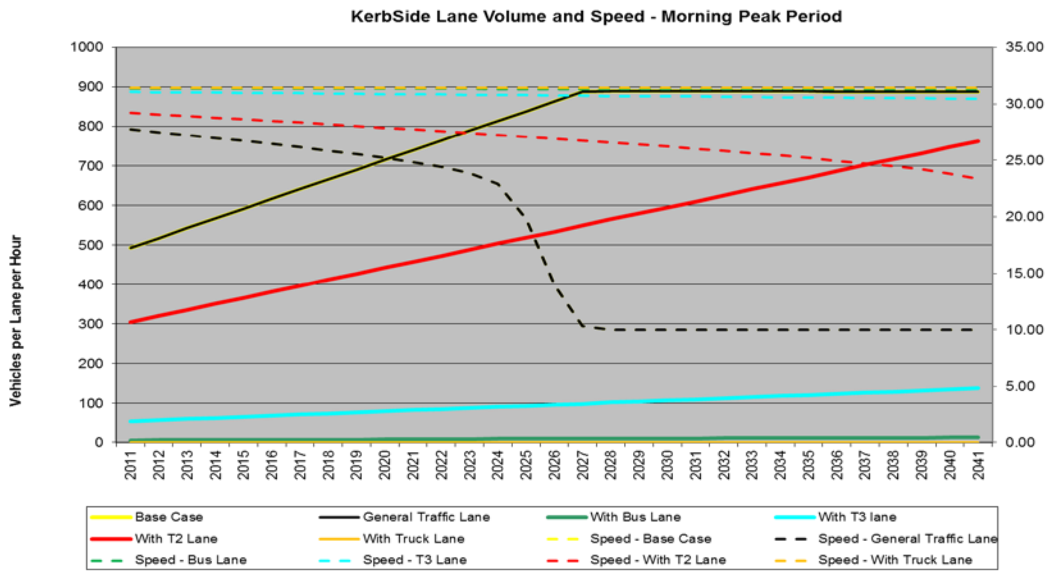


Figure B.18 Example of performance of other lanes

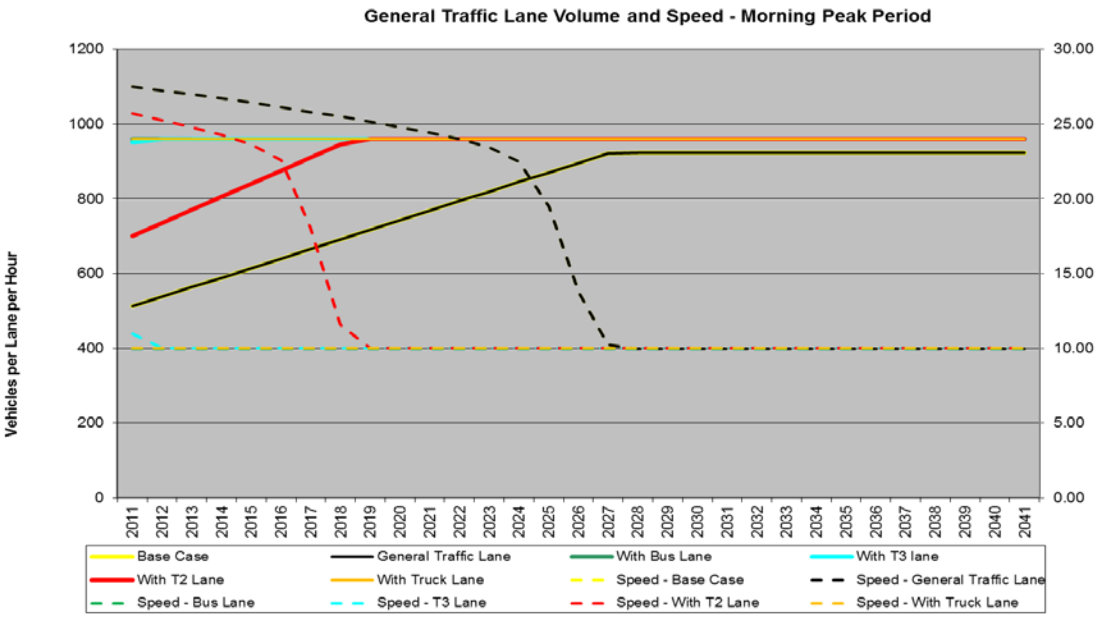


Figure B.19 Example of changes in traffic volumes and public transport patronage

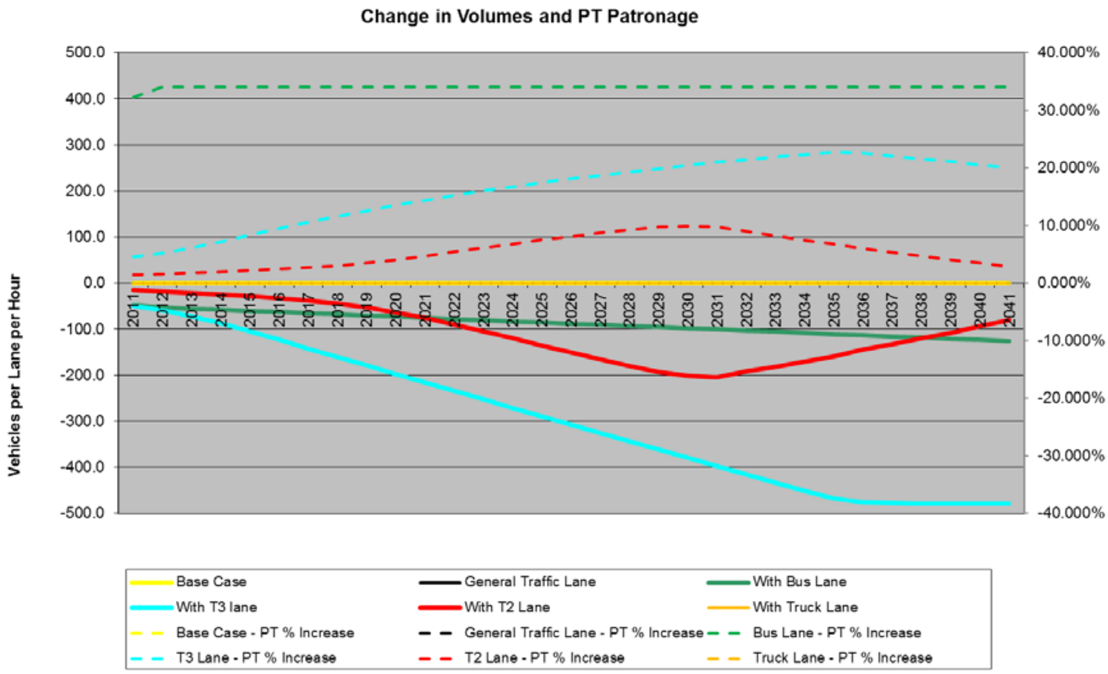


Figure B.20 Example of bus service capacity

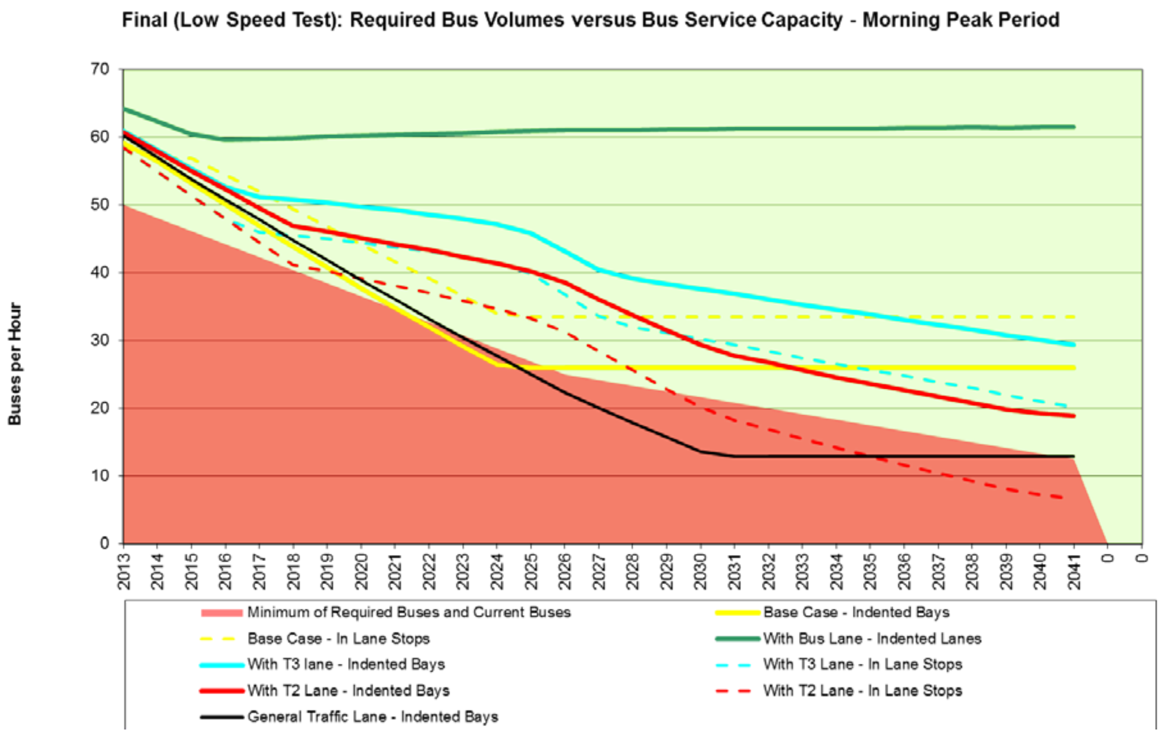


Figure B.21 Example of corridor productivity

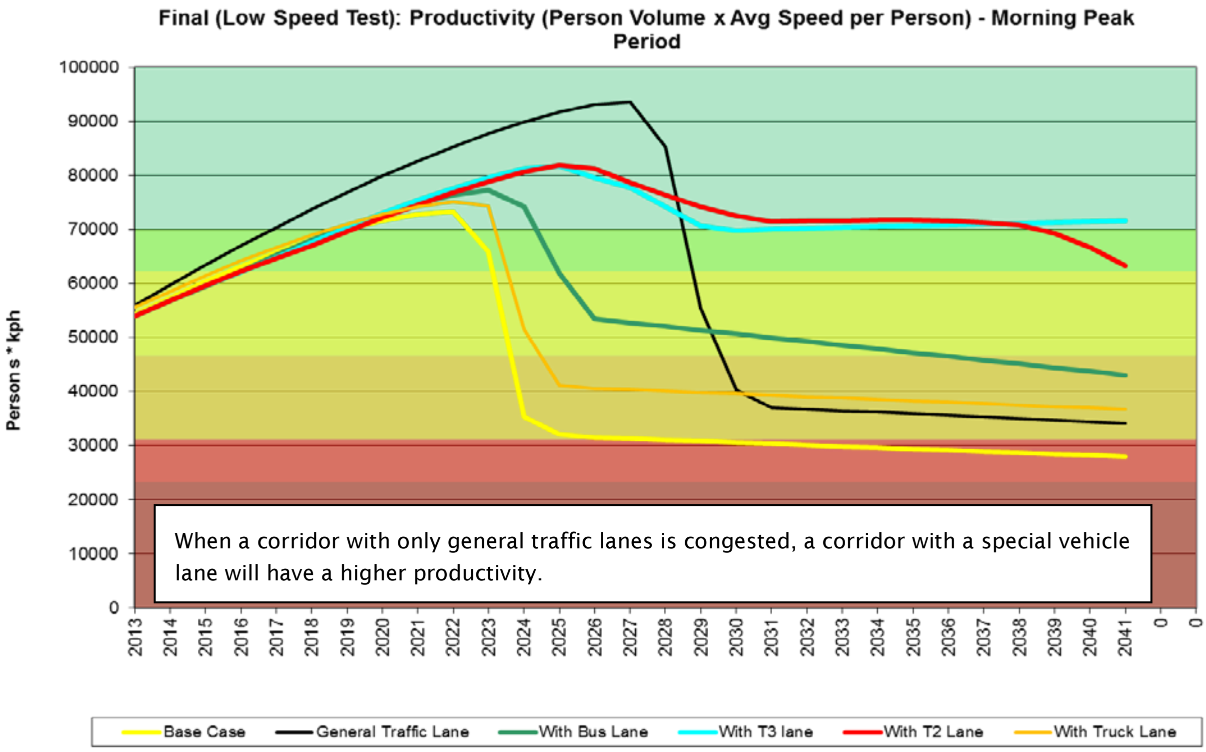


Figure B.22 Example of travel speed per person

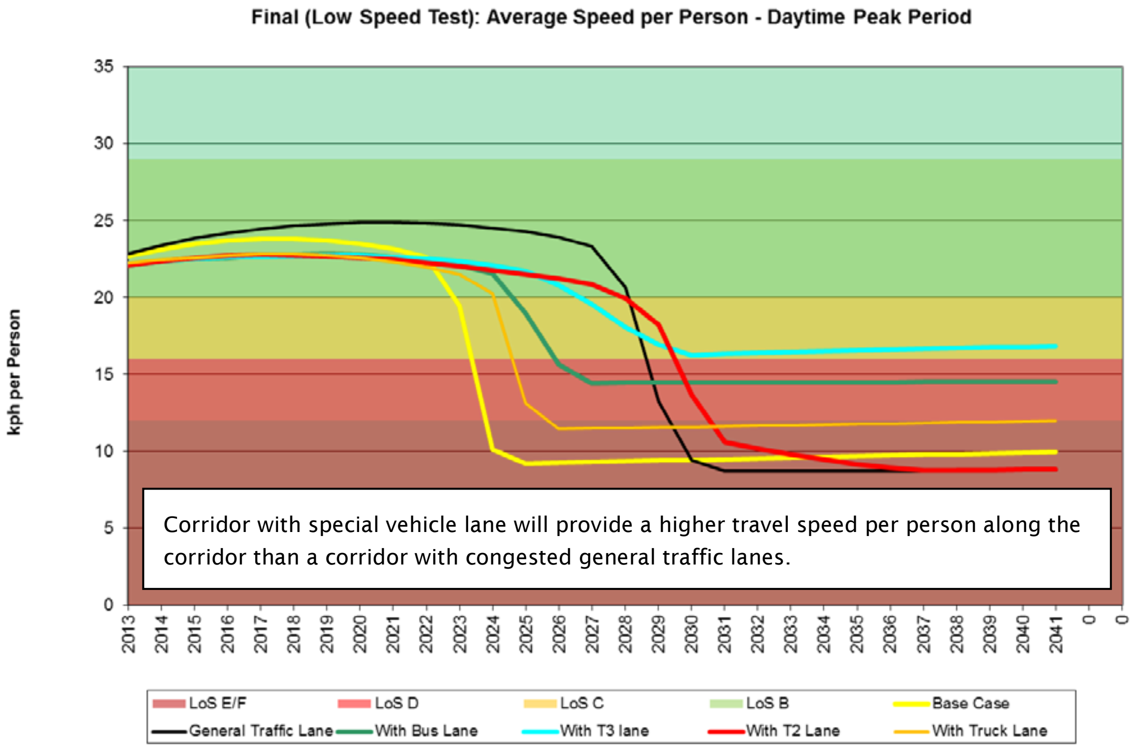


Figure B.23 Example of travel speed per vehicle

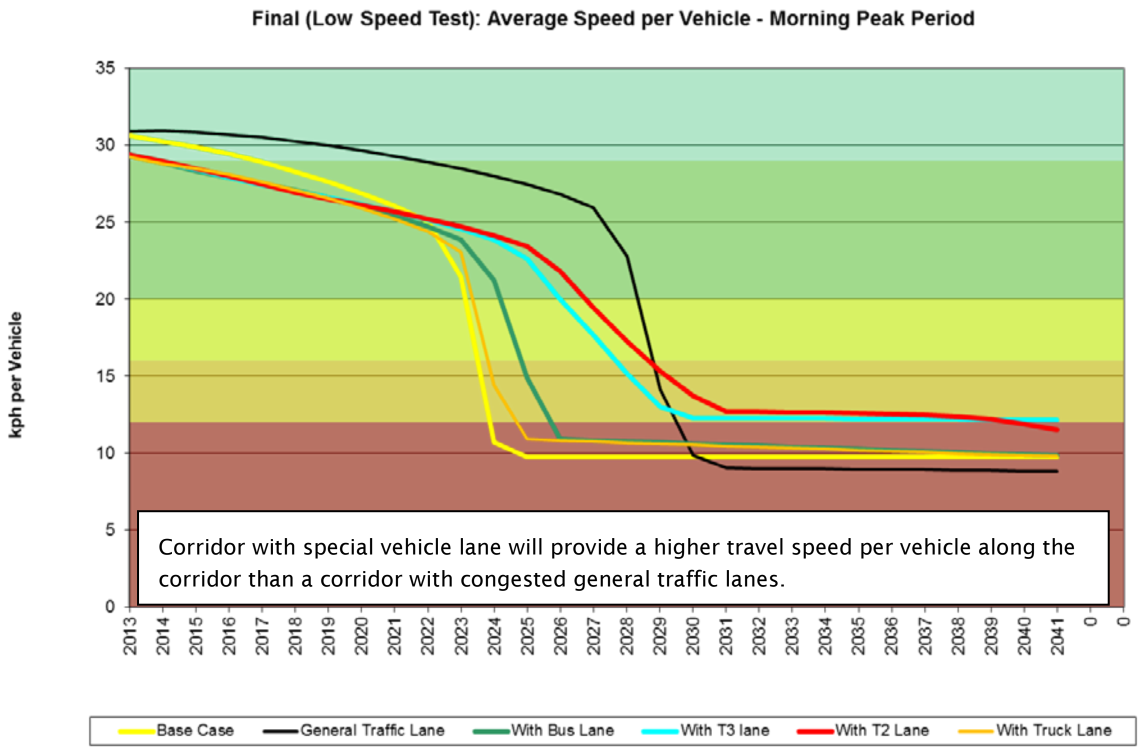
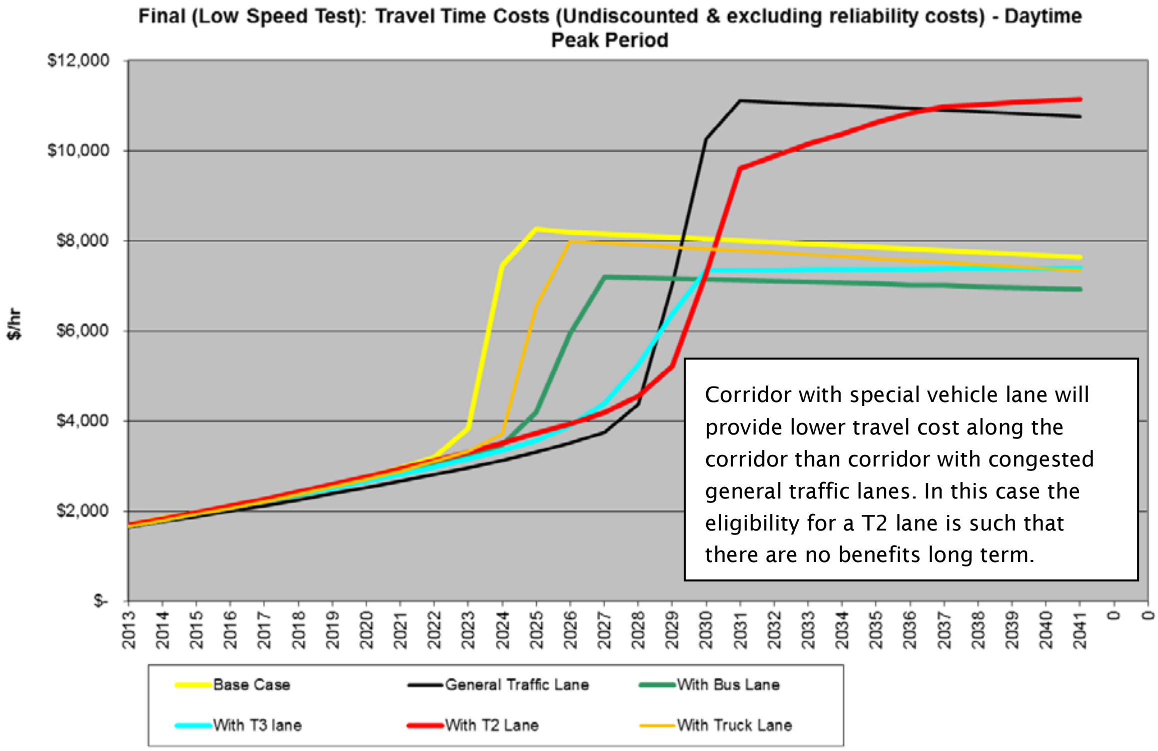


Figure B.24 Example of travel costs



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Appendix C: Special vehicle lane assessment models

Appendix C can be accessed at www.nzta.govt.nz/resources/research/reports/557.