Improving the cost-benefit analysis of integrated PT, walking and cycling

December 2013

M Wedderburn, Sinclair Knight Merz/Colin Buchanan, Wellington

NZ Transport Agency research report 537
Sinclair Knight Merz Ltd

ISBN 978-0-478-40787-7 (electronic)
ISSN 1173-3764 (electronic)

NZ Transport Agency
Private Bag 6995, Wellington 6141, New Zealand
Telephone 64 4 894 5400; facsimile 64 4 894 6100
research@nzta.govt.nz
www.nzta.govt.nz

Wedderburn, M (2013) Improving the cost-benefit analysis of integrated PT, walking and cycling. *NZ Transport Agency research report 537.* 90pp.

Sinclair Knight Merz Ltd was contracted by the NZ Transport Agency in 2011 to carry out this research.

Keywords: Access, active travel, cost-benefit analysis, cycling, egress, integration, public transport, walking

An important note for the reader

The NZ Transport Agency is a Crown entity established under the Land Transport Management Act 2003. The objective of the Agency is to undertake its functions in a way that contributes to an efficient, effective and safe land transport system in the public interest. Each year, the NZ Transport Agency funds innovative and relevant research that contributes to this objective.

The views expressed in research reports are the outcomes of the independent research, and should not be regarded as being the opinion or responsibility of the NZ Transport Agency. The material contained in the reports should not be construed in any way as policy adopted by the NZ Transport Agency or indeed any agency of the NZ Government. The reports may, however, be used by NZ Government agencies as a reference in the development of policy.

While research reports are believed to be correct at the time of their preparation, the NZ Transport Agency and agents involved in their preparation and publication do not accept any liability for use of the research. People using the research, whether directly or indirectly, should apply and rely on their own skill and judgement. They should not rely on the contents of the research reports in isolation from other sources of advice and information. If necessary, they should seek appropriate legal or other expert advice.

Acknowledgements

The author would like to thank the following people:

- the peer reviewers for this project, John Bolland and Tim Hughes
- the members of the Steering Group, chaired by Gerry Dance, for their support throughout the project – Helen Chapman, Sandy Fong, Anke Kole, Joanne Leung, Jason Morgan, Leah Murphy, Matthew Rednall and Steve Spence
- Steve Patton of Auckland Transport, in particular, for providing case study information to test the evaluation tool
- Dave Smith, Stacy Rendall and Steve Abley for their analysis of the New Zealand Household Travel Survey database, and for the useful discussions and comments
- all colleagues at Sinclair Knight Merz (SKM) who assisted in this research, including Thomas Small, David Turner, John Siraut and Simona Dobrescu.

Abbreviations and acronyms

ART	Auckland Regional Transport Model
BaR	bike-and-ride
BCR	benefit-cost ratio
BoB	bike-on-board
BRT	bus rapid transit
CBA	cost-benefit analysis
CSR	Community Street Review
EEM	Economic Evaluation Manual
GJT	generalised journey time
LRT	light rail transit
MoT	Ministry of Transport
MUA	main urban area
NCHRP	National Cooperative Highway Research Program
NZHTS	New Zealand Household Travel Survey
P&R	park-and-ride
SKM	Sinclair Knight Merz
SUA	secondary urban area
TRB	Transportation Research Board
VOC	vehicle operating cost
WHO	World Health Organisation

Contents

Executive summary

As modes of transport, cycling, walking and public transport (PT) have clear and well-understood benefits in terms of transport efficiency and wider economic, social and environmental impacts. What is less well understood is the quantum of the walking and cycling benefits, and the effectiveness of specific interventions in encouraging a greater amount of cycling and walking. This is particularly true of integrating cycling and walking with PT in New Zealand, where there is a lack of evidence on the types of measures, both individually and collectively, that can increase active transport access mode shares. It is known that better integration can also be beneficial to PT, leading to higher patronage and therefore revenue.

The purpose of this research was to examine the available evidence on interventions that could improve the integration of PT with walking and cycling, in order to provide decision makers with a robust basis for the appraisal of measures, using cost-benefit analysis.

This research included an international review of evidence on PT access and egress mode shares. At the origin end of PT trips, we found considerable variation in the access mode shares of different cities. The car played a greater role as an access mode in urban areas dominated by car travel, such as many cities in the US and in New Zealand, whereas in many European and Asian cities, a combination of higher population density and more expansive PT networks meant that walking accounted for over 50% of PT access trips. The role of cycling as a PT access mode was marginal in many countries, but it could account for more than 20% of access trips in cities with high-quality cycling infrastructure, facilities at stations and stops, and a wider cycling culture. At the destination end of PT trips, walking was universally the predominant mode. Cycling played only a minor role as an egress mode at the destination end of trips.

This research also included a comparison between New Zealand and international evidence of walking and cycling catchment areas, the distance people would walk and cycle to access PT services. Analysis of data from the Ministry of Transport's New Zealand Household Travel Survey (NZHTS) showed that at the origin end of PT trips, the median walk-to-bus trip length was 200m, and 75% of walk-to-bus trips were less than 500m. These distances were low compared with the selected international research, which showed that people would often walk distances of 400-800m to reach bus services. The observed distribution agreed with the evidence that people would walk further if the mode to be accessed was faster; people in New Zealand would walk further to access rail and ferry services. The walking catchment size to rail services in New Zealand was closer to that observed in other international research, with a median walk-to-rail distance of over 1km. The distribution of distances cycled to PT stations/stops had a larger catchment area than walking. Although based on a small sample, in New Zealand the mean distance cycled was 1.42km, with 25% of people cycling more than 1.35km to reach PT. In line with international evidence, access and egress trips at the destination end were generally shorter than at the origin end.

A variety of factors could influence whether walking and cycling were used as access modes to PT. Cycling was most often used as an access mode for commuting and education trips. In some countries, including New Zealand, certain demographic and socio-economic groups (eg adult males) were generally more likely to cycle. However, no studies had looked specifically at cycling as an access mode. In countries such as the Netherlands, which have a particularly strong reputation for integrating cycling and PT, bicycle usage tended to be more evenly spread over different demographic groups. Evidence from the US highlighted patterns in PT access based on neighbourhood characteristics such as residential density, pedestrian and bicycle connectivity, surrounding land use, and parking facilities at stations.

There were multiple interventions that could contribute to greater integration of walking and cycling with PT, including:

- land use planning that encouraged residential densities conducive to short walking and cycling trips
- walking and cycling networks that were attractive, perceived to be safe, and offered a direct journey between passengers' trip origins, destinations, and stations or stops
- provision for secure bicycle parking at PT nodes
- provision for the carriage of bicycles on PT
- bicycle rental systems.

The 2010 NZ Transport Agency research report (418) *Forecasting the benefits from providing an interface between cycling and PT* concluded that the provision of bike-on-board (BoB) facilities in New Zealand could lead to an increase in bicycle access to PT, with an estimate of the potential BoB patronage at 1.2% of access trips for buses and 3% for suburban rail services. After reviewing international evidence from the UK, US and Switzerland, we concluded that an access mode share of up to 4% of rail passengers could be achieved through the provision of bicycle stands at stations. The introduction of bicycle hire schemes could be attractive to PT commuters with a longer distance to travel at the destination end of their trip. Recent research into bicycle and pedestrian route choice in the UK and New Zealand can be used to estimate the generalised journey time of access trips to PT based on the quality of the approach routes to stations and stops. As a consequence it is possible to estimate the resulting change in travel behaviour using standard elasticities.

The 2003–2010 NZHTS data was analysed to understand the wider impacts of travel behaviour change interventions. One key finding was that if a transport user shifted to PT as the main mode of transport, this change typically had a knock-on effect on overall daily travel patterns. An analysis of the travel patterns of the population as a whole showed that for each additional PT trip, the average number of daily walking trips increased by 0.95 and the distance walked increased by 1.21km (ie walking as a main mode, additional to any walking trips to access PT). For each additional PT trip there was an average daily reduction of two car driver trips and 45km driven (people of driving age 18+ only). The diversion rate for additional mode shift to PT could not be directly implied from this statistical relationship, and complementary travel behaviour change measures would be required to sustain this level of mode shift.

This research resulted in the development of an evaluation tool (available with this report at www.nzta.govt.nz/resources/research/reports/537), which incorporates the findings from studies of travel behaviour in New Zealand and internationally, for estimating the benefit-cost ratio of improving walking and cycling access to PT. The economic evaluation parameters remain consistent with the current valuations contained in the Transport Agency's *Economic evaluation manual*.. An illustrative application of the evaluation tool, for Puhinui Station in Papatoetoe, Manukau City, is included within this report.

The report includes a review of how walking and cycling at either end of a PT trip is represented in data collection, transport planning and modelling, and makes practical recommendations to aid integrated planning in the future.

Abstract

This research project developed an evaluation framework for estimating the cost-benefit analysis of integrating PT with walking and cycling.

The research was based on a review of the available international evidence of public transport access and egress behaviour. Where evidence was available, analysis of trip chains from the New Zealand Household Travel Survey highlighted patterns of public transport access and egress in a New Zealand context and, importantly, provided an indication of the mode shift and trip generation impacts of improved access to public transport.

This research report is accompanied by a spreadsheet evaluation tool, which can be employed to estimate the dollar value of improvements to the integration of public transport, walking and cycling. The research compared the monetary appraisal values from international business case guidance with the NZ Transport Agency's *Economic evaluation manual*, and the evaluation tool is consistent with this guidance.

The report includes a review of how walking and cycling at either end of a PT trip is represented in data collection, transport planning and modelling, and makes practical recommendations to aid integrated planning in the future.

1 Introduction

1.1 Background

As modes of transport, cycling, walking and public transport (PT) have clear and well-understood benefits in terms of transport efficiency and wider economic, social and environmental impacts. What is less well understood is the quantum of the walking and cycling benefits, and the effectiveness of specific interventions in encouraging a greater amount of cycling and walking. This is particularly true of integrating cycling and walking with PT in New Zealand, where there is a lack of evidence on the types of measures, both individually and collectively, that can increase active transport access mode shares. It is known that better integration can also be beneficial to PT, leading to higher patronage and therefore revenue, and reduced congestion.

There are multiple interventions that can contribute to greater integration of walking and cycling with PT, including:

- land use planning, which encourages densities conducive to short walking and cycling trips
- walking and cycling networks that are attractive, perceived to be safe, and offer a direct journey along desire lines between trip attractors, generators and stations or stops
- provision for secure bicycle parking at PT nodes
- provision for the carriage of bicycles on PT
- bicycle rental systems, including bicycle share systems such as Vélib (Paris), and systems dedicated to rail travellers such as OV-Fiets (Netherlands).

The NZ Transport Agency research report *Forecasting the benefits from providing an interface between cycling and PT* (Ensor et al 2010) provided strategic regional forecasts and benefit-cost ratios for measures to integrate cycling and PT. That research concluded that in all of the urban areas assessed, the benefit-to-cost ratio of secure bicycle parking at either end of a PT trip and having a 'bike-on-board' (BoB) system on PT exceeded 1:1, with the highest ratios in the main urban areas with high levels of congestion.

The scope of this current research project was to develop an analytical assessment framework that would improve the scheme appraisal of activities to integrate PT, walking and cycling activities.

1.2 Research objective

The purpose of this research was to develop an analytical assessment framework to:

- understand how provision for walking and cycling at either end of a PT trip affects the attractiveness of that mode
- understand the wide range of initiatives and measures that can improve PT integration with walking and cycling
- forecast demand for PT trips integrated with walking and cycling

- calculate the costs and benefits of alternative proposals to improve integration.

1.3 Evaluation tool[1]

To accompany this research report, Sinclair Knight Merz (SKM) developed an evaluation tool spreadsheet to assist in the appraisal of measures to integrate PT and walking or cycling. The spreadsheet tool aims to:

- provide an easy-to-use tool to estimate the demand for walking and cycling as a PT access mode
- calculate the monetary costs and benefits of alternative options to improve integration at individual stations and stops.

The tool is intended to be flexible, to adapt to different levels of data availability. The minimum data requirements for use of the tool are:

- estimates of daily boarding/alighting at the station/stop
- an estimate of the number of passengers interchanging between PT modes
- population and employment data for the surrounding area (eg from census data)
- cost estimates of the measures proposed (some unit values are included in this report).

If data is available on access mode shares, a station-specific profile of access and egress can be employed. Alternatively, the tool can estimate the access/egress mode shares based on station typology and/or regional averages in New Zealand.

The evaluation tool is designed to be used as one spreadsheet for each station or stop. It can be applied to a single bus stop or a major multimodal interchange. It is designed to enable the user to evaluate several alternative options for the station/stop.

The economic evaluation should be conducted over a specified evaluation period linked to the life of the asset (eg 10 or 15 years). The evaluation tool is designed to estimate passenger impacts for a single year - either the proposed implementation year or a future-year scenario. If users want to test the impacts of integration measures combined with forecast population/employment growth, separate spreadsheets should be completed for the implementation year and any future-year scenario(s). This will make it possible to disaggregate the impacts of the integration measures from the impacts of population/ employment growth.

1.4 Case study: Puhinui Station access

A case study of Puhinui rail station in Papatoetoe, Manukau City, was selected to illustrate an application of the evaluation tool. Within the framework of the Auckland Electrification Project (AEP), KiwiRail is replacing a number of bridges to provide sufficient height clearance. As part of this work, KiwiRail has agreed to introduce the minimum level of pedestrian and cycling facilities required to receive consent on the bridges. Auckland Transport (formerly Manukau City Council) prepared a funding application for enhanced facilities on four of the bridges (Opus 2010).

1 The evaluation tool can be found at www.nzta.govt.nz/resources/research/reports/537.

The case study evaluation is not presented in a separate chapter of this report. Instead, where relevant, the technical chapters in this report use the Puhinui case study to illustrate the various parameters included in the evaluation tool.

The general parameters for the evaluation ('General' sheet in the evaluation tool) are presented below:

- Appraisal period: 15 years. (The evaluation period for cycle facility improvements is generally 10-15 years. Note that the estimated asset life for the actual railway bridge works would be considerably longer than 15 years).
- Implementation year: 2012.
- Cost estimate: 2010 prices.

Up to three different options can be tested with the evaluation tool. In the case of Puhinui Station, the following three illustrative options have been presented:

- Option 1: As per the original funding application, covering the additional costs to KiwiRail of the wider bridge and the bicycle facilities on the approaches to the station.
- Option 2: As option 1, but including additional cycle-parking facilities.
- Option 3: As option 1, but including additional cycle-parking facilities and pedestrian improvements.

The cost estimates used in the case study were prepared during the scheme assessment phase. Therefore a cost contingency allowance of 15% was added by the evaluation tool.

The evaluation tool inputs are based on a typical weekday and the outputs are converted to annual values, using an annualisation factor. Since Puhinui Station is served by rail services all day during the week and at the weekend, an annualisation factor of 320 was selected.

A walk-to-transit factor of 2 was used (see discussion in section 7.3.2).

1.5 Report structure

The remainder of this report is structured as follows:

- Chapter 2 discusses the definition of PT access and egress modes, how data on access modes is collected, and how access modes are represented in existing transport models.
- Chapter 3 compares the available New Zealand and international evidence on PT access mode shares and walking and cycling catchment areas.
- Chapter 4 discusses the international evidence on factors that affect walking and cycling to access PT, including trip purpose, demographic and socio-economic factors, and factors relating to the area surrounding the station or stop.
- Chapter 5 presents measures to improve walking and cycling access to PT and evidence from the literature review on how demand for these can be forecast.
- Chapter 6 discusses diversion rates, including the mode shift in the main mode of transport and the access modes, and trip generation.

- Chapter 7 presents the economic evaluation parameters employed to conduct cost-benefit appraisal of the integration of PT with walking and cycling.
- Chapter 8 summarises the conclusions and presents a series of recommendations for future data collection, transport modelling guidelines, economic evaluation and future research priorities.

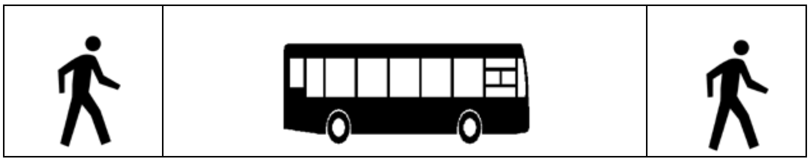
2 Defining public transport access and egress

2.1 Access and egress options

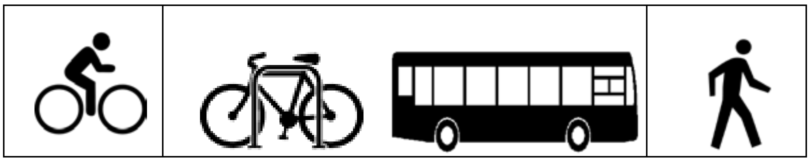
Every journey by PT requires at least three trip stages or trip legs: the access stage at the start of the journey; the PT component of the journey; and an egress stage at the end of the journey. In some cases users might also need to walk between PT modes at an interchange.

In essence, there are four distinct PT trip combinations where walking and cycling constitute the access and egress modes:

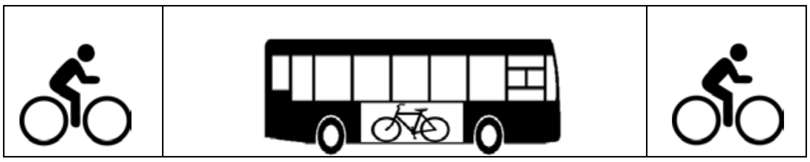
1 Walking can be the mode of access and egress for all types of PT.



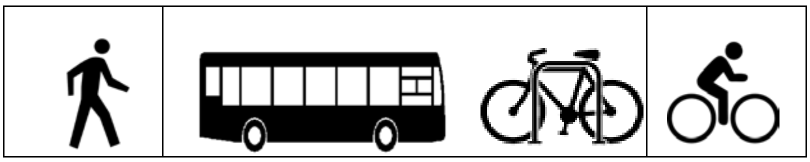
2 The bicycle can be used as an access mode to PT, with parking facilities at the origin station/stop. Walking will typically be used as the mode of egress.



3 The same bicycle can be used as mode of access and egress if the carriage of bicycles is allowed on PT. Alternatively, users could have the opportunity to park or hire a bicycle at either end of the PT trip.



4 Users can choose to walk as an access mode at the origin end and use the bicycle as an egress mode at the destination end of their PT trip. This combination is relatively rare, although it is a target market for many urban bicycle-hire schemes and there are examples of bicycle-parking facilities at stations to cater for this market.



2.2 Public transport trip chains in the New Zealand Household Travel Survey (NZHTS)

The largest source of information on PT access modes in New Zealand is the New Zealand Household Travel Survey (NZHTS). This survey is administered on behalf of the Ministry of Transport (MoT), and the NZHTS dataset that was analysed for this report included travel by approximately 40,000 people from 22,000 households in New Zealand between 2003 and 2010. Changes in travel behaviour during this period have not been analysed here, although this is the subject of the Transport Agency research report *National travel profiles part B: trips, trends and travel predictions* (Milne et al 2011).

The NZHTS dataset of trips contains over 280,000 records, each representing an individual single trip leg. The MoT definition of a *trip leg* is as follows:

> *A trip leg is a section of travel by a single mode with no stops. Thus if one walks to the bus stop, catches the bus to town and walks to his/her workplace, he/she has completed three trip legs (home-bus stop, bus stop 1 to bus stop 2, bus stop 2-work).*

A *trip chain* is a series of trip legs where no stop between legs exceeds a specified time, either 30 or 90 minutes - short intervening activities would typically include dropping off children at school, or popping into a shop for 15 minutes. For this analysis the 30-minute trip chain definition was used.

As mentioned above, every PT trip can be seen as a trip chain of at least three trip legs – more if users interchange between modes.

The definition of *walking trips* that was included in the dataset was changed to fit the period for which data was available. In 2003, the NZHTS included a minimum distance threshold for walking trips, and walking trips below 100m were not included within the dataset. By 2010, the definition had been amended to state that walking trips of less than 100m should be recorded in certain circumstances - namely, where there was a change of purpose, a street was crossed, or the mode changed. Otherwise short walking trips where the purpose did not change were not recorded. These definitions resulted in a significant proportion of PT trip chains that were missing an access or egress trip leg. Trip chains for which no PT access leg was recorded were therefore assumed to contain a 50m (30 second) walking trip, which was added to the start of the chain. Likewise, a 50m (30 second) walking trip was appended to any chain for which no PT egress leg was recorded.

Data was extracted from the MoT NZHTS through a process of filtering and categorisation. Invalid trip leg and trip chain responses were filtered out of the dataset. Trip chains were excluded where any trip leg within the chain was invalid; eg:

- trips for which there was an incomplete response
- trips where data was missing or illogical, such as a distance of zero for a trip leg.

Filtered trip chains were classified by area, activity, home-basis of the chain, and chain type. The following definitions were applied during this filtering process:

- Multiple adjacent legs within a chain made by the same mode were merged to provide an overview of the chain. For example, a chain of Walk-Walk-PT-Walk would be presented as Walk-PT-Walk in the output. However, the total legs output would represent the initial number of segments - in this example, four.

- The PT trip chain results only included local PT services.
- The NZHTS data for trip legs by ferry did not contain distance information. The distance was calculated using the travel time of the leg, and assuming an effective speed. The Auckland Regional Transport ART3 model indicated that some Auckland ferries operated with an effective speed of 20km/hr, while other Auckland ferries operated at 33km/hr. Consequently, all ferry legs were assumed to have an effective speed of 25km/hr.

Previous Transport Agency research projects have employed the NZHTS trip chains dataset to explore travel behaviour in terms of trip chains (Abley et al 2008; O'Fallon and Sullivan 2009; Milne et al 2011). Further information on NZHTS definitions, methodology, data validation and travel behaviour trends can be obtained from these sources. Where possible in this report, analyses have been broken down by geographic regions, using the same classification as the previous research; namely, the main urban areas of Auckland, Wellington and Canterbury as separate categories; Main Urban Areas (MUAs); Secondary Urban Areas (SUAs); and Rural Areas (RAs).

Unless otherwise specified, all outputs in this report sourced to NZHTS stem from the above-described dataset.

2.3 Public transport access and egress in transport models

One important element of the literature review for this study examined how PT access and egress are currently represented in various types of transport model. The aim of this review was to understand how an improved evaluation framework could be incorporated into transport modelling and to inform recommendations for improving the guidance around data collection, modelling methods and parameters.

2.3.1 Strategic multimodal models

Mode choice models are employed in strategic transportation modelling to forecast, among other things, changes in the transport mode choice as a result of changes in land use and/or transport infrastructure.

Chapter 4 of the Transport Agency's *Economic evaluation manual (EEM) vol 2* (2010b) provides some guidance on the evaluation of transport service enhancements. However, no specific guidance on standards for multimodal choice modelling is provided. Currently, multimodal transport models that include mode choice modelling are available for the three largest agglomerations in New Zealand:

- Auckland Regional Transport Model (ART)
- Christchurch Transportation Model (CTM)
- Wellington Transport Strategy Model (WTSM).

All of these models include discrete choice models to estimate mode choice between car and PT for all or some of the trip types modelled. In the case of the CTM and WTSM, end-to-end trips by walking and/or cycling are also partially forecasted to a lesser degree of complexity.

In discrete choice modelling, the relative utility of available mode options is calculated. This is expressed as generalised journey time (GJT) or cost. The estimation of GJT for PT trips includes the in-vehicle journey time, waiting time, fares, the time spent accessing the mode at each end of the trip, and interchange penalties. All of these models include walking (but not cycling) for PT access and egress, and in some cases other motorised access mode (bus feeder routes or park-and-ride (P&R) options).

A review of the mode choice calibration documentation for the above models found that the calculations employed for public transport GJT were not consistent across the models (see table 2.1).

Table 2.1 Public transport GJT calculation in New Zealand mode choice models

	Auckland: ART[a]	Canterbury: CTM[b]	Wellington: WTSM[c]
Calculation of walk time to access PT	From zone centroid[d] - crow-fly or road network not specified	From zone centroid - crow-fly or road network not specified	Node for walk access/egress and p-connector (walk-car) to road network - based on actual distance, not crow-fly
Walk speed	Speed not specified	4.8kph	5kph
Factors for walk and wait time relative to in-vehicle time	Walk time x 2 Wait time 3-minute penalty Interchange 8-minute penalty	Walk time x 2 Wait time x 2 Interchange 12-minute penalty	Factors not specified
Allocation to stops	Method not specified	Walk Choice Model – allocation to stops at access, egress and interchange Service Frequency Model – attractiveness of stops based on frequency Alternative Alighting Model – apportions share of a service to alternative alighting points	Method not specified
Cycling as PT access mode	No (or aggregated with walking)	No (or aggregated with walking)	No (or aggregated with walking)

a) SKM 2008a

b) Traffic Design Group and MVA 2008 and 2009

c) SKM 2008b

d) The central point of an area or zone where all trips are assumed to start or finish.

All of the above models adopt standard practice and calculate access time to PT from individual zone centroids to the PT network. The effectiveness of this method is highly dependent on the nature of the zoning system. This method is relatively robust in the dense CBD areas, where zone sizes are small, but its reliability is variable in larger outlying zones. In these larger zones (typically based on administrative boundaries), there is a great deal of aggregation between areas of high PT accessibility and inaccessible areas.

Some agglomerations also employ PT models to optimise their networks; eg the Auckland Passenger Transport model (APT). Public transport models require an approach to estimating catchment sizes, and hence access mode shares, when new lines and stations/stops are introduced. The degree to which such models attempt to explain the choice between access modes to alternative stops and stations can vary.

2.3.2 Accessibility modelling approaches

Improved methods to calculate indicators of walking and cycling access to PT can be found in accessibility modelling. This form of modelling does not seek to explain actual transport behaviour but to highlight the variation in access to services and facilities. These forms of model have been developed for two principal (and complementary) reasons:

- to guide development planning decisions – ie by locating higher-density development in locations that are accessible by active and PT modes
- to study the level of access and choice of access experienced by residents of different neighbourhoods, and address any imbalances through changes to the provision of transport or services – eg in areas of poor access to medical centres, this could involve improving the transport services to existing medical facilities, or creating new medical centres to serve these neighbourhoods.

An example of accessibility measurement is the London Public Transport Accessibility Level (PTAL) methodology (Transport for London 2010a), where the walking times from points of interest to all of the available PT access points within defined catchment areas are calculated. For example, all bus stops within 8 minutes' walking distance (equivalent to 640m at an average walk speed of 4.8km/hr). Walking distance is measured from the actual road network rather than crow-fly distances. This is undertaken for all available PT modes, and the final PTAL is calculated as a composite measure of the proximity of stops/stations within the defined thresholds and the frequency of service available at each of these. This tool has served as a key indicator in development planning decisions for many years. However, one criticism of this early methodology is that only access to the PT network is measured, rather than access through the full transport network. In other words, there is no indication of the choice of destinations available from the stops/stations identified.

More sophisticated multimodal accessibility tools have been developed in recent years. Computational power is no longer a barrier to such tools and indeed, online multimodal journey-planning tools that employ GIS measures of accessibility and algorithms to calculate optimal door-to-door journey options are now available in many cities. Two examples of multimodal accessibility tools are the Land Use and Public Transport Accessibility Index (LUPTAI) in Queensland (Pitot et al 2006) and the accessibility measurement tool developed by Abley Consultants in New Zealand (Abley 2010). These tools are used to calculate the number of services and facilities of a specified type by walking, cycling or PT (including the access walking distance). Instead of simple access thresholds, they employ bands of access to multiple destinations to calculate a composite accessibility index.

2.3.3 Local detailed modelling applications

In recent years, new modelling applications have been developed that seek to explain pedestrian route choice within local areas. Pedestrian route choice modelling has been undertaken using Space Syntax theory, both inside buildings and in the public realm. This professional discipline seeks to establish statistical relationships between the layout/configuration of urban networks and pedestrian movement. This technique can be used to forecast changes in pedestrian movement as a result of changes to layout; eg changes to pedestrian networks as a result of large redevelopment sites.

Microsimulation of pedestrian movement seeks to model the detailed pedestrian–pedestrian interaction. It is typically employed in busy pedestrian environments, such as transport interchanges, and can include interior and exterior environments. Several software packages exist, including LEGION and a package used in combination with VISSIM. However, these models only deal with route choice at a very detailed level and do not seek to explain strategic pedestrian route choice.

More recently, there have been attempts to model pedestrian behaviour within a traditional transport modelling framework. One example is the model built by Colin Buchanan (2010) for the Vauxhall Nine Elms Battersea Opportunity Area in London. This model sits within a wider strategic hierarchy of models, where future trip generation, mode choice, assignment and distribution were calculated using a London-wide regional model. At the local level, a model of PT access was developed that allocated trips to and from the PT network, whereby forecast passenger volumes at the stations in the study area were taken from the strategic PT model outputs. A model of pedestrian route choice was calibrated based on observed behaviour from pedestrian-tracking surveys. The model included parameters of pedestrian routes such as distance, linearity, general route quality, and penalties for different crossing types. Individual parameters of pedestrian route attractiveness are discussed in more detail in section 5.7 of this report.

2.3.4 Future outlook

It can be seen from the above examples that there are varying approaches to PT access and egress. Yet the pace of change is fast and it is entirely feasible that better representations of multimodal trip chains will be included in standard city-wide transport models in the medium term. There are several factors driving this change:

- *Processing power:* Increasing the number of journey options in mode choice models can increase processing time exponentially. For example, moving from a simple mode choice between car and PT to include P&R options multiplies the processing requirement by three or four times, and if other PT combinations are subsequently included, it increases exponentially. However, if computational advances continue at the same pace as in the last 20 years, this scale of increased computational requirements could feasibly become irrelevant over the next 10 years.
- *Coding requirements:* Regardless of computational requirements, the level of complexity described above would require prohibitive resources in network coding. Yet as common data platforms are developed for other applications (eg walking networks for journey planning applications, or bicycle parking inventories for asset management), the coding requirements will fall in the future as long as the compatibility of systems can be achieved.
- *Understanding of travel behaviour:* Finally, as the focus of transport planning shifts to travel demand management, our understanding of travel behaviour and how to measure it is changing. For example, it is now accepted as international good practice to record all trip legs of PT trips when undertaking travel surveys, meaning that improved data for calibration of mode choice models is becoming available. Technical advances in the recording of travel using GPS and accelerometer technology are also expected to improve the reliability of walking and cycling data collection in the future.

To ensure that there is consistency in the data, methods and parameters employed in future models, this report includes a series of recommendations for updates to the relevant guidance and standards (section 8.2).

However, in the short to medium term, it is recommended that the impact of measures to improve the integration of PT and walking/cycling in New Zealand are modelled outside of the main mode choice models. In essence, this can be accommodated within the traditional modelling structure. Firstly, access to PT by walking and cycling can be calculated for relevant zones in the model. This can then be included in the existing mode choice framework to reflect variation in the quality of access; eg by applying penalties to zone connectors. However, the process can also be thought of as being circular, since the modelled PT assignment can subsequently be used to prioritise stops and stations where improvements to integration would deliver best value for money.

3 Evidence of current patterns of public transport access and egress

3.1 Overview

This section presents an overview of the available evidence on the access and egress modes of PT trips. The issues of access mode share and the catchment size of the access modes are presented in turn.

Access and egress at the origin or destination end of PT trips are discussed separately. The 'origin' end of the trip generally refers to a transport users' home location. The 'destination' end of the trip can be, for example, a place of employment or education, shops or services. It is noted that many of the sources cited in this research refer solely to 'access' and 'egress'. However, the terminology of 'origin' and 'destination' is applied consistently within this report, since the access route from an origin (eg home) to a station is likely to be the egress route on the return trip.

Evidence from the NZHTS of current patterns of access and egress are presented. Where the available sample sizes are sufficient, these findings are broken down geographically to highlight any variation.

When comparing international patterns of PT access, a central question remains as to how comparable European, North American or Asian examples are to New Zealand cities. It is worth considering that population density is typically higher in European and Asian cities (eg 3-6000 inhabitants per km^2), supporting higher rates of PT usage overall. The three largest cities in New Zealand have an urban density closer to 1000 inhabitants per km^2, which is closer to North American cities; eg San Francisco, where P&R options or feeder routes play a larger role in facilitating access to PT.

However, the density of the urban area of Auckland is similar to some European cities that are known for high levels of PT usage and cycling (eg the Copenhagen metropolitan area). This suggests that with a general shift in mobility culture and the right provision, there is scope to promote cycling as an access mode at the origin end of PT trips in lower-density suburban areas.

It should also be borne in mind that bicycle helmets are not compulsory in many of the comparator cities. None of the European or Asian countries cited have generally applicable bicycle helmet legislation. In the US, less than half of all states have state-wide mandatory helmet laws. It is not known if the presence of bicycle helmet laws has a specific impact on the use of cycling as a mode to access PT. However, the experience of Australian cities indicates that this may be a barrier to cycling at the destination end of a PT trip, and to bicycle hire schemes in particular.

All results presented in this chapter have been adjusted to exclude PT feeder modes. The rate of interchange between PT modes at a given station or stop was principally governed by the level of PT connections available. Conversely, the focus of this chapter was to highlight patterns of access to the first boarding point and egress from the last alighting point of trips through the PT network.

3.2 Public transport access/egress mode share (origin)

Internationally there is great variation in bicycle usage to access PT. The Netherlands and Copenhagen are often cited as exemplary in terms of the integration of cycling and PT, achieving levels of over 25% of all home-based access trips. Overall, New Zealand sits with the traditionally less cycle-friendly nations, with bicycle access mode shares around 0.5-2%.

Similarly, the proportion of car-based access can vary across cities depending on density, mobility culture, and provision for P&R options. The evidence from the NZHTS indicates that only 16% of access trips from origin to PT are by car, and two-thirds of those are trips as a car passenger. This may be because the P&R option in New Zealand is generally associated with rail, which has a relatively small share of the total PT market. Table 3.1 provides a summary of the access/egress mode shares.

Table 3.1 Access/egress mode shares (origin to all PT modes combined)

Main mode	Access mode[a]	Access mode share	Source
Public transport (all modes)	Cycling	Netherlands, Copenhagen: 26-27% Munich: 13% UK: 2%	Martens 2004
		NZ: 0.9%	NZHTS (MoT)
	Walking	NZ: 84%	
	Car passenger	NZ: 11%	
	Car driver	NZ: 5%	

a) All results adjusted to exclude PT feeder modes.

With regards to cycling, there is a clear pattern evident in the international and New Zealand data. Overall, the faster PT networks, as well as those that cover longer distances (such as regional trains), have higher levels of cycling at the origin end of the trip (Martens 2004), which may be due to several factors. The overall distance of the PT trip may play a role, since people are less likely to use cycling as an access mode for very short trips. If the stations/stops are further apart in outlying areas and/or on express routes, cycling becomes preferable to walking as an access mode. The mode choice for accessing PT is usually the one that optimises the overall journey time, especially for commuter trips. In many cases, cycling to access a faster service may be preferable to using either a slower PT service or a feeder service. Origin-based access trips are presented for different modes in turn.

3.2.1 Bus modes

Walking is the predominant mode used to access bus services, both in New Zealand and internationally (see table 3.2). Bus networks are typically designed to penetrate residential areas to the extent that bus stops are within walking distance of the vast majority of origins. The origin-based cycling mode share in New Zealand is significantly lower than all of the European comparator cities.

Table 3.2 Access/egress mode shares (origin to bus)

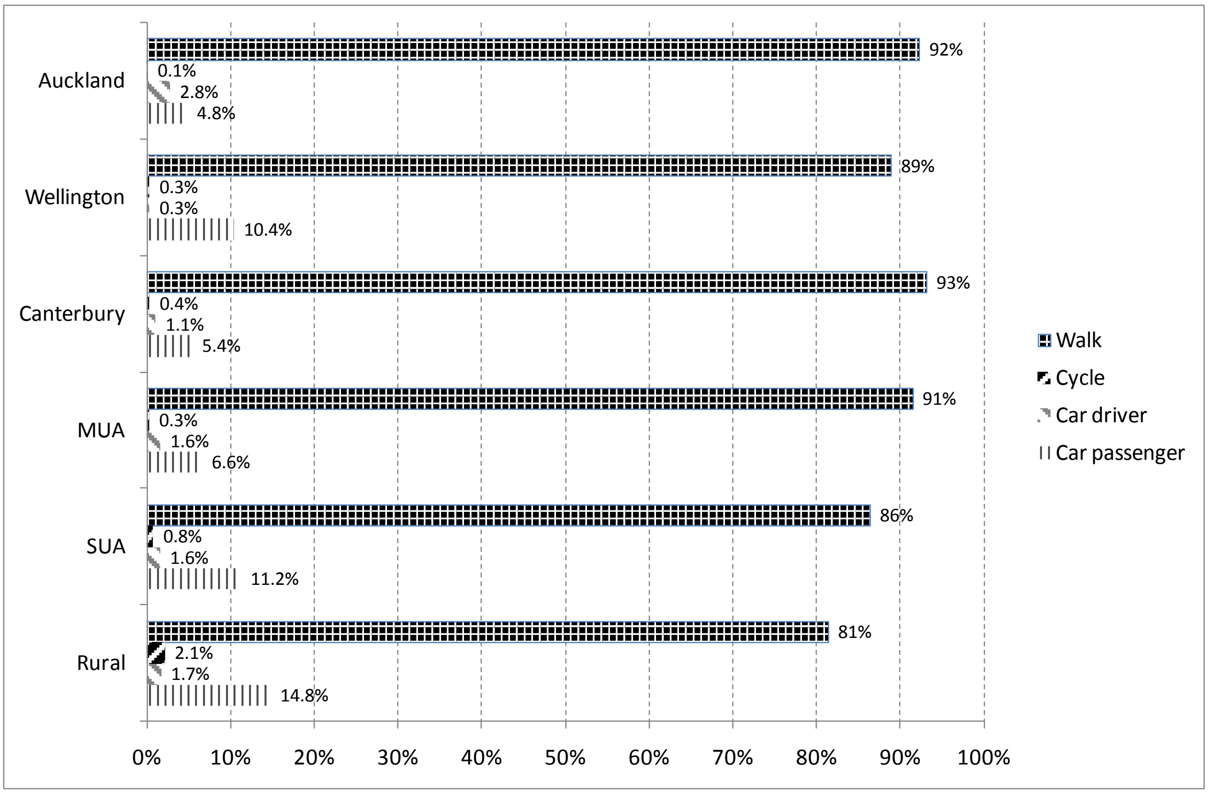
Main mode	Access mode[a]	Access mode share	Source
City bus	Cycling	Netherlands, Copenhagen, Munich, UK[b]: 4-6%	Martens 2004
All local buses		NZ: 0.8%	NZHTS (MoT)
	Walking	NZ: 89%	
	Car passenger	NZ: 9%	
	Car driver	NZ: 2%	

a) All results adjusted to exclude PT feeder modes.

b) The UK figure comes from *Bike and ride: its value and potential* (Taylor 1996), and is based on surveys at three P&R sites and is therefore unlikely to be representative of the majority of UK urban bus services.

The sample of bus trips in the NZHTS dataset is large enough to analyse origin-to-bus access mode shares geographically (N = 3732 raw trip chains). As can be seen in figure 3.1, the use of cycling and cars as access modes is higher in secondary urban areas and rural areas in New Zealand.

Figure 3.1 Access/egress mode shares (origin to bus), by region



3.2.2 Rail modes

Urban rail networks such as Underground train or Metro systems are constructed where residential densities are high, and therefore the bicycle access mode share is low at around 5% or less, even in European cities famous for cycling. The majority of trips to access these modes is on foot.

At the other end of the scale, origin-based bicycle access mode shares tend to be highest for regional trains, reaching over one-quarter of trips in the Netherlands and Copenhagen and remaining firmly below

5% in the UK and US. In spite of the challenging topography in many regions of Switzerland, that country's extensive regional rail network typically has a bicycle mode share in excess of 5% for trips between origin and station.

The rail networks in Auckland and Wellington can be described as suburban rail services, connecting outlying suburban settlements to the core CBD area. Table 3.3 shows that New Zealand is placed in between the international comparator cities with regard to access mode share – lower bicycle access mode share than the European cities, but a higher walking (and lower car driver) access mode share than the US networks. In terms of car access mode share, the Wellington Intercept Surveys undertaken by Opus and Arup in 2012 showed only a 46% car driver and passenger mode share, compared with the 61% measured in the 2003-2010 NZHTS.

Table 3.3 Access/egress mode shares (origin to rail)

Main mode	Access mode[a]	Access mode share	Source
Underground train/Metro	Cycling	Netherlands, Munich: 1-5%	Martens 2004
Suburban/ commuter train	Cycling	Netherlands: 48%	Rietveld 2000
		Munich: 10% Copenhagen: 22%	Martens 2004
		Netherlands: 48% Tokyo: 20% San Francisco: 1%	Wibowo and Olszewski 2005
		US: 0-7%	Transport Research Board (TRB) 2006b
		Auckland: 2.0% **Wellington: 0.4%**	NZHTS (MoT)
		Wellington: 0.8%	Opus and Arup 2012
	Walking	Netherlands: 37%	Rietveld 2000
		Netherlands: 34% Tokyo: 72% San Francisco: 32%	Wibowo and Olszewski 2005
		US: 1-50%	TRB 2006b
		Auckland: 64% **Wellington: 39%**	NZHTS (MoT)
		Wellington: 52%	Opus and Arup 2012
	Car (passenger and driver)	Netherlands: 15%	Rietveld 2000
		Netherlands: 17% Tokyo: 5% San Francisco: 67%	Wibowo and Olszewski 2005
		Wellington: 46%	Opus and Arup 2012
	Car passenger	US: 6-28%	TRB 2006b
		Auckland: 21% **Wellington: 26%**	NZHTS (MoT)

Main mode	Access mode[a]	Access mode share	Source
	Car driver	US: 28-92%	TRB 2006b
		Auckland: 12% **Wellington: 35%**	NZHTS (MoT)
Regional train	Cycling	Netherlands, Copenhagen: 25-30% Munich: 16% UK: 3%	Martens 2004
		US: 1-5%	TRB 2006b
		Switzerland: 5-8%	Bundesamt für Strassen 2008
	Walking	US: 12-85%	TRB 2006b
	Car passenger	US: 5-18%	
	Car driver	US: 9-72%	

a) All results adjusted to exclude PT feeder modes.

3.2.3 Ferry

Internationally there is relatively little evidence of the access modes used to move from origin locations to commuter boat services. In London, the data quoted by Policy Exchange (2009) suggested that 93% of passengers arrived on foot and 3% by bicycle (excluding interchange from PT feeder modes).

The NZHTS trip chains dataset we analysed contained only 99 ferry trip chains and therefore no statistically robust analysis of current access mode shares could be obtained. However, the data suggested that over 50% of origin-to-ferry access trips were by car. It also suggested that the share of bicycle access was probably higher than for bus or rail trips, at 3-4%, which matched the findings in *Forecasting the benefits from providing an interface between cycling and public transport* (Ensor et al 2010).

3.2.4 Bus rapid transit (BRT)/tram/light rail transit (LRT)

Several intermediate modes are situated in between bus and rail PT. The evidence collated by the Transport Research Board (2006) indicated that the observed proportion of LRT access trips by walking or car drivers in the US varied greatly depending on neighbourhood density and the availability of P&R facilities (see table 3.4).

With regards to BRT networks, Martens (2004) distinguished between city and express buses. It is interesting that express bus networks in the Netherlands and Copenhagen attract a much higher cycling mode share than city buses (since stops are typically further apart), although this is still half the bicycle mode share to access suburban or regional rail networks. This finding provides a benchmark for understanding access patterns to potential bus rapid transit (BRT) corridors.

Table 3.4 Access/egress mode shares (origin to BRT/LRT)

Main mode	Access mode[a]	Access mode share	Source
Express bus	Cycling	Netherlands, Copenhagen: 12-14%	Martens 2004
LRT	Cycling	US: 0-3%	TRB 2006b
	Walking	US: 27-98%	
	Car passenger	US: 0-11%	
	Car driver	US: 2-62%	

a) All results adjusted to exclude PT feeder modes.

3.3 Public transport access/egress mode share (destination)

Access and egress modes at the destination end of a PT trip tend to differ significantly from the origin end. In radial PT networks, the majority of trips at the destination end of trips occur in dense CBD areas. Therefore walking is often the mode of choice from the station to destination because the compact nature of CBDs around the world favours walking accessibility. Moreover, the majority of passengers have no vehicle at the destination end of their trip.

However, walking restricts the reach of the catchment area of PT and in some cases users need to find other options for reaching the desired station/stop. City-wide bus, tram and metro-based systems may have good network coverage, and the vast majority of PT users can walk to their final destination. However, cities with suburban or regional rail networks arriving at terminal stations (eg Auckland and Wellington) have longer egress trip legs. This can constrain the attractiveness of PT or require passengers to interchange onto feeder PT modes (in some cases adding to passenger numbers on the most crowded sections of the PT network), leading to the term ‘egress problem’.

3.3.1 Bus modes

The evidence from the NZHTS showed that over 99% of access/egress trips between destinations and bus stops were made on foot (see table 3.5).

Table 3.5 Access/egress mode shares (destination to bus)

Main mode	Access mode[a]	Access mode share	Source
All local buses	Cycling	NZ: 0%	NZHTS (MoT)
	Walking	NZ: 99%	
	Car passenger	NZ: 0.6%	
	Car driver	NZ: 0.1%	

a) All results adjusted to exclude PT feeder modes.

The sample of bus trips in the NZHTS dataset was large enough to analyse destination-to-bus access mode shares geographically. There was virtually no variation between regions.

3.3.2 Rail modes

The rate of cycling at the destination end of public trips was low, at between 0% and 2% in New Zealand and internationally (with the exception of the Netherlands). Walking was the predominant access and egress mode for getting between the rail stations and the destinations.

The pattern of car usage and walking observed by the Transport Research Board (2006) was very different from the remaining comparator cities (see table 3.6). However, it should be noted that besides CBD locations, this sample included destination stations classed as 'suburban employment centres' and 'suburban retail centres'. Yet this still does not explain why such a high proportion of passengers appeared to have a car available at the non-home end of their rail trip.

Table 3.6 Access/egress mode shares (destination to rail)

Main mode	Access mode[a]	Access mode share	Source
Suburban/ commuter train	Cycling	Netherlands: 16%	Rietveld 2000
		Netherlands: 16% Tokyo: 2% San Francisco: 1%	Wibowo and Olszewski 2005
		US: 1%	TRB 2006b
		Auckland: 2.0% **Wellington: 0%**	NZHTS (MoT)
		Wellington: 0.6%	Opus and Arup 2012
	Walking	Netherlands: 72%	Rietveld 2000
		Netherlands: 74% Tokyo: 97% San Francisco: 94%	Wibowo and Olszewski 2005
		US: 29%	TRB 2006b
		Auckland: 97% **Wellington: 96%**	NZHTS (MoT)
		Wellington: 94%	Opus and Arup 2012
	Car (passenger and driver)	Netherlands: 11%	Rietveld 2000
		Netherlands: 10% Tokyo: 1% San Francisco: 5%	Wibowo and Olszewski 2005
		Wellington: 3.8%	Opus and Arup 2012
	Car passenger	US: 17%	TRB 2006b
		Auckland: 0% **Wellington: 2.7%**	NZHTS (MoT)
	Car driver	US: 53%	TRB 2006b
		Auckland: 1.0% **Wellington: 1.5%**	NZHTS (MoT)

Main mode	Access mode[a]	Access mode share	Source
Regional train	Cycling	US: 1-5%	TRB 2006b
	Walking	US: 21-92%	
	Car passenger	US: 3-14%	
	Car driver	US: 4-64%	

a) All results adjusted to exclude PT feeder modes.

3.3.3 Ferry

The London data quoted by Policy Exchange (2009) indicated that (excluding interchange from PT feeder modes) walking accounted for 98.8% of onward trips from commuter boat terminals to the destination, with the remaining 1.2% being made by bicycle.

The NZHTS trip chains dataset contained only 99 ferry trip chains and therefore no statistically robust analysis of current access mode shares could be obtained. The data suggested that over three-quarters of access and egress trips at the destination end were on foot. Interestingly, the destination end bicycle mode share was the same as the origin end, at around 3-4%, suggesting that many of the cyclists captured in the dataset were carrying a bicycle on the ferry.

3.3.4 Bus rapid transit (BRT)/tram/light rail transit (LRT)

The data from the Transport Research Board (2006b) had a similar profile to the commuter and regional rail modes, with walking as the most common access/egress mode at the destination end of LRT trips (table 3.7).

Table 3.7 Access/egress mode shares (destination to BRT/LRT)

Main mode	Access mode[a]	Access mode share	Source
LRT	Cycling	US: 1-3%	TRB 2006b
	Walking	US: 50-95%	
	Car passenger	US: 1-12%	
	Car driver	US: 3-36%	

a) All results adjusted to exclude PT feeder modes.

3.4 Access and egress mode shares in the evaluation tool

Users can input the available data on daily boarding and alighting in the station parameters sheet of the evaluation tool (available on www.nzta.govt.nz/resources/research/reports/537). This should be estimated from ticket data or station counts for a typical weekday and broken down into the time periods specified.

All boarding and alighting (including interchange) should be input into this table. If there is interchange between PT services at the station/stop, the total number of interchanging passengers should be entered separately into the appropriate cell.

If the available data includes information on the access and egress modes that passengers use at the station/stop, this can be entered manually into the evaluation tool. Alternatively, users can select 'regional average' from the drop-down box, and default values based on the PT modes and the geographical region of the station/stop will be applied. In both cases, the proportion of passengers interchanging from other PT modes is calculated automatically from the boarding and alighting information.

The default values in the evaluation tool (tables 3.8 and 3.9) are based on the NZHTS evidence described above.

Table 3.8 Evaluation tool default access and egress modes (origin), by mode and region

Mode	Region	Walk	Bicycle	Car driver	Car passenger
Rail[a]	Auckland MUA	65.3%	0.4%	12.4%	21.8%
	Wellington MUA	39.3%	0.4%	34.7%	25.6%
	All other regions[b]	46.4%	0.8%	30.2%	22.6%
Ferry[a, c]	All regions	35.3%	1.5%	28.0%	35.2%
BRT/LRT[d]	All regions	79.4%	0.6%	5.0%	15.0%
Bus	Auckland MUA	92.3%	0.1%	2.8%	4.8%
	Wellington MUA	88.9%	0.3%	0.3%	10.4%
	Canterbury MUA	93.2%	0.4%	1.1%	5.4%
	Other MUA	91.5%	0.3%	1.6%	6.6%
	SUA	86.4%	0.8%	1.6%	11.2%
	Rural	81.4%	2.1%	1.7%	14.8%

a) The default values are intended to reflect a situation where there is no provision for BoB facilities. Therefore the origin-based bicycle-to-rail mode share in Auckland and other regions is reduced to 0.4%, the origin-based bicycle-to-ferry mode share is reduced to 1.5%, and destination-based bicycle-to-ferry-and-rail mode shares are reduced to 0%.

b) Only Auckland and Wellington are served by suburban rail services. This value is included for potential future forecasting needs.

c) Although the NZHTS data on ferry trip chains was not statistically robust, the origin-based access/egress mode shares looked sensible and were therefore adopted. However, the destination-based proportion of access/egress mode share by car driver was set to 0%.

d) Since there was no New Zealand data to inform the BRT/LRT default values, these were based on the assumption that the bicycle and car proportions lay somewhere between those observed for bus and rail. In practice, users planning new BRT or LRT stations should use local knowledge to estimate the potential access mode shares.

Table 3.9 Evaluation tool default access and egress modes (destination), by mode and region

Mode	Region	Walk	Bicycle	Car driver	Car passenger
Rail[a]	Auckland MUA	98.9%	0.0%	1.0%	0.0%
	Wellington MUA	95.8%	0.0%	1.5%	2.7%
	All other regions[b]	96.9%	0.0%	1.3%	1.8%
Ferry[a, c]	All regions	87.9%	0.0%	0.0%	12.1%
BRT/LRT[d]	All regions	98.4%	0.0%	0.7%	0.9%
Bus	Auckland MUA	99.5%	0.0%	0.0%	0.5%
	Wellington MUA	99.5%	0.0%	0.0%	0.5%
	Canterbury MUA	99.1%	0.0%	0.0%	0.9%
	Other MUA	98.7%	0.0%	0.6%	0.7%
	SUA	100.0%	0.0%	0.0%	0.0%
	Rural	99.3%	0.0%	0.1%	0.6%

a) The default values are intended to reflect a situation where there is no provision for BoB facilities. Therefore the origin-based bicycle-to-rail mode share in Auckland and other regions is reduced to 0.4%, the origin-based bicycle-to-ferry mode share is reduced to 1.5%, and destination-based bicycle-to-ferry-and-rail mode shares are reduced to 0%.

b) Only Auckland and Wellington are served by suburban rail services. This value is included for potential future forecasting needs.

c) Although the NZHTS data on ferry trip chains was not statistically robust, the origin-based access/egress mode shares looked sensible and were therefore adopted. However, the destination-based proportion of access/egress mode share by car driver was set to 0%.

d) Since there was no New Zealand data to inform the BRT/LRT default values, these were based on the assumption that the bicycle and car proportions lay somewhere between those observed for bus and rail. In practice, users planning new BRT or LRT stations should use local knowledge to estimate the potential access mode shares.

3.5 International evidence of catchment sizes

The choice of mode to access a PT station/stop is also influenced by the distance travelled. Research into catchment sizes by walking and cycling is used to inform planning standards for PT infrastructure. The literature review carried out for *Forecasting the benefits from providing an interface between cycling and public transport* (Ensor et al 2010) summarised some of the catchment area planning standards from international evidence (see table 3.10).

Table 3.10 Public transport catchment areas for walking and cycling (Ensor et al 2010)

Source/study area	Walking	Cycling
US, Canada (Robinson 2003)	0.25 miles (0.4km)	3 miles (4.8km), 12 times walking distance
Netherlands, Germany, UK (Martens 2004)	-	2-5km
UK (Department of Transport 2004)	10 minutes, 0.8km	3.2km, 4-15 times walking distance
US (Victoria Transport Policy Institute 2010)	10 minutes	3-4 times walking distance
Scotland (Scottish Executive 2000)	-	2-5km
China (Lu et al 2003)	500m	20 minutes
Australia (Pedal Power ACT 2007)	700m, 10 minutes	3-4 times walking distance (2.1-2.8km)

3.5.1 Walking catchment size (origin and destination)

Several authors have specified that an appropriate walking distance to access PT is between 300 and 800 metres (Daniels and Mulley 2011; O'Sullivan and Morall 1996). However, some authors think this underestimates the distance people are willing to walk to catch PT.

In the US, the 2001 National Household Travel Survey found that walking was the mode for 8.7% of all trips, and 86% of all PT trip chains started with a walk trip leg. The average single-mode walking trip was around 1km and lasted approximately 16 minutes. Walk trip legs that were recorded as part of a PT trip chains were around 20 minutes for both access and egress (Agrawal and Schimek 2007). The survey did not capture any walking distances, but on the basis of an average walking speed of 1.4m/s, it could be estimated that the average walking trip to PT was approximately 1.68km long in total, or around 800m at both the origin and destination trip ends.

In Brisbane, research by Burke and Brown (2007) found that the median distance that people walked from origin to PT was 600m and the 85th percentile was 1.3km, while the distances walked from PT to destination were 470m and 1.09km respectively.

There is also strong evidence to suggest that walking distances are higher if the transport mode that is being accessed is faster. For example, analysis conducted at the Calgary LRT stations recommended that the guidelines for planning the LRT network should be separate from those for the bus network (O'Sullivan and Morall 1996). Based on the location of the stations, the paper recommended a radial distance of between 400m for CBD office locations and 900m for CBD residential locations. This can reflect a greater willingness to walk to access a faster mode, but the distance people walk to PT is also influenced by the density of stations/stops. In other words, one reason for people walking further to rail than to bus is simply that the rail stations are further apart.

Buehler (2011) looked at the influence of distance on choice of transport in Germany and the US. The study showed that in 2001 in Germany, 34% of all trips (all modes) were shorter than 1.6km and 61% were shorter than 4.8km, while in the US the percentages were 27% and 48% respectively. Although Americans travelled longer distances, their preference for travel by car was apparent at all distances, with 67% of the trips under 1.6km being by car compared with only 27% of the same type of trips in Germany. The paper pointed out that there was strong evidence for the direct relationship between proximity to PT and low percentages of car usage, with households located within 400m of PT being twice as likely to use PT as those located within 1000m. Nevertheless, the study also showed that in Germany, households located more than 1km away from PT were more likely to travel by bike, foot or PT than similarly located households in the US, and therefore distance alone did not fully explain levels of patronage and mode choice.

3.5.2 Cycling catchment size (origin and destination)

Research into the use of bike-and-ride (BaR) in the Netherlands, Germany and the UK found that the usual bicycle access distance covered by BaR users was between 2km and 5km, with the possibility of larger catchment areas for faster modes of PT (Martens 2004). Rail-based modes that had higher bicycle access mode shares also showed the largest catchment, whereby approximately 75% of BaR users bicycled for more than 2km.

More recent research into cycling catchment areas comes from China and has looked at comfortable cycling distances to access PT such as the Beijing subway system. The research of Mai et al (2010) found an average cycling distance in Beijing of around 4.2km in 2007. This distance is within the margins identified by many European and North American research papers.

3.6 Catchment sizes in New Zealand

Typical catchment sizes for New Zealand were derived from the NZHTS trip chains dataset. Initial checks of the relationship between walking distance and time indicated that the reported walking speeds fall into a sensible range of around 1.2-1.5m/s when aggregated. Therefore this analysis has focused solely on distance, and time values have been estimated using average speeds by mode.

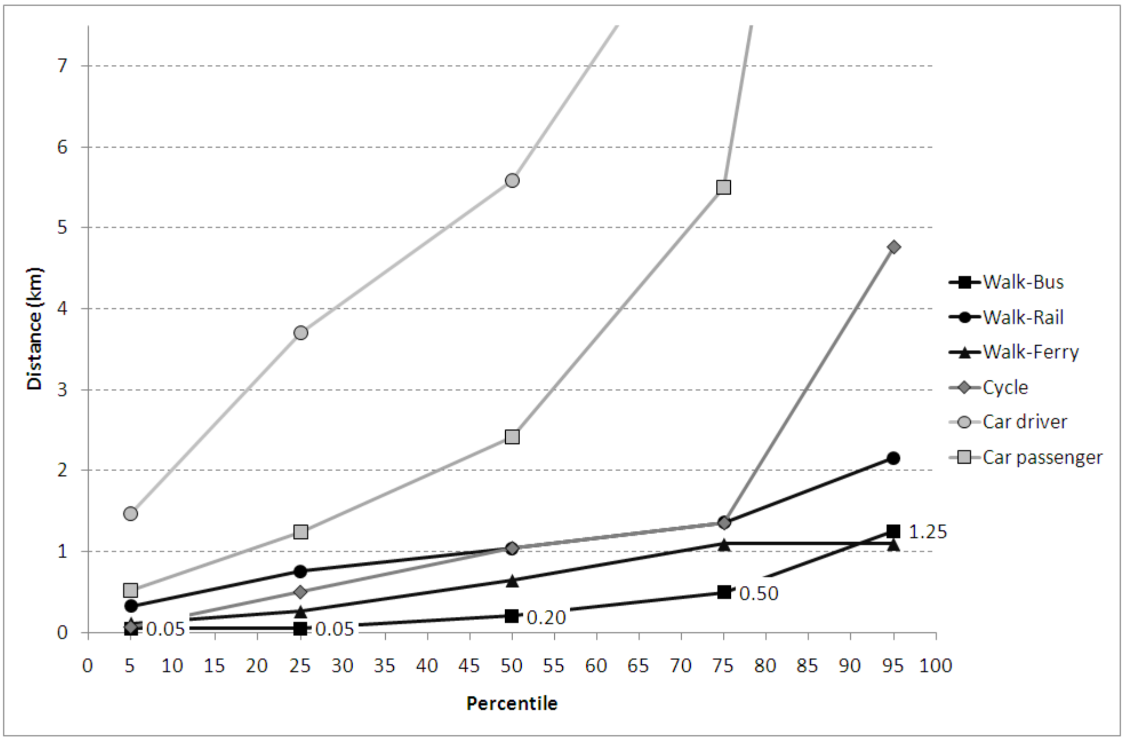
Many of the international studies underline that there are differences in catchment at the origin and destination end of the PT trip. This also applies in New Zealand, and therefore origin and destination catchment areas are presented separately.

3.6.1 Catchment sizes (origin)

Analysis of the NZHTS trip chains dataset (see figure 3.2) showed that the median walk-to-bus trip length was 200m, the mean distance was 370m, and 75% of walk-to-bus trips were less than 500m. These distances were low compared with the international research, which showed that people often walk distances between 400m and 800m to reach bus services. The observed distribution agreed with the evidence that people will walk longer if the mode to be accessed is faster; people in New Zealand will walk further to access rail and ferry services, where the stations tend to be further apart. The walking catchment size to rail services was more similar to that observed in other international research, with a mean distance of 1.13km.

The distribution of distances cycled to PT stations/stops had a larger catchment area than walking. Although based on a small sample, in New Zealand the mean distance cycled was 1.42km, while the distribution was highly skewed with only 25% of people cycling more than 1.35km to reach PT. However, the median cycle distance of 1km was much lower than international comparators such as Martens (2004), who reported a median distance of 2km in several European cities.

Figure 3.2 Distribution of PT catchment sizes, by mode (origin)



There was some variation in catchment sizes by geographic region in New Zealand (see table 3.11). In particular, walking distances from origin to bus stop were much lower in secondary urban areas and rural areas. It could be that in these areas, a higher proportion of bus trips may be on school services that typically stop close to the residential streets served.

Table 3.11 Distribution of PT catchment sizes (km), by mode and region (origin)

Mode combination	Region	Mean	Median	75th percentile	95th percentile
Walk-rail	National	1.13	1.04	1.36	2.16
	Auckland[a]	1.32	1.19	1.52	2.40
	Wellington	0.93	0.84	1.23	2.04
Walk-bus	National	0.37	0.20	0.50	1.25
	Auckland	0.39	0.17	0.54	1.44
	Wellington	0.36	0.25	0.49	1.09
	Canterbury	0.45	0.30	0.58	1.29
	MUA	0.36	0.10	0.42	1.36
	SUA	0.24	0.08	0.26	1.16
	Rural	0.25	0.05	0.31	1.02
Walk-ferry[a]	National	0.61	0.64	1.09	1.10
Bicycle – PT (all modes)[a]	National	1.42	1.04	1.35	4.76
Car passenger – PT (all modes)	National	4.97	2.41	5.50	17.87
Car driver – PT (all modes)	National	8.10	5.59	9.46	22.11

a) Note that these sample sizes were not statistically reliable and should be treated as indicative only.

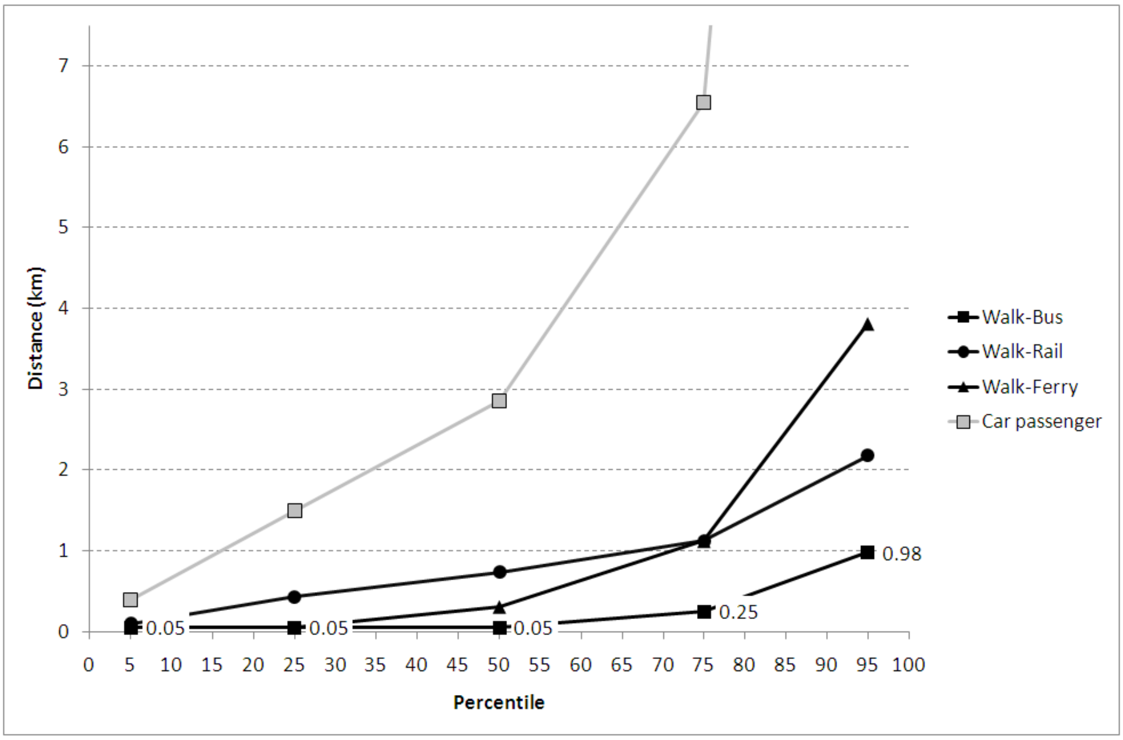
Car trips from origin to PT were generally over much greater distances, although there was a significant difference between the figures for car drivers and passengers. Around 50% of passengers who were dropped off by car travelled for less than 2.5km, whereas only 15% of car drivers travelled less than 2.5km.

3.6.2 Catchment sizes (destination)

Analysis of the NZHTS trip chains dataset (see figure 3.3) showed that the observed median walking distance from bus stops to destinations was only 50m; ie 50% of trips were below the 100m threshold previously applied in the NZHTS, and were therefore allocated a notional distance of 50m. The mean distance walked was only 230m at the destination end (compared with 370m for the origin end). The mean walk-to-rail distance was also lower at the destination end, at 0.91km (compared with 1.13km for the origin end).

Evidence from London showed that walking distances to commuter boat services were much longer at the destination trip end (Policy Exchange 2009). Whereas at the origin end of the trip the vast majority of passengers lived within 400m and 1.2km of their boarding pier, destinations were much more widely dispersed around Central London, with walking times of 15-20 minutes (approximately 1.6km) frequently observed. This pattern of walk-to-ferry distances was also observed in New Zealand, where most ferry passengers lived in close proximity to the pier used (mean walking distance of 0.61km at the origin end). In both Wellington and Auckland, the main destination pier was located at one end of the CBD, and some users walked further at the destination trip end (a mean walking distance of 0.95km).

Figure 3.3 Distribution of PT catchment sizes, by mode (destination)



Again, there was some variation in destination catchment sizes by geographic region in New Zealand (see table 3.12). Walking distances from destination to bus stop were much lower in secondary urban areas and rural areas. Rail passengers in Auckland appeared to walk considerably further to their final destination than passengers in Wellington, which was to be expected in view of the more compact layout of the latter's CBD and the availability of bus services through the CBD area.

Table 3.12 Distribution of PT catchment sizes (km), by mode and region (destination)

Mode combination	Region	Mean	Median	75th percentile	95th percentile
Rail-walk	National	0.91	0.73	1.12	2.17
	Auckland[a]	1.43	1.20	1.63	3.99
	Wellington	0.66	0.62	0.85	1.56
Bus-walk	National	0.23	0.05	0.25	0.98
	Auckland	0.30	0.05	0.34	1.18
	Wellington	0.29	0.15	0.39	1.00
	Canterbury	0.36	0.18	0.52	1.16
	MUA	0.18	0.05	0.08	0.89
	SUA	0.07	0.05	0.05	0.05
	Rural	0.11	0.05	0.05	0.39
Ferry-walk[a]	National	0.95	0.31	1.12	3.81
PT (all modes)-car passenger	National	7.97	2.86	6.55	29.16

a) Note that these sample sizes were not statistically reliable and should be treated as indicative only.

3.7 Walk and bicycle catchment sizes in the evaluation tool

In the station catchment sheet of the evaluation tool, users are asked to enter an estimate of the number of residents and employees within defined walking and cycling catchment areas. Where possible, the catchment area can be estimated by calculating distance isochrones[2] and querying census datasets using GIS, or alternatively this may simply be estimated as an approximate proportion of the adjacent census boundary areas.

The evaluation tool contains defined walking and cycling catchment areas for all modes and regions. These are based approximately on the observed 75th percentile catchment areas from the NZHTS, but are expressed as round numbers (see table 3.13). In the evaluation tool it is assumed that 75% of demand for a station/stop stems from within this catchment area.

2 The term *isochrone* refers to the actual geographical area that can be reached using the pedestrian or cycle network within a specified distance. This differs from a buffer, which refers to the spherical area within a specified distance as the crow flies.

Table 3.13 Evaluation tool default catchment areas (origin and destination)

Mode	Region	Walking: 75th percentile catchment area (m)	Cycling: 75th percentile catchment area (m)
Rail	Auckland MUA	1600	2500
	Wellington MUA	1200	2500
	All other regions	1200	2500
Ferry	All regions	1200	2500
BRT/LRT	All regions	1000	2500
Bus	Auckland MUA	500	1400
	Wellington MUA	500	1400
	Canterbury MUA	500	1400
	Other MUA	400	1400
	SUA	300	1400
	Rural	300	1400

3.8 Case study: Puhinui Station access

Puhunui Station is defined in the station parameters sheet of the evaluation tool as in Auckland MUA. The closest station typology is that of suburban neighbourhood. This typology is defined in the following manner (see table 4.1): 'Low-medium density suburb, 1-3-storey buildings, land use predominantly residential and neighbourhood retail, limited pedestrian and bicycle connectivity, station has some off-street parking, local PT interchange.'

Puhinui is defined as a railway station without interchange to other modes. The nearest bus stop is a walk of around 250m from the station entrance. Therefore it is assumed that the bus-rail interchange is negligible, since other stations on the same lines offer better interchange.

ARTA rail passenger count data from 2010 was available. The breakdown by time of day was not available and so it was estimated here for illustrative purposes (table 3.14).

Table 3.14 Puhinui Station boarding and alighting profile (2010)

Time period	Boarding	Alighting
AM peak (07:00-09:00)	200	31
Interpeak (09:00-16:00)	76	30
PM peak (16:00-19:00)	40	200
All day	316	261

No detailed data on rail passenger access/egress mode shares was available. However, this could be estimated based on the station typology (table 3.15).

Table 3.15 Puhinui Station estimated access and egress mode shares

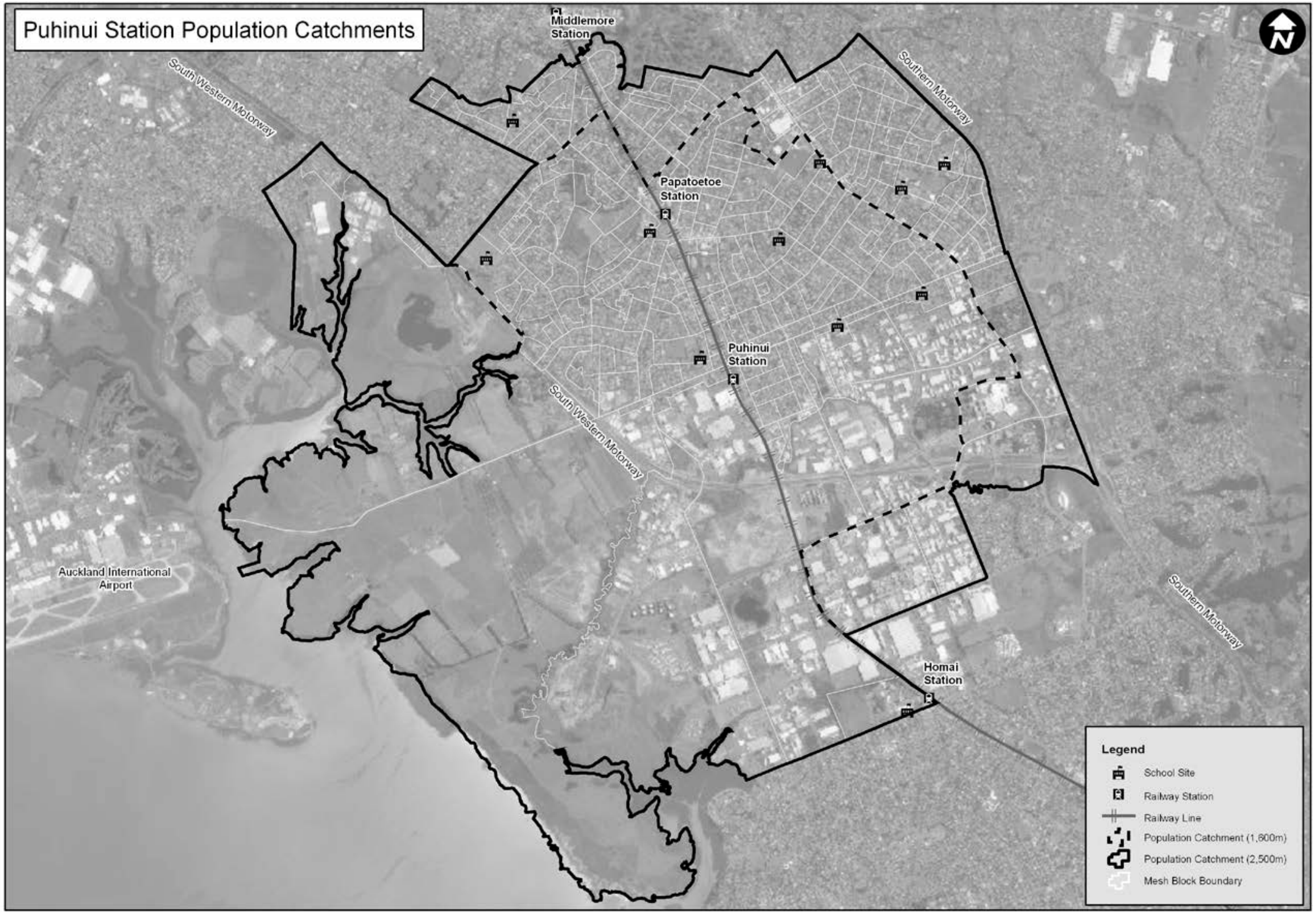
Access/egress mode (regional average)	Access/egress at origin trip end (%)	Access/egress at destination trip end (%)
Walk	48.7	65.5
Cycle	0.9	0.7
Interchange from other transit mode	0.0	0.0
Car driver	32.3	26.6
Car passenger	18.2	7.3
Other	0.0	0.0

As illustrated in table 3.16, the default walking and cycling catchment areas for an Auckland railway station were 1600m and 2500m. These catchments are shown graphically in figure 3.4 on the next page. Puhinui Station lies in a low-medium-density suburban area. The majority of the surrounding area to the north of Puhinui Road is residential in nature. There is also a large industrial employment area located immediately to the south of Puhinui Road, leading to a relatively high employment density for a suburban station.

Table 3.16 Puhinui Station walking and cycling catchment area profile

	Walking catchment area	Cycling catchment area
75th percentile catchment area (m)	1600	2500
Size of catchment area (km^2)	22.7	30.8
Residents in catchment area	23,625	38,439
Employees/students in catchment area	16,914	29,990
Residential density (population per km^2)	1040	1248

Figure 3.4 Puhinui Station catchment areas



4 Factors influencing the choice of access and egress modes

4.1 Overview

There is considerable evidence regarding the factors that affect users' decisions about which modes to use to access PT. The choice of walking or cycling is sensitive to a variety of factors, both internal (eg personal preference, mobility constraints, perceived level of security, etc) and external factors (eg infrastructure provision, facilities, weather conditions, etc), and their influence will weigh differently in different situations.

4.2 Factors relating to trip purpose

Research into PT access and egress reveals that the choice of access/egress mode can vary by trip purpose. Martens (2004) looked at how BaR patronage changed, based on trip purpose, in the Netherlands, Germany and the UK. The research found that in all countries the majority of people who cycled to take the train did so to go to work, with education as the second most common reason.

Although non-utilitarian trips accounted for a large proportion of single-mode cycling trips (in the US and Canada, recreational trips accounted for 50% of bicycle trips), there was little evidence of cycling as a PT access mode for leisure trips (Pucher et al 2011). This study identified that PT access/egress trips accounted for only 3% of all North American bicycle trips.

These findings suggest that people are more willing to cycle to PT for regular journeys where speed and reliability are more important. This may be partly because cycling can require more pre-journey planning in terms of the availability of bicycle parking and BoB services. However, even in countries with widespread cycling facilities, such as the Netherlands, commuting remains the most common purpose for bicycle access trips.

In the evaluation tool, access and egress mode shares are assumed to be the same across peak and off-peak periods. The evidence from the NZHTS database showed that the majority of PT trip chains were for commuting and education purposes. Therefore the resulting distribution of bicycle access trips will reflect the evidence above in most cases.

4.3 Factors relating to user demographic and socioeconomic characteristics

Numerous studies have looked at the relationship of demographic and socioeconomic variables, such as age, gender, income, car ownership and ethnicity, to travel behaviour. Research in the US and Canada has found that in the last 20 years there has been a notable increase in cycling activity among people aged 40-64, while for people aged under 16, cycling has decreased from 56% of all bike trips in 2001 to 39% in 2009 (Pucher et al 2011). In terms of ethnic groups, the dominant group was non-Hispanic whites, who made up 77% of all bike trips in the US in 2009 although they accounted for only 66% of the population.

The Pucher study also found there was a notable difference in the income variable, with more people in the lower-income quartiles cycling than those in the top two quartiles. In terms of car ownership, households without cars were twice as likely to cycle as households with cars. Conversely, research in the UK has shown that professionals, who are normally linked to higher income and car ownership levels, cycled more than people in areas that were officially classified as deprived (Parkin et al 2008).

In New Zealand, NZHTS 2007-2010 data showed that walking and cycling varied across age groups and gender. Males spent more time cycling than females for all age groups. Females of all ages cycled the shortest average distance per head of population per week, at 1km or less, while males aged 18 years and over cycled the longest average distance, at 2.4km per person per week.

Overall, the available literature points out certain social categories that are more likely to be early adopters of cycling in all countries, across all geographies and climates (Pucher et al 2011; Parkin et al 2008). However, the evaluation tool that accompanies this report[3] does not forecast the use of cycling as an access mode based on the demographic and socioeconomic characteristics of the catchment area population. It cannot be extrapolated from the above evidence that these groups are also most likely to cycle to access PT. The motivations for cycling a short distance to access PT services may appeal to very different groups than the motivations for cycling long distances for recreational or commuting purposes.

4.4 Factors relating to the surrounding environment

The surrounding environment refers to variables such as land-use mix, street layout, residential density, topography and weather. There was little evidence relating specifically to these factors with reference to the mode choice for accessing public transport.

The statistical evidence of how land-use mix, residential density or street layouts alone influence the travel behaviour of people was limited, and many of the studies that looked at the relationship of these factors and patronage of walking or cycling did not find conclusive evidence (Boarnet and Crane 2001). Nevertheless, studies that analysed these factors in conjunction with various other variables such as topography, darkness and rainfall, as well as demographics, found that the latter could have a far stronger influence on the results than urban form alone (Cervero and Duncan 2003).

While walking as an access mode is highly dependent on residential density, the opposite can be true for cycling. Martens (2004) concluded that in Germany or the Netherlands, inner-city BaR patronage tended to be lower than in the surrounding areas, where the residential density and frequency of stations was lower. For example, in cities such as Munich the inner city BaR patronage was 4.5%, while in the surrounding towns it was around 10%. The same situation applied to the Netherlands, where in the main cities the average patronage for BaR PT access was 22%, while in the suburbs it was 43%.

In spite of this evidence, other recent studies have reinforced the idea that there isn't any conclusive evidence pointing to a certain type of urban density that discourages active or public transport modes. Mees (2009) looked at residential densities across cities in Australia, Canada and the US in relation to PT patronage, as well as cycling and walking numbers. They concluded that many cities that were believed to have high public transport usage because of their high residential density in fact had no higher or lower rate of public transport usage than other cities at the opposite end of the residential density spectrum. For example, Portland had half the population density of Los Angeles but had a PT mode share (work trips

3 Available on www.nzta.govt.nz/resources/research/reports/537.

only) of 6% compared with only 4.7% in Los Angeles. The percentage of people walking (work trips only) was slightly higher, at 3.1% compared with only 2.7% in Los Angeles, and levels of cycling to work were 0.8% and 0.6% respectively. Moreover Australian cities such as Canberra and Hobart, although having lower population densities than Portland, had higher travel-to-work mode shares of PT as well as higher shares of walking and cycling.

Along with residential density, researchers often look at the impact of mix of land uses. It is believed that the segregation of land uses has a negative effect on walking and cycling trips in particular, as it renders impossible the traditional patterns of community interaction based on short distances to retail, entertainment and leisure facilities. A study by Cervero and Duncan (2003) found that there were differences between the environmental factors that affect walking and those that affect cycling. In terms of factors that affect walking, the diversity of land uses in neighbourhoods was the strongest predictor of walking. Cycling, on the other hand, seemed to be influenced by a combination of various factors such as residential density, diversity of uses and neighbourhood design, especially at the origin end of the trip. Also, the research found that factors relating to the built environment play a greater role in influencing users' travel choices in their residential neighbourhoods rather than at the destination end of PT trips. It is also believed that an increase in population density could induce more cycling, mainly because it generates physical constraints for motor vehicle users, such as increased parking problems (Parkin et al 2008).

Land-use mix can also influence walking, through softer environmental factors such as light and surveillance from active frontages, and street activity resulting from mixed uses. These factors have been shown to generate more walking and cycling (Jones 2001).

Development patterns characterised as urban sprawl are frequently associated with high levels of car ridership and low levels of walking and cycling. A paper by Smart Growth America (2002), which looked at the relationship between urban sprawl and its influence on travel behaviour, confirmed this idea, and noted that it also results in more air pollution. When other exogenous variables such as demographics were controlled for, the relationship remained strong.

Guidelines for providing access to public transportation stations, published by TRB in 2006, included a tool for predicting the mode share of trips to access different types of station. One of the elements of this tool was empirical evidence of access mode shares in the US, categorised by a number of station typologies. These typologies were defined based on a series of neighbourhood and station characteristics, as follows:

- housing density
- scale of buildings in the surrounding area
- distance from CBD
- importance of interchange (local, subregional)
- pedestrian and bicycle connectivity in the surrounding area
- surrounding land uses
- parking facilities at the station.

Although the empirical evidence collected for these guidelines relates to public transport stations in the US, both the range of observed values and the description of the station typologies are not dissimilar to the New Zealand context. Therefore the evaluation tool that we developed includes a list of station typologies derived from the TRB guidelines (see table 4.1). It should be noted that the definitions and names have been adapted slightly be more relevant to New Zealand. In the evaluation tool, users can select one of the station typologies from a drop-down list. Subsequently, the origin and destination access mode shares at the station can be computed on the basis of 'station typology'. This option estimates baseline access mode shares based on the average (mean) of the estimated mode share, by 'regional average' and by station typology.

Table 4.1 Station typology definitions in the evaluation tool (amended from TRB 2006b)

Station typology	Definition
Urban commercial CBD	Urban core CBD, tall buildings, mixed land uses (office, retail, civic, entertainment, residential), high-quality pedestrian and bicycle connectivity, station has no off-street parking, important PT interchange
High-density urban neighbourhood	Urban neighbourhood, tall buildings, land use predominantly residential and neighbourhood retail, high-quality pedestrian and bicycle connectivity, station has no off-street parking, important PT interchange
Medium-density urban neighbourhood	Medium-density inner suburb, 2-5-storey buildings, land use predominantly residential and neighbourhood retail, high-quality pedestrian and bicycle connectivity, station has no off-street parking, local PT interchange
Medium-density urban neighbourhood with parking	Medium-density inner suburb, 2-5-storey buildings, land use predominantly residential and neighbourhood retail, limited pedestrian and bicycle connectivity, station has off-street parking, important PT interchange
Suburban retail or employment centre	Mall or commercial development in low-density suburbs, limited pedestrian and bicycle connectivity, park-&-ride is prioritised, local PT interchange
Suburban Transit Oriented Development (TOD)	Medium-density outer suburb, 2-5-storey buildings, land use predominantly residential and neighbourhood retail, good pedestrian and bicycle connectivity around station, station has some off-street parking, local PT interchange
Historic transit suburb	Traditional medium-density suburb, 2-5-storey buildings, land use predominantly residential and neighbourhood retail, good pedestrian and bicycle connections to transit, station has some off-street parking, local PT interchange
Suburban neighbourhood	Low-medium-density suburb, 1-3-storey buildings, land use predominantly residential and neighbourhood retail, limited pedestrian and bicycle connectivity, station has some off-street parking, local PT interchange
Suburban neighbourhood and interchange	Medium-density outer suburb, 2-5-storey buildings, land use predominantly residential and neighbourhood retail, good pedestrian and bicycle connectivity around station, station has some off-street parking, important PT interchange
Satellite centre	Low-medium-density subregional hub, 1-3-storey buildings, land use includes residential, retail and office, good pedestrian and bicycle connections to transit, park-&-ride is prioritised, important PT interchange
Special events/campus	Adjacent to entertainment venue, airport, conference centre, campus, etc
Suburban highway P&R	P&R site in low-density suburbia targeting interchange from highway

The TRB guidelines (2006b) also provide an illustrative categorisation of these residential densities (see table 4.2).

Table 4.2 Illustrative residential densities for station typology classification (amended from TRB 2006b)

Location type	Residents per sq. km
Central business district	N/A
Central city – high-density areas with tall buildings	>3200
Inner suburbs – medium-density with 2-5-storey buildings	1600-3200
Outer suburbs – low-medium density with 1-3-storey buildings	1000-1600
Low-density suburbs	<1000

5 Measures to integrate public transport, cycling and walking

5.1 Overview

In terms of the cycle-to-PT mode share, Ensor et al (2010) pointed to evidence in the US and Canada that integration between these two modes had had a positive effect on increasing main mode and access mode shares. Research has shown that in cities where integration is greater, and is accompanied by investments in cycling infrastructure (bicycle lanes, bicycle parking, etc) and promotional activities, the share of all PT patronage can reach 4-5%, compared with an average of 1% across the New Zealand cities.

Provision of adequate infrastructure is regarded as the most important factor contributing to the increase or decrease in cycling mode choice (Pucher et al 2010). This can include both infrastructure to improve access to the stop or station, BoB facilities, and end-of-trip facilities such as secure bicycle parking. The measures considered in this study were bicycle parking at rail stations, bicycle parking at bus stops, bicycle racks on buses, carriage of bicycles in railway carriages, and short-term rental bicycles.

5.2 Bike-on-board (BoB)

The ability to carry a bicycle on PT opens up wider catchment areas at each end of the PT journey. In *Forecasting the benefits from providing an interface between cycling and public transport*, Ensor at al (2010) conducted a thorough review of the potential market for BoB facilities. Due to the lack of New Zealand data, they focused on benchmarking against comparable cities in the US that had invested heavily in BoB infrastructure. Santa Clara was identified as being similar to the larger urban areas in New Zealand in terms of mobility patterns, and Santa Barbara was identified as being more similar to New Zealand secondary urban areas. On this basis, their report highlighted the mode share potential for BoB on different PT modes (see table 5.1).

Table 5.1 Potential take-up of BoB facilities (% of PT passengers) (Ensor at al 2010)

Mode	Average BoB %	Typical range of BoB %	Relevant cities
Bus	1.2%	0.5-3%	All
Train, ferry	3%	1.5-6%	Wellington, Auckland

The carriage of bicycles on MAXX trains in Auckland is allowed subject to purchase of a bicycle ticket, although it is not encouraged at peak times (and is subject to the discretion of the driver at busy times). The situation in Wellington is more complex, with bicycle carriage permitted on all train types in the off-peak period (subject to available capacity), but excluded from peak-period services where these are operated by the more recent Matangi rolling stock. The NZHTS trip chains dataset confirmed that cycle-to-rail usage was higher in Auckland than Wellington. Although the sample of Auckland rail trips was small, the bicycle access mode share at the origin and destination ends was 2%, whereas in Wellington the equivalent bicycle share was 0.4% at the origin end and zero bicycle use at the destination end.

However, the 2% bicycle access mode share in NZHTS responses was higher than the data obtained from Auckland Regional Council, which indicated that approximately 0.5% of passengers carried bicycles on trains (Ensor et al 2010). The Auckland Regional Council data stemmed from actual ticket sales and should therefore be more reliable (although it may have included a small underestimation if some users were failing to purchase the NZ$1 ticket or were using folding bicycles).

It is probable that the BoB potential is higher for ferry than rail because a sizeable minority of ferry passengers walk a considerable distance at the destination trip end. Although based on a small sample, the NZHTS data indicated a 4% bicycle-to-ferry access mode share at both the origin and destination end. The majority of ferries in Auckland and Wellington currently carry bicycles.

The carriage of bicycles on urban buses has been shown to be successful in certain markets, depending on the distance of the routes, the areas served, and whether they filled any specific gaps in the bicycle network. The carriage of bicycles in urban areas can be facilitated through the provision of a bicycle rack on the front of the bus. Ensor et al (2010) estimated the potential demand for this type of facility as 1.2% of total PT patronage. Bike racks on the front of buses were first trialled in New Zealand in Canterbury in 2007. Since then they have been fitted to over 150 buses, mainly operating in the Greater Christchurch area, equating to around two-thirds of the urban fleet. The most recent data showed around 2000 trips using the racks per month, equating to 0.2% of all urban PT boardings (Barker 2012). Since the installation of bike racks on all the urban fleet is not yet complete, it is too early to understand from the Christchurch experience whether the 1.2% of patronage estimated in Ensor et al's report is realistic in the urban areas of New Zealand.

Bicycles being carried on BRT vehicles would generally need to be on a rack similar to those on conventional bus services. Some LRT vehicles include racks in the interior of the vehicle; eg Portland, Oregon. Such racks need to be located near a set of doors, so that cyclists can board and alight with minimum disruption to other passengers, and the racks need to store bicycles in a manner that does not block access through the vehicles for all passengers, including wheelchair users. It can be assumed that the demand for BoB on this type of vehicle would be greater than on a conventional bus service, but lower than on suburban rail services.

Because of the above evidence, the evaluation tool accompanying this report[4] includes a set of assumptions about the potential demand for BoB on different modes (see table 5.2). It should also be noted that the increasing popularity of folding bicycles means that there is likely to be a minimal level of background demand for BoB, even if the carriage of full-size bicycles is prohibited. Systems that discourage peak-time carriage of bicycles, or where users have little certainty of being able to take their bicycle on the vehicle at certain times of the day, should be classed as 'off-peak only'.

Table 5.2 Proportion of patronage using BoB, by mode, in the evaluation tool

Mode	No BoB provision	Off-peak only	BoB provision at all times
Rail	0.4%	0.8%	3.0%
Ferry	0.4%	0.8%	4.0%
BRT/LRT	0.0%	0.4%	2.0%
Bus	0.0%	0.4%	1.2%

Given the potential patronage benefits from better BoB integration, it is worth considering why operators are reluctant to implement the BoB system. Research has suggested that it is not the costs involved in

4 Available on www.nzta.govt.nz/resources/research/reports/537.

fitting racks on buses, trains and ferries that is an issue, but that the main reasons are inconvenience to other passengers, possible conflict with disabled passengers, and space requirements (McClintock and Morris 2003).

5.3 Bicycle parking

There is considerable evidence of the success of providing bicycle parking at trip destinations, such as at workplaces and schools. In the UK, for instance, providing outdoor bike parking has been estimated to raise the bicycle share of trips by 0.5 percentage points, while secure indoor parking has been estimated to increase the share by 0.8 percentage points and by a further 1.3 percentage points if shower facilities are added (Wardman et al 2007 in Pucher et al 2010). Stated preference research in the US and Canada sought to value end-of-trip facilities compared to journey times. The findings found that users valued the provision of secure parking at their destination as equivalent to a reduction of 27 minutes in cycling time, and the provision of shower facilities as a 4-minute reduction of in cycling time (Hunt and Abraham 2007 in Pucher et al 2010).

Studies in the Netherlands have shown that providing bicycle parking at both rail stations and bus stops, especially at the origin end of the trip, significantly increases both cycling and PT patronage (eg Rietveld 2000). In the Netherlands, this translated to a 35% bicycle-to-rail mode share from origin to rail, and a 10% mode share at the destination end. However, it is difficult to transfer the experience of the Netherlands to New Zealand. Notably, it is impossible to disentangle what proportion of this bicycle-to-rail access should be attributed to bicycle-parking facilities at rail stations, to the quality of the infrastructure, to the topography of the country, or indeed to the wider mobility culture where cycling is a popular mode choice.

Other comparator countries, such as the US, UK and Switzerland, are more relevant to New Zealand in terms of overall travel behaviour and level of cycling, and useful benchmarks on the bicycle access mode share at the origin end of PT trips can be obtained from them (see table 5.3).

Table 5.3 Example bicycle access mode shares from comparator countries

Country	Comments	Bicycle access mode share
US	Low PT mode share, low bicycle usage nationally, fragmented provision of bicycle stands at stations	LRT: 0-3% Suburban trains: 0-7% Regional trains: 1-5%
UK	Medium PT mode share, low bicycle usage nationally, fragmented provision of bicycle stands at stations and little specific provision at bus stops	Regional trains: 3%
Switzerland	High PT mode share, medium bicycle usage nationally, general provision of bicycle stands at rail stations, challenging topography for cycling in many towns	Regional and suburban trains: 5-8%

This evidence can be used to estimate average bicycle access mode shares in New Zealand (see table 5.4). When applied in the evaluation, these average mode shares can be used to calculate the change in demand. In this way, the evaluation tool takes into account baseline conditions at the station/stop and whether these favour cycling or not. Overall, the above evidence suggests that a range of 2-5% bicycle access mode share at the origin end of trips is feasible if high-quality outdoor bicycle stands are provided at rail stations and ferry terminals (average 3.5% mode share applied in the evaluation tool). The average rate is likely to be nearer 2% at BRT/LRT stations, and 1.5% at conventional urban bus services.

The only evidence on the potential increase in bicycle mode share due to the provision of secure covered parking (eg bicycle hub or bicycle lockers) stems from the Wardman et al (2007, in Pucher et al 2010) research mentioned earlier, although that related to work destinations and not to PT interchanges. This would translate into an additional 5% increase in mode share in New Zealand, which would not be a large increase in usage. In practice, the provision of bicycle lockers may attract the same users as bicycle stands, but would affect the type of bicycle people feel comfortable about leaving at a station and their willingness to pay for the additional security.

Table 5.4 Bicycle access mode share (origin) in the evaluation tool

	Rail	Ferry	LRT/BRT	Bus
No dedicated bicycle parking	1.0%	1.0%	0.8%	0.8%
Outdoor bicycle stands	3.5%	3.5%	2.0%	1.5%
Covered secure bicycle parking (eg lockers)	3.68%	3.68%	2.10%	1.58%

'Bicycle hubs', which are popular in some European cities, can increase the profile of cycling as a means to access PT. The recently published UK *Cycle-rail toolkit* (ATOC 2012) sought to define a good bicycle hub, and suggested it would be located at a larger rail station and would include secure bicycle parking, a bicycle pump and some repair facilities (possibly linked to a cycle shop), and bicycle hire and information materials. In some cases, bicycle hubs are staffed and have been linked to shower facilities, lockers and even the sale of refreshments. For the purpose of the evaluation tool accompanying this report, bicycle hubs were not considered as an additional category, since there was little evidence of an increase in cycling generated by their presence.

5.4 Bicycle hire

Cycling is typically less common at the destination end of a PT trip for the simple reason that users generally do not have a bicycle at their disposal there. This has been described as the 'cycling egress problem'.

In some cities, cycling could theoretically be an attractive proposition, particularly from rail termini, if the walk to the final destination is long or the onward PT modes are very crowded. As well as BoB (discussed earlier) and bicycle parking at terminus stations (described above), bicycle hire schemes can solve the cycling egress problem. Although there are successful bicycle parks at terminus stations where regular commuters can park a second bike, they present several issues:

- they are likely to only be attractive to regular commuters who are very keen cyclists
- they requires excellent security provision
- the parking facility can take up considerable space in what could be a prime retail location.

Conversely, bicycle hire systems at city centre stations would attract a wider user group, security is the responsibility of the system operator, and because of the higher turnover of bicycles, they require less space.

Evidence of good integration of bicycle hire schemes with PT comes from Barcelona, where 28% of users use the bikes in combination with PT (mainly train and Metro), and Lyon, where 94% of users are also PT users (Bührmann 2008 cited in Pucher et al, 2010). In some cities, the journey by bike has replaced mainly tube, bus and walking trips, adding to the evidence that cycling could be a better and faster alternative for longer access/egress distances. A 2010 survey on the performance of the Barclays Cycle Hire in London found that 46% of users used the bikes as part of a longer journey, mainly linked with PT such as train, walking, Underground and bus (GLA 2010). The data on the London bicycle hire scheme, collected by Stannard (2011), confirmed that over 60% of trips were commuting journeys, over 20% of trips were combined with train journeys, and 16% of journeys occurred in the AM peak hour (08:00-09:00).

However, the overall impact of bicycle hire schemes on the city-centre egress problem can only be limited. Even if 20% of the estimated daily 22,000 London bicycle hire trips were morning peak trips from rail terminals, this would equate to only 1.86% of the estimated 236,500 peak-hour rail passengers arriving at Central London terminus stations daily (TfL 2010c) (assuming that peak-hour patronage would be half of 3-hour peak patronage).

While bicycle hire systems are developing quickly and the concentration of docking stations in close proximity to major rail termini are becoming more common, the current level of information does not indicate how best to deal with the high peaks of demand experienced at interchanges, or what the total size of this potential market is.

It has been suggested, particularly in light of the experience in Australian cities, that mandatory helmet laws reduce the potential demand for bicycle hire schemes (in many of the European schemes, including London, helmets are not compulsory). However, some cities with helmet laws have established successful bicycle hire schemes - eg Capital Bikeshare in Washington DC. In terms of the destination end of PT trips, carrying a bicycle helmet might not be perceived as a major inconvenience by regular commuters. It is therefore difficult to estimate to what degree helmet laws in New Zealand would affect the uptake of bicycle hire at major commuter stations.

Since both Auckland and Wellington have rail termini that serve relatively wide CBD areas, it is probable that there is a market for bicycle hire at city centre stations. Using the London example, it could be assumed that 1.86% of peak rail passengers arriving in a city centre station would switch to using a bicycle hire scheme that had good CBD-wide coverage. The 1.86% value reflects not only potential demand but also what is currently operationally possible in terms of the number of docking stations near railway stations, and how quickly they can be replenished during the peak period. In light of the discussion about bicycle helmet laws, in the evaluation tool accompanying this report the potential uptake of bicycle hire has been halved to 0.93% of peak rail passengers.

5.5 Cumulative impact

The three above options for improving integration with cycling – BoB, bicycle parking and bicycle hire – may appeal to the same target market. Therefore when applying the demand forecasts presented above, it is important to avoid double-counting.

If bicycle parking and BoB are both available at the origin end of the PT trip, it is assumed that bicycle parking appeals to a wider market. The appeal of BoB depends to a large extent on the length of the access trip leg at the destination end. Therefore, it is assumed in the evaluation tool that 50% of the potential BoB users overlap with the potential bicycle-parking users, and the other 50% are independent of them.

Bicycle hire facilities and BoB are also likely to appeal to similar user groups to overcome the egress problem at destination stations. Therefore it is assumed in the evaluation tool that 75% of the potential BoB users overlap with the potential bicycle hire users, and that only 25% are independent of them.

5.6 Bicycle route quality

The choice of cycling as a PT access mode is also affected by the quality of the routes available to reach the station or stop. A number of studies have been carried out seeking to place a quantitative estimate on cyclists' preference for different types of cycling facility.

Parkin et al's 2008 research into the factors that influence journey-to-work bicycle mode share found that the variable representing the intensity of transport demand had a negative coefficient, which confirmed that larger traffic volumes were linked with a decreased willingness to cycle. Other significant variables included maintenance of the highway network, and hilliness.

Research from Portland, Oregon that used GPS devices to track cyclists' route choice (Dill 2009) showed that cyclists were willing to trade off distance against route quality to a certain extent. Of the cycling activity recorded, 52% of non-leisure-based cycling took place on dedicated bicycle infrastructure (shared paths, cycle paths and cycle lanes), while streets made up only 8% of the network that was used. Furthermore, when asked about the importance of factors in choosing a route, cyclists stated that minimising distance and avoiding routes with lots of vehicle traffic were the two most important factors, with almost equal rating for each.

In New Zealand, *Assessment of the type of cycling infrastructure required to attract new cyclists* (Kingham et al 2011) focused on the type of cycling infrastructure required to encourage 'new' cyclists (this included people who already cycled for leisure, but not for utilitarian purposes). The study was conducted using a form of stated preference to illustrate different forms of infrastructure. The results indicated that segregated cycle paths (eg behind a parking lane) were generally preferred, although the option of a kerbed cycle lane was also acceptable to many participants. Signalised junctions were preferred over roundabouts. For straight-ahead movements at traffic signals, a cycle path with separate cycle signal control was the preferred solution. For right-turning movements, head-start lights were the preferred options, closely followed by the hook turn. In all the situations presented in the study, the preferred solution was sufficient for participants to state that they would be willing to use the facility, except for the right-turning movement, where some participants still stated that they would never cycle through the junction, even if it had head-start lights.

A 2012 study by Rendall et al compared observed cycle route choices, using datasets from Portland, Oregon and Christchurch, New Zealand. Links and junctions in the cycle network were calibrated against the observed patterns of cycle route choice. The resulting model of cycle route choice has been incorporated into the evaluation tool that accompanies this report. Cycle route parameters are expressed as generalised journey time (GJT). This is a concept commonly employed in transport modelling, and essentially represents a measure of journey time weighted by factors that affect users' perceptions and preferences for certain travel conditions. The GJT of cycling on a given route can be calculated based on the characteristics of the individual links and junctions that make up that cycling route.

Cycle link types were defined in Rendall et al's report (2012) by the level of segregation from the general traffic and the volume of traffic flow on that link, expressed in vehicles per day (vpd). The GJT was calculated by applying a time-scaling factor (see table 5.5). A value of 1.00 was applied to a residential street with low traffic flows or a street with an on-street cycle lane and on-street parking. Off-peak cyclists showed a stronger preference for off-street bicycle paths, but were slightly less sensitive to high volumes of mixed traffic (which may occur at peak times).

Table 5.5 Cycle GJT parameters (links) (Rendall et al 2012)

Link type	Time-scaling factor	
	Peak	Off-peak
Bike path (off-street)	0.92	0.87
Bike lane (on-street without parking)	0.96	0.94
Bike lane (on-street with parking)	1.00	1.00
Mixed traffic (less than 10,000vpd)	1.00	1.00
Mixed traffic (10-20,000vpd)	1.19	1.11
Mixed traffic (20-30,000vpd)	1.71	1.70
Mixed traffic (30,000+vpd)	4.65	4.16

Cycle junction types were defined by the junction control type and movements that cyclists made. The junction penalties were expressed in seconds of GJT (see table 5.6). Off-peak cyclists were overall more sensitive to junction types.

Table 5.6 Cycle GJT parameters (junctions) (Rendall et al 2012)

Junction type	Penalty (seconds)	
	Peak	Off-peak
Traffic signals (excluding left-turn)	3.10	5.30
Stop sign	0.70	1.30
No signal, right turn: 10,000-20,000vpd	13.00	24.00
No signal, right turn: 20,000+vpd	34.00	64.00
No signal, left turn: 10,000+vpd	5.60	9.90
No signal, crossing: 5000-10,000vpd	6.10	11.00
No signal, crossing: 10,000-20,000vpd	8.70	15.00
No signal, crossing: 20,000+vpd	48.00	91.00

5.7 Walk route quality

The integration of PT and walking is largely dependent on the quality of the walking access route in the immediate vicinity of the station or stop. The quality of the walking routes can be represented as a GJT in a similar fashion to cycle route quality, whereby a scaling factor is applied to the time/distance walked and penalties are applied to reflect the barriers encountered at road crossings. Studies are available that have sought to place a quantitative estimate on pedestrians' preferences for different types of facility, although the evidence relies more heavily on a range of qualitative factors.

Abley and Turner's 2011 report *Predicting walkability* described several studies conducted over the last decade that have attempted to quantify the walking environment quality variables, and explored the validity of the New Zealand Community Street Review (CSR) methodology. CSR is a structured audit tool for evaluating the quality of walking routes with community and stakeholder groups, combining local knowledge of the issue with a professionally developed scaling system to quantify the issues (NZ

Transport Agency 2010b). Abley and Turner's report examined the correlation between quantifiable attributes of the walking environment and the scores attributed by the CSRs.

The final model for predicting the walking quality of individual links included the following variables:

- footpath condition (on a 3-point scale)
- quality of greenery (on a 3-point scale)
- vehicle speed relative to speed limit (on a 3-point scale)
- presence of comfort features (Y/N)
- deviation around obstacles (on a 3-point scale)
- parkland or residential land use
- minimum path effective width (in metres)
- number of hiding places along the path
- average step height (in millimetres)
- design effort (on a 3-point scale).

Another quality-scoring methodology employed to quantify the quality of the walking environment is the Pedestrian Environment Review System (PERS) developed by Transport for London in the UK. This is an audit tool that can be employed by an experienced auditor to evaluate the quality of pedestrian routes, links, crossings, PT waiting areas and public spaces. All scores are expressed on a 7-point scale. Transport for London developed a Valuing Urban Realm toolkit, which employs PERS as a measure of quality to conduct cost-benefit analyses of improvements to the walking environment (Transport for London 2012).

Colin Buchanan (2010) calibrated a pedestrian route choice model for walking trips to and from Underground stations on the fringe of Central London. The aim of the model was to forecast pedestrian movements from new and existing Underground stations. Besides actual walking distance, this model included linearity, the location of crossings, and a general environmental quality score. The route choice model calibrated by Colin Buchanan employed a 7-point quality scale ranging from -3 to +3 for each link. The quality scores for each link were based on a simplified scoring system, derived from the PERS link criteria and based on the following:

- personal security – active or inactive frontages, level of natural surveillance, quality of lighting
- quality attributes – traffic impacts such as noise and fumes, available space for walking, attractiveness of the urban character or park/waterside links
- link condition – quality of materials and maintenance of the walking infrastructure.

Using an average walking speed, the walking time on each link was scaled by the quality score multiplied by a factor of -0.02 (ie a quality score of -2 equated to a +4% scaling factor).

The calibrated model also employed a measure of linearity to reflect the simplicity and legibility of the walking route. Studies of pedestrian routes show that people do not always choose their route by the shortest distance but by minimising the number of turns – in other words, reducing the route complexity by reducing the number of decision points. In route choice modelling terms, this can simply be applied as a penalty on the angular turns required. This is not considered within the GJT calculation in the evaluation tool that accompanies this report.

Since there is no calibrated model of walking route choice in New Zealand, the evaluation tool combines the scoring system of the New Zealand CSR with the calibrated multiplier factor from the London model (Colin Buchanan 2010). Although the quality-scoring methods in both studies vary significantly, this was regarded as a valid approach in the short term because both studies employ a 7-point scale where the middle score is regarded as of 'neutral' quality, and to a certain extent it is the relative quality scores of individual links (as opposed to the absolute scores) that determine route choice. In due course the London multiplier factor should be replaced with the findings of a calibrated New Zealand walking route choice model. In the mean time, however, it is acknowledged that these findings need to be treated with care, and additional sensitivity testing is recommended.

The GJT also includes a series of junction and crossing penalties (see table 5.7), which are often important if pedestrians need to cross high-volume roads to access the station or stop. Default values for signalised and grade-separated crossings can be derived from the calibrated model developed by Colin Buchanan (2010). Alternatively, average actual waiting times can be calculated for individual crossings. Finally, average waiting times for uncontrolled crossings can be obtained from section 6.5.2 of the New Zealand *Pedestrian planning and design guide* (LTNZ 2007).

The penalty for a footbridge or subway applies to a single facility where the pedestrian is forced to walk up and down one time (multiple penalties are applied for complex grade-separated walkways with multiple footbridges or subways). It does not apply where pedestrians can walk at-grade and the roadway is raised or lowered. Similarly, it does not apply if a footbridge or subway used to access a station platform is extended across a road (from a pedestrian perspective this is a benefit, as there is no additional change in vertical alignment and he/she benefits from not having to cross the road).

Table 5.7 Walking GJT parameters (junctions) (derived from Colin Buchanan 2010)

Junction type	Penalty (unweighted in seconds, subsequently factored by wait time factor of 2.5)
Footbridge or subway	72 seconds
Signal-controlled junction or crossing	Locally calculated average waiting time or default value of 24 seconds per crossing arm
Uncontrolled crossing	Option to insert average waiting time in seconds, estimated from *Pedestrian planning and design guide*, section 6.5.2 (LTNZ 2007)

5.8 Application of cycle and walk route quality in the evaluation tool

A significant improvement in the quality of access by walking or cycling can induce a change in demand for these access modes, and even in demand for PT as a main mode.

In order to forecast the possible change in access mode, the demand elasticity is applied directly to the change in GJT of the access trip leg. Balcombe et al (2004) stated that the majority of evidence on the perception of access and egress time focuses on attribute valuation studies, producing results where the perceived time is expressed as a factor relative to in-vehicle time. From the meta-analysis of elasticity results, this study suggested a series that would weight factors by PT mode, distance travelled and walk time in minutes (see table 5.8). The same factors were applied to bicycle access and egress trips.

Table 5.8 Walk (or cycle) access time weightings expressed in units of in-vehicle time, by main mode (derived from Balcombe et al 2004)

PT mode	Units of in-vehicle time
All access modes and all PT modes	1.32
Rail	1.65
Ferry	1.65
BRT/LRT	2.30
Bus	1.91

In order to forecast the change in main mode, the demand elasticity was applied to an estimated total PT generalised journey time. Total PT generalised journey time was estimated for the origin and destination end of each combination of PT mode and region, using the evidence from the NZHTS. For example, the GJT for rail trips in Auckland estimated for origin access/egress was calculated using the following parameters:

- origin access/egress:
  - walk - mean distance of origin-end walk trip legs to access rail in Auckland (NZHTS) (mean walk speed of 1.33m/s)
  - cycle - mean distance of origin-end cycle trip legs to access all PT modes (NZHTS) (mean cycle speed 4.17m/s)
- wait time - based on the following assumptions, which include a weighting factor of x2:
  - rail - 30 minutes
  - ferry - 20 minutes
  - BRT/LRT - 10 minutes
  - bus - 20 minutes in Auckland, Wellington, Canterbury, 30 minutes in other MUAs and SUAs, 60 minutes rural
- in-vehicle time - mean distance and speed of rail trips in Auckland (NZHTS)
- destination access/egress - mean distance and speed of all destination end access/egress trip legs (NZHTS).

Balcombe et al (2004) provided elasticity values for PT demand with regards to the access trip leg walk time. In the evaluation tool that accompanies this report, the commute value is employed in the peak periods, and leisure value in the remainder of the day (see table 5.9). No equivalent values are provided for cycling as part of a PT trip. It is therefore assumed that peak-time bicycle access trips are as sensitive to access time as walk access trips, but that the sensitivity of cyclists to off-peak journey time is half that of walkers.

Table 5.9 Elasticities for PT demand with regards to walk and cycle time (derived from Balcombe et al 2004)

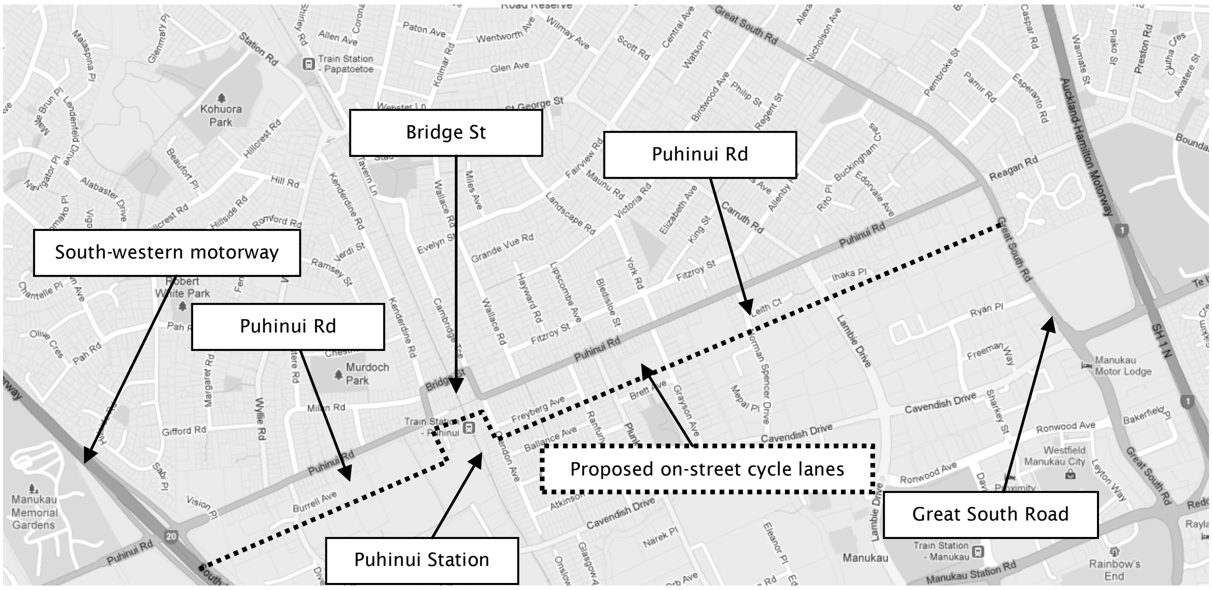
Access/egress mode	Peak	Off peak
Walk	-0.35	-0.32
Bicycle	-0.35	-0.16

5.9 Case study: Puhinui Station access

5.9.1 Bicycle route quality

The main element of this scheme (options 1, 2 and 3, as outlined in section 1.4) involves the introduction of bicycle facilities on Bridge St and Puhinui Rd between the motorway access and the Great South Road (see figure 5.1).

Figure 5.1 Location of cycle lanes



In 2010, only 30 bicycles per day were counted crossing Bridge St (see table 5.10).

Table 5.10 Bridge St (Puhinui) bicycle counts (Opus 2010)

<table>
<tr><th>Direction</th><th>All day by direction</th><th>AM peak (07:00-10:00)</th><th>Inter-peak (10:00-15:00)</th><th>PM peak (15:00-18:00)</th><th>All day (07:00-18:00)</th></tr>
<tr><td>Eastbound</td><td>16</td><td rowspan="2">9</td><td rowspan="2">8</td><td rowspan="2">13</td><td rowspan="2">30</td></tr>
<tr><td>Westbound</td><td>14</td></tr>
</table>

In 2010, the Bridge St rail bridge had an average daily traffic flow of 21,600 vehicles. Therefore the do-minimum cycling conditions have been assumed to constitute cycling mixed in with a flow of 20-30,000 vehicles per day.

The main element of the Puhinui Rd scheme is the introduction of on-street cycle lanes. Some of these would be combined with car parking, and therefore all of the improved cycle-lane facilities are categorised as 'Bike lane (on-street with parking)'. In the evaluation tool that accompanies this report, this is converted to a change in cycling GJT. For example, the GJT on the 950m western section of Puhinui Rd would fall from 393 to 231 seconds. The quality benefits of enhanced cycling facilities accrue to cyclists accessing the station and other cyclists using Puhinui Rd and Bridge St.

The evaluation tool does not calculate trip generation for main-mode cycling (and walking) trips. New cycling trips can be calculated using the tool in SP11 of EEM2 (NZ Transport Agency 2010b), although these have not been included in the Puhinui case study.

5.9.2 Bike-on-board (BoB)

On all MAXX trains in Auckland, the carriage of bicycles is discouraged at peak times due to capacity issues. In the case study evaluation, the bicycle carriage policy was therefore classed as 'off-peak only'. This was assumed not to change under the three options, and no costs were therefore required.

5.9.3 Bicycle parking

At the time of this research there was no dedicated bicycle parking at Puhinui Station. Under options 2 and 3, outdoor cycle stands would be introduced at the station. In the case study evaluation, no secure cycle lockers were assumed to be introduced since the next station on the railway line, Papatoetoe, already had secure cycle lockers.

A bicycle hire scheme was not considered for Puhinui Station under any of the options.

5.9.4 Walk route quality

The original scheme for Puhinui Station did not specifically make any provision for enhancements to the pedestrian environment. Under option 3, provision would be made for additional improvements to the crossings around the station, which addresses one significant barrier to walking to Puhinui Station; namely, the lack of provision of safe crossing points.

In 2010 only 122 pedestrians per day were counted crossing Bridge St (see table 5.11). However, this was unlikely to represent a busy pedestrian thoroughfare, since all pedestrian movements to the station and along Puhinui Rd could use the pedestrian bridge at the station entrance. It was assumed that the non-station-related pedestrian flow was at least equal to the station flows.

Table 5.11 Bridge St (Puhinui) pedestrian counts (Opus 2010)

Direction	All day by direction	AM peak (07:00-10:00)	Inter-peak (10:00-15:00)	PM peak (15:00-18:00)	All day (07:00-18:00)
Eastbound	74	35	22	65	122
Westbound	48				

All pedestrians accessing the station from the north of the Puhinui Rd/Bridge St alignment needed to cross this alignment. At four junctions (Puhinui Rd/Kenderdine Rd, Kenderdine Rd/Bridge St, Bridge St/Cambridge Rd, Cambridge Rd/Kenderdine Rd), the natural point for pedestrians to cross was a blind corner that had no facilities to assist crossing.

As illustrated in table 6.2 of the New Zealand *Pedestrian planning and design guide*, the mean pedestrian queuing delay on a two-lane, two-way road with 2000 vehicles in the peak hour is estimated to be around 33 seconds (LTNZ 2007). This delay can be reduced to around 12 seconds through the introduction of kerb extensions and a median refuge. In the evaluation tool that accompanies this report, this is converted to a change in walking GJT. Crossing delays are weighted by a factor of 2.5 in the evaluation tool, resulting in a reduction in walking GJT from 83 seconds to 30 seconds.

A summary of the impacts in each of the three options is shown in table 5.12.

Table 5.12 Puhinui - summary of impacts (options 1-3 as outlined in section 1.4)

Impacts		**Option 1 (cycle facilities)**	**Option 2 (cycle facilities + cycle parking)**	**Option 3 (cycle facilities, cycle parking + pedestrian crossing facilities)**
Reduction in GJT through improved cycle facilities (peak)	Access route 1: Puhinui Rd west (950m)	From 393 to 231 seconds	From 393 to 231 seconds	From 393 to 231 seconds
	Access route 2: Bridge St (410m)	From 168 to 98 seconds	From 168 to 98 seconds	From 168 to 98 seconds
	Access route 3: Puhinui Rd east (2000m)	From 821 to 480 seconds	From 821 to 480 seconds	From 821 to 480 seconds
Impact of introducing cycle-parking facilities		No dedicated cycle parking (estimated latent demand of 5 bicycles per day)	Provision of 20 outdoor cycle stands (estimated demand of 18 bicycles per day)	Provision of 20 outdoor cycle stands (estimated demand of 18 bicycles per day)
Reduction in GJT through provision of kerb extensions and median refuges at four crossing points		None	None	From 83 to 30 seconds

6 Diversion rates

6.1 Overview

For the purpose of improved cost-benefit analysis, it is not sufficient to predict total demand for cycling or walking. This demand should be accompanied by evidence of what the user has done previously. This is often termed the diversion rate.

Essentially, if an increase in the number of pedestrians or cyclists using a facility is observed, there are four possible reasons for this:

- *Trip reassignment:* The user of the pedestrian or bicycle facility has not changed the mode of transport but has changed the choice of station or choice of route as a result of the new facility.
- *Access mode shift:* The user of the pedestrian or bicycle facility has changed the mode of transport to access the station or stop; eg the user previously travelled by car or bus.
- *Main mode shift:* The user of the pedestrian or bicycle facility has started using the PT service as a result of the improvement in access to the station or stop; eg the user previously travelled all the way by car.
- *Trip generation:* The user of the pedestrian or bicycle facility would not have made the trip previously, or makes more frequent trips as a result of the improved access to the station or stop.

Passengers may switch from one PT service to another if they find it easier to access a specific station/ stop by walking or cycling. While the change in the choice of access can be defined as 'trip reassignment' or 'access mode shift' under the above definitions, the change in the PT mode used (eg if a user switches from an existing service to a different one because of better integration with cycling) was outside the scope of this study and its impact was not considered in the evaluation framework.

The most robust data for calculating diversion rates comes from longitudinal studies of disaggregated travel data covering the period before and after an intervention. This type of data is typically collected in the evaluation of measures such as personalised travel planning. Unfortunately, very few of the international studies on access to stations and stops include longitudinal analysis of disaggregated data.

In the absence of longitudinal data, diversion rates can be inferred from cross-sectional analyses. For example, some of the studies reviewed included cross-sectional comparisons of the main mode share, from which diversion rates could be inferred (eg Buehler 2011). For this type of analysis, trip rates by mode, or vehicle-kilometre rates by mode, are preferable measures to the main mode share expressed as the percentage of trips. Overall, as summarised by Buehler (ibid), there are a large number of international empirical studies of travel behaviour when exploring mode choice for the main mode of transport. However, no similar examples have been identified in the study of access and egress modes for PT trips.

EEM2 (NZ Transport Agency 2010b) quoted diversion rates from research by Wallis and Schmidt (2003). Based on a review of international evidence on cross-elasticities resulting from measures to discourage car use ('stick measures'), the authors estimated an average of around 0.4 additional PT trips per peak car trip would be suppressed, and 0.2 additional PT trips in the off-peak period. This would equate to between 2.5 and 5 suppressed car trips per additional PT trip. Unfortunately, no equivalent cross-elasticities were derived for measures to improve PT service levels ('carrot' measures).

6.2 Diversion rates for the main mode

Travel behaviour data in the NZHTS was interrogated to understand how users' travel patterns vary between people who use car or PT as the main mode of their trip. The use of this cross-sectional data is valid if it is inferred that users who change their main mode of travel will behave in a similar manner to people already using that mode. There are many confounding factors affecting this assumption, such as the level of car access of individual households.

For this purposes of this analysis, the NZHTS trip chains dataset was converted to daily trip rates, by mode combinations (see table 6.1). These trip rates could be expressed as either the average daily number of trip chains or the average daily distance travelled by that mode. Furthermore, trip rates could be interrogated for the population as a whole or for the subset of the population who made at least one trip chain by this mode.

Table 6.1 NZHTS trip chains, by main mode (all New Zealand)

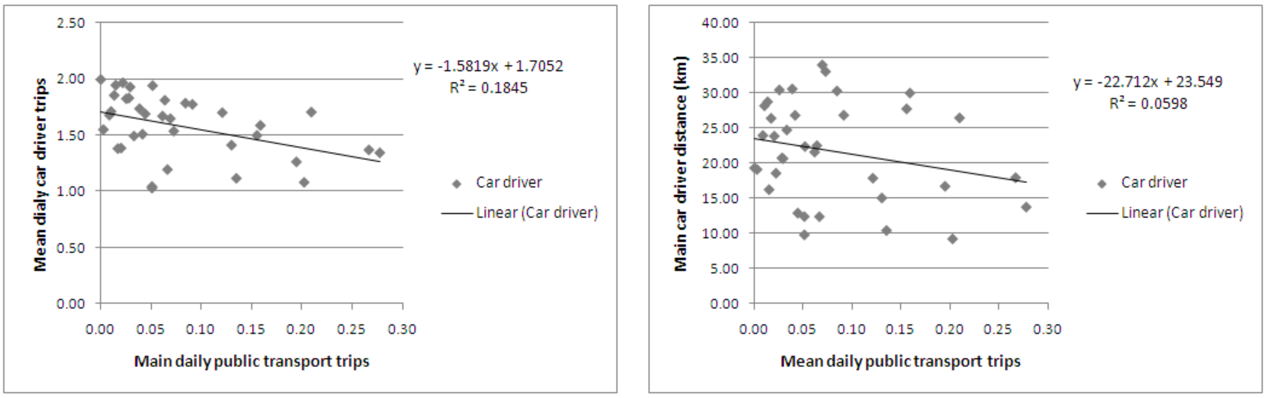
Mode	N (trip chains)	Trip rates for the population as a whole		Trip rates per person making at least one trip chain by this mode	
		Mean daily trip chains	Mean daily distance travelled (km)	Mean daily trip chains	Mean daily distance travelled (km)
All PT combinations	4947	0.09	1.21	1.19	15.37
Walk	18,727	0.34	0.43	1.22	1.57
Bicycle	2752	0.04	0.20	1.29	6.01
Car driver	87,076	1.55	20.46	2.64	34.71
Car passenger	48,254	0.82	11.90	1.78	25.91
Other	4366	0.08	1.39	1.49	26.62

Linear elasticities between the trip rates were calculated to understand the impact of mode switch to PT. Since the NZHTS sampling framework was based on meshblocks, the trip rates were calculated for each meshblock. The number of persons sampled within each meshblock varied significantly (ranging from 209 persons to a single respondent). The trip rate analysis for meshblocks with less than 100 persons produced very scattered results. Conversely, relatively stable linear relationships were observed for the 36 meshblocks with 100 or more respondents (corresponding to a total of 4709 respondents and 26,893 trip chains).

In the absence of reliable data on diversion rates, the elasticities produced provided information about the nature of travel behaviour change if users would switch to PT. Figure 6.1 shows an example of the typical outputs. At the level of individual meshblocks, it can be seen that there was an inverse relationship (ie more PT trips would mean fewer car driver trips). However, the slope of the relationship was not one for one, and implied that for each additional PT trip there would be 1.58 fewer car driver trips on average. Correspondingly, for each additional public transport trip, the total distance travelled as a car driver would reduce by 23km.

Figure 6.1 Car driver elasticities relative to an increase of 1 PT trip

Car driver trips per increase of 1 PT trip **Car driver distance (km) per increase of 1 PT trip**



The R^2 value is a measure of the explanatory power of these linear relationships (a value of 1 would suggest that 100% of variation is explained). The linear relationships analysed all have R^2 values below 0.5, suggesting that less than 50% of variation is explained in each case. When interpreting these results it should be considered that the relationships only explain a small proportion of the variation between meshblocks; ie it was assumed that all other external factors were equal.

In some areas of New Zealand, a large proportion of PT usage is related to school travel. Therefore as a sensitivity test, the same analysis was also carried out for the trip rates of persons aged 18 or over, who would generally be travelling independently (table 6.2).

Table 6.2 Elasticities relative to increase of 1 PT trip (all New Zealand)

Main mode	Population	Trips per increase of 1 PT trip		Distance (km) per increase of 1 PT trip	
		Trips	R-squared	Distance (km)	R-squared
Walk	All	**+0.9522**	**0.173**	**+1.2097**	**0.205**
	18+ only	**+1.1692**	**0.430**	**+1.2775**	**0.351**
Bicycle	All	+0.0687	0.009	+0.5915	0.039
	18+ only	+0.0756	0.035	+0.3263	0.016
Car driver	All	**-1.5819**	**0.185**	-22.712	0.060
	18+ only	**-2.0627**	**0.284**	**-44.972**	**0.179**
Car passenger	All	+0.6150	0.087	-11.922	0.038
	18+ only	+0.3074	0.060	-7.2491	0.033

The results showed a positive correlation between PT and walking main-mode trips. The decision to use PT, in particular for a key activity of the day such as work or education, would have an impact on users' wider travel patterns since they would not have a car at their disposal at their destination. This would lead to an increase in other walking trips during the day. For each additional PT trip, the average number of daily walking trips would increases by 0.95 and the distance walked would increase by 1.21km (walking as a main mode; ie additional to any walking trips to access PT). The relationship was even stronger for the 18+ sample.

Overall there was a similarly positive relationship between PT and cycling main-mode trips. However, this may simply have reflected the fact people who live in urban areas are more likely to cycle and to use PT. The relationship for the whole of New Zealand was very weak and there was no consistent pattern across the New Zealand regions. In the evaluation tool, it is assumed that there is no change to cycling rates as a result of increased PT usage.

As described above, there was a negative relationship between PT and car driver trips. Given that many PT trips are undertaken by younger persons who do not have independent access to a car, this relationship was even stronger for respondents aged 18 or over, implying that for each additional PT trip there would be a reduction of two car driver trips and 45km driven.

The relationship between car-passenger trips was more complex and statistically much weaker. There was a positive correlation between PT trip rates and car passenger rates. This is in part due to the prevalence of education trips, whereby younger PT users would also more likely be car passengers. However, a similar but weaker relationship existed for the respondents aged 18 or over. This reflected the fact that there would be other adult user groups without access to a car for their own use. Yet in part this also reflected the fact that people choosing PT to travel to employment or education would be more likely to travel with friends/colleagues for other activities of the day. Despite the positive correlation between trips, the distance travelled as a car passenger would fall for each additional car-passenger trip. This was not surprising, since PT trips would be likely to replace longer car-passenger trips.

For application in the evaluation tool, as a conservative estimate, the car driver and walking diversion rates are based on the population as a whole and the car passenger rate on the 18+ sample only (see table 6.3).

Table 6.3 Main mode diversion elasticities in the evaluation tool

Main mode	Trips per increase of 1 PT trip	Distance (km) per increase of 1 PT trip
Walk	+0.9522	+1.2097
Bicycle	0.0000	0.0000
Car driver	-1.5819	-22.712
Car passenger	+0.3074	-7.2491

However, the diversion rate for additional mode shift to PT cannot be directly implied from the above statistical relationships. There are a number of inherent biases to cross-sectional analysis that may overestimate the impacts, in particular factors relating to overall levels of mobility and access to a car. If an individual with few barriers to car-based mobility chooses to switch to PT for a main trip of the day (eg for commuting), they still have the option of undertaking other trips with the car at another time of the day. However, some of the constraints apply equally to all users switching mode; notably that PT commuters have fewer options for non-home-based car trips and are likely to switch to other modes for trips during the working day. Complementary travel behaviour change measures may also be required to sustain this level of mode shift.

Therefore in the evaluation tool, the default main-mode diversion elasticities are only applied fully to the proportion of the catchment area population (including employees and students) directly targeted by travel behaviour change measures (either community, school or workplace measures). The default main-mode diversion elasticities are reduced by 50% for the remainder of the catchment population.

6.3 Diversion rates for access/egress at the destination end

At the destination end of PT trips, the predominant access/egress mode is walking. In the evaluation tool, it is assumed that the shift to additional walking trip legs as a result of improved access to PT is mode shift proportional to the other access modes used.

Conversely, the data from the evaluation of London's bicycle hire (Stannard 2011) provided some information about which users may switch to cycling at their destination. The original predictions for the system were that the shift would be from walking (34%), buses (32%) and the Tube (20%). The initial evaluation report stated that over half of users switched from various modes to bicycle hire (GLA 2010). Stannard (2011) provided a detailed breakdown of the modes used before the introduction of the bicycle hire (table 6.4).

Table 6.4 Mode shift to London bicycle hire system (Stannard 2011)

Access mode originally used	% shift
Train	35%
Walking	29%
Tube	24%
Bus	5%
Car	3%
Private bicycle	2%
Other	1%

These findings suggested that bicycle hire was used as a means to overcome the egress problem of longer walking trips or crowded PT at the destination end. In the absence of equivalent local evidence, the evaluation tool uses these findings as the basis for access mode diversion elasticities at the destination end of the trip (table 6.5).

Table 6.5 Destination access mode diversion elasticities in the evaluation tool

Access modes	Change in trips or distance per increase of 1 cycling trip at destination end
Other transit mode	-0.64
Walk	-0.29
Car driver	0.00
Car passenger	-0.03

6.4 Diversion rates for access/egress at the origin end

As there was no reliable evidence of the diversion rates at the origin end of PT trips, the evaluation tool starts from the assumption that the shift to additional walking or cycling trip legs as a result of improved access to PT is proportional to the other access modes used. However, since there is much greater variation in the distance travelled, the proportion shifting from each mode is amended according to the typical distance profile of access mode trips.

The proportion of users shifting from each of the other access modes is therefore calculated based on the existing access mode share multiplied by the proportion of access mode users living within a defined catchment distance.

Using the NZHTS evidence on the distribution of the distances travelled by various modes for access/egress trips at the origin end, as presented in section 3.6, the approximate proportions of users shifting mode were estimated (see table 6.6). For example, it was estimated that in New Zealand, typically 15% of people driving to PT lived within a 2500m cycling catchment area. Therefore if car drivers made up 60% of the access/egress mode share at a specific station, the proportion of new cyclists shifting from car driver would be calculated as 9% (60% multiplied by 15%). The proportions shifting from each access mode were finally factored upwards to a total of 100%. The profile of distances travelled to access PT meant that car passengers were more likely to switch to walking and cycling than car drivers (50% of car passengers making trips of less than 2.5km, compared with only 15% of car drivers).

Table 6.6 Proportion of access trips within walking and cycling catchments, by access mode (origin)

Access mode	Walking catchments			Cycling catchments	
	300-500m	1000-1200m	1600m	1400m	2500m
Other transit	5%	15%	30%	25%	40%
Walk	-	-	-	90%	100%
Bicycle	25%	50%	75%	-	-
Car driver	1%	3%	5%	4%	15%
Car passenger	5%	20%	30%	25%	50%

6.5 Case study: Puhinui Station access

The cycle facility improvements at Puhinui Station (all options) were forecast to lead to an increase in 10 cycle access trips per day (see tables 6.7 and 6.8). Under options 2 and 3, where complementary cycle parking is introduced, an increase of 26 cycle access trips per day was predicted. The increase in cycling as an access mode would lead to an increase in PT usage of an extra nine trips per day. The remainder of the additional cycle access trips were assumed to represent a mode shift from walking and car.

The small mode shift to PT would have a knock-on effect on the predicted main-mode trips, leading to a predicted reduction of 111 car driver kilometres and an increase of 6km walked.

The increase in cycling as an access mode was partially due to a shift from walking as an access mode. This pattern continued across all three options, even where pedestrian access facilities were also improved under option 3.

Table 6.7 Daily trips, by mode and the impact of options 1-3 (as outlined in section 1.4)

Mode	Do-minimum	Option 1 change	Option 2 change	Option 3 change
Main mode				
Walk	17,076	+5	+5	+5
Cycle	850	0	0	0
PT	454	+9	+9	+10
Car driver	82,072	-8	-8	-9
Car passenger	44,667	+2	+2	+2

Mode	Do-minimum	Option 1 change	Option 2 change	Option 3 change
Access/egress mode				
Walk	420	-7	-21	-17
Cycle	6	+10	+26	+26
Car driver	227	-1	-2	-3
Car passenger	105	-1	-4	-6

Table 6.8 Daily kilometres travelled, by mode and the impact of options 1-3 (as outlined in section 1.4)

Mode	Do-minimum	Option 1 change	Option 2 change	Option 3 change
Main mode				
Walk	7172	+6	+6	+7
Cycle	83	0	0	0
PT	558	+11	+11	+12
Car driver	1,506,379	-111	-111	-126
Car passenger	423,151	-36	-36	-41
Access/egress mode				
Walk	230	-4	-8	-8
Cycle	9	+14	+37	+37
Car driver	1839	-6	-17	-26
Car passenger	587	-7	-19	-29

7 Economic evaluation

7.1 Overview

An established methodology for evaluating transport demand management measures in New Zealand is laid out in the 2010 *Economic evaluation manual volume 2*. (NZ Transport Agency, ch.3). The key tasks of the literature review undertaken as part of this research were to review the EEM2 values in light of international good practice, to identify any gaps in the EEM2 and to discuss application of the values available. Although EEM2 does not explicitly provide evaluation methods for integrating PT with walking/cycling, it does include monetary values for most of the relevant parameters. Where there are gaps or methodological questions, these are discussed further in the recommendations in chapter 8.

7.2 Costs

The costs of walking and cycling facilities include the net costs to the Transport Agency and approved organisations of:

- investigation and design
- implementation/construction, including property and supervision
- maintenance
- operating
- monitoring.

7.2.1 Bicycle-parking costs

The provision of standard bicycle-parking facilities at station and bus stops includes the cost of installing (and subsequently maintaining) bicycle stands, such as Sheffield stands. Estimates of unit costs are available from the US and Switzerland (see table 7.1). It is unclear whether these values include the cost of secure measures, such as a contribution to station CCTV costs.

Table 7.1 Example unit costs for bicycle parking (2008 values)

Source	Estimated costs in NZ$
US: NCHRP *Guidelines for analysis of investment in bicycle facilities* (TRB 2006a)	Capital cost of providing 20 secure bicycle parking spaces estimated at $5292 in total, with an annual maintenance cost of NZ$967
Swiss bicycle parking guidelines (Bundesamt fur Strassen 2008)	Capital costs per bicycle-parking space: - uncovered stands $378-630 each - covered stands $1261-2521 each
UK: *Cycle parking. Information sheet FF37* (Sustrans and CTC 2004)	Costs to supply and install: - bicycle stand for 2 bicycles: $221 - bicycle locker for 1 bicycle: $1106 - shelter for 20 bicycles: $2213-11,063 total

Some cities have now started to invest in other forms of bicycle parking. Individual bicycle lockers are generally steel bicycle-storage facilities that require considerably more space than standard bicycle stands. The capital cost of the steel boxes is higher than normal stands, and the cost of maintenance/ administration can be substantially higher depending on the locking mechanism. Another alternative is a communal secure bicycle-storage facility, typically with space for 20 or more bicycles and requiring a code or swipe card for entry.

Some cities have installed bicycle hubs at main stations, offering bicycle parking alongside other facilities. In some cases, these hubs offer opportunities for ancillary revenue generation (bicycle hire to tourists, bicycle repairs, sale of products, or even a cafe.

7.2.2 Bike-on-board (BoB) costs

Ensor et al (2010) reported that the cost of fitting bike racks to buses in New Zealand would be between NZ$1000 and NZ$5000 per vehicle, and the cost of fitting a complete fleet with bike racks was likely to be in the range of NZ$2000 per vehicle (2010 prices). The unit cost per bike rack of the first six buses in the Canterbury trial was NZ$2500 (Barker 2012). More recently, bike racks have been included in vehicle specifications during tendering and thus incorporated into the operators' vehicle capital costs.

The cost of fitting bike racks to rail or ferry vehicles would depend on the nature of facilities provided and whether this was undertaken as part of a general fleet refurbishment, or retrofitting individual vehicles. There could also be an ongoing cost due to lost passengers if vehicle crowding was exacerbated.

7.2.3 Bicycle hire scheme costs

The capital and operational costs of providing bicycle hire docking stations near to terminus stations in the CBD would most likely form an integral part of city-wide proposals. The capital cost of docking stations can vary significantly. For example, one scheme operating in Southern Europe has an average capital cost of €30,000 (around NZ$47,000) for a docking station of 10-20 bicycles spaces, and the cost of the payment unit and its connection to power is significant. Other systems, such as the DB Call-a-Bike system in Germany have no fixed docking stations, so a large proportion of the capital cost is in the back-office facilities that administer the booking service.

It is also worth considering that bicycle hire facilities at terminus stations may have particularly high operational costs when compared with other docking stations because they have the most peak demand, which in turn requires daily management on the ground to replenish the bicycles.

7.2.4 Other financial impacts

Measures to integrate PT with walking and cycling may also incur other cost and revenue impacts that do not form part of the cost–benefit appraisal. However, scheme promoters may need to produce forecasts of these impacts as part of the financial case for the investment. These impacts could include:

- operational revenue (eg bicycle hire scheme revenue or subscription fees for bicycle lockers)
- road maintenance cost reductions as a result of lower car usage and/or PT maintenance cost increases as a result of higher ridership
- parking maintenance cost savings as a result of lower car usage

- secondary revenue sources (eg sponsorship and advertising)
- reduced PT operating costs if the need to provide additional services is avoided (eg enabling growth on rail key PT corridors without the requirement to run additional feeder services).

7.3 Benefits

The benefits of improving the integration of PT with walking and cycling can be grouped into the following categories:

- *Benefits accruing to people who shift their mode of travel*: As described in section 3.2 of EEM2 (NZ Transport Agency 2010b), the impacts of mode shift are evaluated using a consumer-surplus-based evaluation method. Therefore some of the perceived benefits may be internalised by people who shift to another mode.
- *Benefits accruing to existing users*, including:
    - travel time savings to existing users from improvements to facilities
    - perceived benefits to existing users from improved quality of facilities
    - safety benefits to existing users from the treatment of hazardous locations.
- *Wider benefits to society accruing as a result of the reduction in road traffic*: These benefits can accrue either as a result of PT access trips by private vehicle being replaced by walking and cycling, or as a result of private vehicle trips being replaced by PT trips if the marginal impact of improved walk/bicycle access induces main-mode shift. Most of the wider benefits are dependent on location and time of day. The wider benefits consist of:
    - health benefits (can be categorised as a user benefit or a societal benefit, depending on valuation method)
    - travel time and vehicle operating cost (VOC) savings for other road users
    - parking-user cost savings
    - reduced environmental impacts.

7.3.1 Mode change benefits

Under the 'consumer perceived cost approach' adopted by the EEM, changes in cost, travel time or travel quality for people changing mode are assumed to be included in the perceived net benefit. However, if the mode shift is the result of a change in the perceived attractiveness of the mode, the 'rule of half' is applied to new users. Thus the benefit to new users is assumed to be valued at half the benefit accruing to existing users. The EEM therefore proposes a standard value derived from analysis of mode change in New Zealand, which is expressed as a benefit per trip per percentage point mode change (table 7.2).

Table 7.2 Mode change benefits - NZD/trip for one percentage point mode change, 2008 values (EEM2, NZ Transport Agency 2010b, section 3.8, table 3.1)

Mode shift typology	Benefit
Vehicle driver to public transport	0.29
Vehicle driver to cycle/walk	0.29

7.3.2 Travel time savings

Measures that generate travel time savings (or increases) to existing pedestrians, cyclists and PT users can be valued using the 'value of time' methodology presented in section A4 of EEM1. These values are broken down by trip purpose (in-work, commute-to-work and non-work) and mode. Table 7.2 summarises the key values employed in the evaluation tool.

Table 7.3 Value of time per vehicle occupant - NZD/hr, 2002 values (EEM1, NZ Transport Agency 2010a, section A4.2, table A4.1)

	In-work travel	Commuting to/from work	Other non-work travel
PT passenger	21.70	4.70 seated + 6.60 standing	3.05 seated + 4.25 standing
Pedestrian	21.70	6.60	4.25
Cyclist	21.70	6.60	4.25
Car or motorcycle driver	23.85	7.80	6.90

It is also customary, under some guidance, to apply different values of time for the means of accessing modes and main modes, in particular for walking. For example, walking time for access, egress and interchange between PT is valued at twice the value of time for trips where walking is the main mode. Additional weightings are sometimes applied to walking up and down stairs or crossing roads (eg TfL 2010b). The EEM does not include any such guidance on the relative perception of time for different elements of the PT trip chain. Therefore the evaluation tool includes a default weighting factor as one of the general parameters that can be amended. The default weighting factor of 2 should be employed in the absence of any additional research in New Zealand.

7.3.3 Quality of facilities

Under the 'consumer perceived cost' approach adopted by the EEM, improvements to the quality of the walking or cycling environment that contribute to mode shift are assumed to be perceived by the people who shift to walking and cycling. The benefits are therefore captured within the mode-change benefits to new users.

Conversely, existing pedestrians and cyclists will benefit from the improved facilities. Section 8.4 of EEM2 (NZ Transport Agency 2010b) proposes a method for valuing improvements to the walking and cycling environment – from previous 'stated preference' (SP) research, relative benefit factors for different types of cycling facility were calculated and can be applied relative to cycling in on-street conditions with no dedicated infrastructure. These factors can be applied in the calculation of cycling GJT (see table 7.4). For example, the perceived amenity of cycling on an off-street cycle path is double that of cycling on-street with no cycle lane, so the former can be expressed as half the GJT of the latter for the same distance cycled.

Table 7.4 Relative benefit for different types of bicycle facilities (EEM2, NZ Transport Agency 2010b, section 8.4, table 8.1)

Type of cycling facility	Relative benefit
On-street with parking (no marked cycle lane)	1.0
On-street with parking (marked cycle lane)	1.8
On-street without parking (marked cycle lane)	1.9
Off-street cycle path	2.0

The same principle also applies to quality enhancements on the PT network. Quality attributes relating to the passenger experience in PT vehicles and at stops/stations are found in tables 7.3-7.5 of EEM2 (NZ Transport Agency 2010b). For example, table 7.5 contains user values for improvements to stops/shelters, ticketing facilities, security and information provision. Although these attributes are not included in the evaluation tool, any complementary measures to stops or stations should be valued separately, using these values.

The NCHRP *Guidelines for analysis of investments in bicycle facilities* (TRB 2006a) used similar research, combined with standard values of time, to estimate cyclists' willingness to pay (WTP) for cycling on off-street cycle paths, on-street lanes without parking and on-street lanes with parking. The resulting values were NZ$5.40 (2008 prices), NZ$4.76 and NZ$4.19 per hour cycled, respectively.

More recently, revealed preference data has been employed to calibrate cycle route choice models. Rendall et al (2012) compared data from Portland, Oregon and Christchurch to calibrate a set of cycle route choice factors for New Zealand (discussed earlier in section 5.6 of this report). These values are employed in the evaluation tool. The link-scaling factors are used to calculate GJTs (assuming a mean cycling speed of 15kph). The intersection delays are expressed as GJT in seconds.

The literature review in this research identified several sources containing parameter values for individual elements of the public realm (eg TfL 2010b) such as crossings, perceived security, quality of the environment, surface quality, capacity and legibility. However, as described earlier in section 5.7 of this report, the evaluation tool employs an estimated walking access route GJT using values that are ideally derived from CSRs, or alternatively, from a simplified audit method that covers similar criteria.

The change in perceived journey times is converted into monetary values, using the standard walking or cycling value of time. For the sake of simplicity, the commute values are applied to peak cyclists and the non-commute values to off-peak cyclists.

The evaluation tool includes an option to assess the benefits to all existing pedestrians/cyclists. The monetary benefit of improved walking and cycling links accrues to all existing users, including non-PT users.

7.3.4 Road safety benefits

Mode shift to PT as a result of improved integration with walking and cycling can result in mixed road-safety outcomes. At an aggregate level, mode shift from car to PT use is generally associated with a reduction in accident risk. Table 3.3 in EEM2 (NZ Transport Agency 2010b) provides resource cost corrections that can be applied to changes in vehicle-kilometres by private vehicle, motorcycle or bus (see table 7.5).

Table 7.5 Marginal accident reduction cost - NZD/km, 2008 values (EEM2, NZ Transport Agency 2010b, table 3.3)

	Private vehicle	Motorcycle	Bus
Rural	0.02	0.22	0.17
Urban off-peak	0.03	-0.18	0.07
Urban peak	-0.03	0.02	-0.14

Conversely, shifting from car to walking or cycling as an access mode incurs a higher accident risk for users. Under the consumer perceived cost approach adopted by the EEM, the internal costs of changes to accident risk are assumed to be perceived by the users who switch mode. In terms of the remaining externality cost, section 3.8 in EEM2 (ibid) recommends that this should be offset by the marginal reduction in accident risk that occurs as walking and cycling increase. This critical mass effect was observed by Jacobsen (2003), who compared the evidence from a range of US and EU cross-sectional and time-series datasets of pedestrian/cyclist injuries and fatalities with walking and cycling rates, concluding that the relationship was not linear. As a rule, risk increases by a 0.4 power, meaning that a doubling of walking produces a 32% increase in accidents. This is sometimes referred to as the 'safety in numbers' effect.

The evaluation tool calculates the change in total vehicle-kilometres by private vehicles (both accessing PT and main mode) and buses, and applies marginal accident-reduction cost values per kilometre. It is assumed that there is no change in motorcycle use because this is not listed as a separate access mode in the NZHTS data.

Individual measures to improve walking and cycling access to stations are also likely to contribute to accident reduction. Calculating the road-safety impact of individual measures requires knowledge of the accident history of the streets in question, and site-specific judgement on the potential reduction, by the responsible engineers. Section A6.7 in EEM1 (NZ Transport Agency 2010a) contains a useful reference guide on typical accident reductions for a range of treatments in urban and rural environments, which constitutes a useful basis for estimating the potential scale of multiple measures in appraisal. Calculation of the potential accident reduction and the associated monetary benefits should be conducted outside of the evaluation tool using the guidance provided in EEM1 (ibid).

7.3.5 Health benefits

The health impacts of increased physical activity potentially represent the largest single benefit of increased walking and cycling to access PT. Therefore the literature review into the benefits of increased walking and cycling included a critical review of the available methods.

Essentially, there are several methods employed as the basis of health benefits valuation, as outlined below:

- *Mortality and morbidity:* The costs of mortality and morbidity from preventable illness or disability is calculated, and the influence of physical inactivity as one of a series of contributory causes is established. This can be expressed as a statistical reduction in risk of mortality for persons who meet specific physical activity thresholds. The costs included can include the following:
  - health sector resource costs – costs to the health sector associated with the treatment or prevention of preventable illness or disability

  - lost output resource costs – costs to employers through reduced productivity of employees due to preventable illness or disability

- *Disability-adjusted life years (DALYs):* 'Willingness-to-pay' research can be used to determine the benefits of improved health to citizens. The use of DALYs forces research participants to make trade-offs between longevity of life and the quality of life available to them for those years.
- *Absenteeism:* Costs to employers through lost employee working days are calculated. There is some evidence that employees who meet the recommended physical activity guidelines take fewer days of sick leave in an average year. In 2004, the World Health Organisation (WHO) suggested that this relationship was not conclusive, although absenteeism benefits have since been adopted in some countries (eg DfT 2010).

Regardless of the valuation method adopted, the following two key principles must be respected when applying the benefit:

- *The benefit is only applicable to a genuine net increase in physical activity:* For example, if secure bicycle parking at a station encourages a cyclist to switch from parking their bicycle at another station, only the net change in distance cycled is relevant. Similarly, somebody may be encouraged to start cycling to the station on a daily basis, but might reduce the number of leisure cycle trips they undertake at the weekend.
- *The benefit is not applicable to people who are already very active:* The health evidence is calculated using specific thresholds (ie comparing the health outcomes of people who do at least 30 minutes of moderate physical activity five times a week versus those who do not). Therefore when applying the values to increased physical activity from walking and cycling, it is necessary to establish in the baseline the marginal change to the population who are classed as 'inactive'. In other words, the full benefit is applied to the small proportion of users who move from just below the threshold to just above it.

The literature review conducted as part of this research identified a range of health benefit calculation studies from New Zealand, Australia, Denmark and the UK, and found values that were generally within the same ballpark. The largest meta-analysis of international physical activity studies was conducted by the WHO (2011). The results have been incorporated into an online evaluation tool that estimates the relative risk reduction for all causes of mortality for adults in the population. The evaluation method can be tailored to use nationally specific values for the 'value of a statistical life' (VSL) and the current mortality rate for the age group concerned. The findings of this comprehensive study should be used to enhance the evaluation guidance in New Zealand.

In order to ensure consistency with other business cases, the evaluation tool employs the current physical activity values contained within EEM2. Section 3.8 treats health benefits in a similar manner to accident costs. The health benefits are expressed on a per-kilometre basis, equating to NZ$1.30/km for cycling and NZ$2.60/km for walking. It is assumed for evaluation purposes that half of the benefits are internal and perceived, and therefore the resource cost corrector is equal to half the benefit.

7.3.6 Congestion relief

Any form of mode shift away from car trips, either as the main mode of the trip or as an access mode, can benefit other road users through a reduction in congestion. The cost saving is calculated by comparing the additional journey time incurred when travelling in congested conditions with the equivalent journey time in uncongested traffic levels. Any reduction in the total traffic volume on a road should reduce the vehicle per-capacity ratio and result in faster journey times for other road users. Since congestion is non-linear, even a small reduction in vehicle volumes on congested roads can lead to a large reduction in delays.

Section A4.4 of EEM1 (NZ Transport Agency 2010a) outlines the procedure adopted in New Zealand for calculating congestion relief benefits. Essentially, road users value the resulting journey time saving from congestion relief more highly than their general value of time, capped at maximum increments for certain road types.

Congestion values broken down by region are contained in table 3.2 of EEM2 (NZ Transport Agency 2010b) (see table 7.6 below). These values are applied to the reduction in car-kilometres predicted. This was identified as the preferred method for calculating congestion relief in the evaluation tool, since the reduction in car usage makes use of the assumed diversion rates.

Table 7.6 Average benefits to other road users for travel time, VOC and CO^2 emissions (2008 NZD/km) (EEM2, NZ Transport Agency 2010b, table 3.2)

Time period	Region	Benefit
Peak	Auckland MUA	1.41
	Wellington MUA	1.08
	Canterbury MUA	0.10
	Other Main Urban Area	0.00
	Secondary Urban Area	0.00
	Rural Area	0.00
Off-peak	All regions	0.00

EEM2 (ibid) also has values to calculate congestion relief benefits relative to additional patronage on new PT services (in worksheet SP9, table 1) and for existing services (in SP10, table 1). These values are not interchangeable with EEM2's table 3.2, since the average benefits also include accident savings.

Alternative approaches to calculating congestion relief are applied in other countries, although these comparison values are subject to different levels of congestion and variation in the underlying values of time. In Australia, PriceWaterhouseCoopers (2011) employed a value equating to NZ$0.49 (2008 prices) per car-kilometre removed from the network in Sydney. When applying the congestion relief benefit to an additional kilometre walked, it assumed that the proportion of walkers switching from car travel was equivalent to the mode share of the city as a whole.

In the UK, the Department for Transport estimated the marginal external cost due to congestion of an additional vehicle-kilometre on the network using the National Transport Model (DfT 2007). The weighted average value for all road types was NZ$0.49 (2008 prices) per vehicle-kilometre. For individual road types, the average values could be considerably higher; eg NZ$1.70 on main roads in the large conurbations and NZ$0.71 on main roads in other urban areas.

7.3.7 Parking user cost savings

Increased use of walking and cycling to access PT reduces the need to provide car-parking facilities. If users switch from private vehicle to PT, they no longer require a parking space at their destination. If they switch their access mode from private vehicle to walk/cycle, they no longer require a parking space at their PT station or stop. The reduction in parking provision at CBD destinations has a much higher value due to the large difference in land values between the suburbs and the CBD.

The parking fee paid by users does not always cover the full cost of providing the parking space (especially in CBD areas, where the opportunity cost of the land is highest). Section 3.8 of EEM2 (NZ Transport Agency 2010b) includes resource cost correction factors to account for this difference (see table 7.7 below). The upper range can generally be applied, except in situations where users are made more aware of the real cost of their parking charges; eg through travel behaviour change (TBhC) activities.

Table 7.7 Resource-cost correction for parking cost savings (NZD/one-way trip, 2008 values) (EEM2, NZ Transport Agency 2010b), table 3.5)

Peak period commuting trips to			Off-peak issues to all destinations
Auckland CBD	Wellington CBD	All other destinations	
NZD1.43–NZD4.28	NZD1.43–NZD3.65	NZD0.57–NZD1.14	NZD0.00

7.3.8 Environmental benefits

The EEM includes values for benefits arising from mode shift away from travel by private vehicles. The congestion relief values, as shown in table 7.5 above, aggregate the impacts of congestion relief to other road users (reduced travel time, VOCs and CO^2 emissions). The benefit that accrues through the reduction in actual car trips (EEM2, NZ Transport Agency 2010b, table 3.6, see below) is a composite value that includes several environmental impacts including local air quality, noise and water pollution, and greenhouse gas emissions.

Table 7.8 Marginal environmental costs (aggregated) (NZD/km, 2008 values) (EEM2, NZ Transport Agency 2010b), table 3.6)

	Private vehicle as driver	Private vehicle as passenger
Peak	0.10	0.08
Off-peak	0.05	0.04

7.3.9 Crime and personal security

Wider societal benefits occur if there is an actual reduction in crime. The NZ Treasury (Roper and Thompson 2006) calculated the cost of various types of crimes, including costs incurred by the public sector (justice and health) and by the private sector (loss of property, intangible costs and lost output). From this framework, it would be possible to estimate the specific value of preventing bicycle theft.

The evaluation tool does not include theft-reduction values. However, if there is clear evidence on the number of bicycles currently stolen (for example) and a robust prediction of how the proposed measures will counter this theft, the resulting economic benefit can be calculated separately. It should be noted that these benefits may represent an overestimate of benefits if the bicycle crime simply shifts to other locations.

7.3.10 Other benefits

The literature review for this research identified several other benefits that have not been included in the evaluation tool. Depending on the nature of the scheme evaluation, there may be merit in additionally evaluating the following benefits, qualitatively or quantitatively:

- *Maintenance costs:* Pedestrians, cyclists and PT modes all require less road space than private motorised vehicles. In the case of walking and cycling, they also cause significantly less wear and tear for the public roadway. This could be offset by reduced fuel tax income.
- *Reduction in severance:* Major roads can present a barrier to the local movement of pedestrians and cycles. Since many stations and stops are typically located on or adjacent to major roads, this can be especially true of shorter PT access and egress trips where crossing the road(s) may make up a significant proportion of the time required to access the station. *A walking strategy for NSW: assessing the economic benefits of walking* (PWC 2011) discussed how the 'barrier effect' could be measured in scheme evaluation. It was suggested that the severance impact could be valued as a pedestrian disbenefit per each additional vehicle-kilometre. However, this poses the risk of double-counting in appraisal. The actual physical delay experienced can and should be calculated, taking into account crossing waiting times, forced detours at grade-separated crossings, and relevant weightings for walking versus waiting time.
- *Accessibility:* In many areas, improvements to pedestrian access to stations and stops will have a particularly high benefit to mobility and sensory-impaired users; eg the provision of improved crossings with step-free access and facilities for visually impaired pedestrians. However, it is not common practice to evaluate these measures in economic appraisal where there is a legal duty upon authorities to improve accessibility as part of any schemes they develop.
- *Wider economic benefits:* At an aggregate city-wide level, any measures that increase the capacity, efficiency and geographic reach of the PT network will also have wider economic benefits, or agglomeration benefits. Measures to improve walking and PT access have no impact on PT line capacity, but they could lead to an increase in the geographic reach of PT networks. However, it would be extremely difficult to define an evaluation method that could practically be applied at the scale of individual interventions at stations.

7.4 Case study: Puhinui Station access

7.4.1 Costs

Costs were calculated for the three options at Puhinui Station (see section 1.4). In 2010, the estimated capital cost for the cycle facility improvements at Puhinui Station were $392,000 for the additional bridge widening and $548,000 for the remaining bicycle facility enhancements. The pedestrian improvements under option 3 were estimated at $25,000 capital cost per junction. All carriageway works were assumed to incur a maintenance cost of 2.5% of the capital value per annum.

The provision of 20 cycle stands at the station was estimated to cost $6000 in capital cost to install, with an allowance of $1000 per annum for maintenance (see table 7.9).

Table 7.9 Capital and maintenance costs of the three options (2010 prices)

	Option 1	Option 2	Option 3
Capital cost of additional bridge widening and remaining bicycle facility enhancements	$940,000 + 2.5% annual maintenance	$940,000 + 2.5% annual maintenance	$940,000 + 2.5% annual maintenance
Provision of 20 cycle stands at the station	-	Capital cost: $6000 + $1000 annual maintenance	Capital cost: $6000 + $1000 annual maintenance
Footway improvements at four junctions	-	-	Capital cost: $100,000 + 2.5% annual maintenance

7.4.2 Benefits

The benefits of the three options at Puhinui Station were as follows:

- *Health benefits:* The resource cost correction explained in section 7.3.5 was applied to the total annual change in kilometres walked and cycled.
- *Journey time savings:* Under option 3 there would be a pedestrian journey time saving as the result of the reduced queuing delay for pedestrians. This was multiplied by the pedestrian value of time and the walk-to-transit weighting factor.
- *Journey quality benefits*: The enhancements to walking and cycling infrastructure were calculated as a change in GJT. This was multiplied by the relevant value of time (minus the actual journey time saving).
- *Mode change benefits:* The resource cost correction explained in section 7.3.1 was applied to the annual mode change (expressed in the number of trip stages) to PT, walking or cycling, multiplied by the relevant percentage point mode change.
- *Road safety:* The resource cost correction explained in section 7.3.4 was applied to the total annual reduction in (urban) peak and off-peak car-kilometres. This generated a strategic road-safety disbenefit. Conversely, at a more localised level the original proposal estimated that the introduction of cycle lanes would result in a 10% reduction in bicycle crashes (from the seven bicycle crashes recorded over the previous five years), valued at $260,000 per collision (EEM1, NZ Transport Agency 2010a, table A6.22, 2006 prices, updated to the 2011 price base year). The resulting annual localised safety benefit was entered into the evaluation tool.
- *Congestion relief:* The resource cost correction explained in section 7.3.6 was applied to the total annual change in car vehicle-kilometres.
- *Marginal environmental benefits:* The resource cost correction explained in section 7.3.8 was applied to the total annual change in car driver and car passenger vehicle-kilometres.
- *Parking user cost savings:* The resource cost correction explained in section 7.3.7 was applied to the total annual change in car trips. As advised in section 3.8 of EEM2 (NZ Transport Agency 2010b), the upper range of the resource cost correction was applied, since the change in car vehicle-kilometres was already amended to take into account the effects of travel behaviour change (TBhC) activities.

7.4.3 Economic evaluation of the case study

The resulting economic evaluation indicated that the net cost over a 15-year evaluation period would be over $1.2m for all three options. Under all three options the net benefits totalled more than $1m over the evaluation period, producing benefit-cost ratios in excess of between 0.9:1 and 1.1:1. The largest benefits occurred due to the removal of peak-time car trips from the congested Auckland network, leading to congestion relief and localised safety benefits.

It was also observed that shifting a significant number of PT access trips from walking to cycling could reduce the overall health benefits, since the physical activity gain over the same distance travelled would be less.

Table 7.10 Net present value ($,000) discounted at 8%

	Option 1	Option 2	Option 3
Total capital and maintenance costs	**1247**	**1263**	**1395**
Health benefits (walking)	8	-16	-7
Health benefits (cycling)	31	69	68
Time savings (pedestrian)	0	0	68
Time savings (cyclist)	0	0	0
Quality (walking)	0	0	51
Quality (cycling)	105	105	105
Mode change (new PT users)	0	0	0
Mode change (new pedestrians/cyclists)	1	5	11
Road safety	341	340	338
Congestion relief	479	541	655
Marginal environmental benefit	39	44	53
Parking user cost savings	70	101	134
Total benefit	**1072**	**1188**	**1476**
Benefit-cost ratio (BCR)	**0.9:1**	**0.9:1**	**1.1:1**

8 Conclusions and recommendations

8.1 Conclusions

This research included an international review of evidence on PT access and egress mode shares. At the origin end of PT trips, we found considerable variation in the access mode shares of different cities. The car played a greater role as an access mode in urban areas dominated by car travel, such as many cities in the US and in New Zealand, whereas in many European and Asian cities, a combination of higher population density and more expansive, denser PT networks meant that walking accounted for over 50% of PT access trips. The role of cycling as a PT access mode was marginal in many countries, but it could account for more than 20% of access trips in cities with high-quality cycling infrastructure, facilities at stations and stops, and a wider cycling culture. At the destination end of PT trips, walking was universally the predominant mode. Cycling played only a minor role as an egress mode at the destination end of trips.

This research also included a comparison between New Zealand and international evidence of walking and cycling catchment areas, the distance people would walk and cycle to access PT services. Analysis of data from the MoT New Zealand Household Travel Survey (NZHTS) showed that at the origin end of PT trips, the median walk-to-bus trip length was 200m, and 75% of walk-to-bus trips were less than 500m. These distances were low compared with the selected international research, which showed that people would often walk distances of 400-800m to reach bus services. The observed distribution agreed with the evidence that people would walk further if the mode to be accessed was faster; people in New Zealand would walk further to access rail and ferry services. The walking catchment size to rail services in New Zealand was closer to that observed in other international research, with a median walk-to-rail distance of over 1km. The distribution of distances cycled to PT stations/stops had a larger catchment area than walking. Although based on a small sample, in New Zealand the mean distance cycled was 1.42km, with 25% of people cycling more than 1.35km to reach PT. In line with international evidence, access and egress trips at the destination end were generally shorter than at the origin end.

A variety of factors could influence whether walking and cycling were used as access modes to PT. Cycling was most often used as an access mode for commuting and education trips. In some countries, including New Zealand, certain demographic and socio-economic groups (eg adult males) were generally more likely to cycle. However, no studies had looked specifically at cycling as an access mode, and it is possible that shorter cycling trips to access PT could potentially attract a different market of cyclists. Evidence from the US highlighted patterns in PT access based on neighbourhood characteristics such as residential density, pedestrian and bicycle connectivity, surrounding land use, and parking facilities at stations.

There were multiple interventions that could contribute to greater integration of walking and cycling with PT, including:

- land use planning that encouraged residential densities conducive to short walking and cycling trips
- walking and cycling networks that were attractive, perceived to be safe, and offered a direct journey between passengers' trip origins, destinations, and stations or stops
- provision for secure bicycle parking at PT nodes
- provision for the carriage of bicycles on PT

- bicycle rental systems.

The 2010 Transport Agency research report *Forecasting the benefits from providing an interface between cycling and PT* (Ensor et al) concluded that the provision of BoB facilities in New Zealand could lead to an increase in bicycle access to PT, with an estimate of the potential BoB patronage at 1.2% of access trips for buses and 3% for suburban rail services. After reviewing international evidence from the UK, US and Switzerland, we concluded that an access mode share of up to 4% of rail passengers could be achieved through the provision of bicycle stands at stations. The introduction of bicycle hire schemes could be attractive to PT commuters with a longer distance to travel at the destination end of their trip. Recent research into bicycle and pedestrian route choice in the UK and New Zealand can be used to estimate the GJT of access trips to PT based on the quality of the approach routes to stations and stops. As a consequence, it is possible to estimate the resulting change in travel behaviour, using standard elasticities.

The 2003–2010 NZHTS data was analysed to understand the wider impacts of travel behaviour change interventions. One key finding was that if a transport user shifted to PT as the main mode of transport, this change typically had a knock-on effect on overall daily travel patterns. An analysis of the travel patterns of the population as a whole showed that for each additional PT trip, the average number of daily walking trips increased by 0.95 and the distance walked increased by 1.21km (ie walking as a main mode, additional to any walking trips to access PT). For each additional PT trip there was an average daily reduction of two car driver trips and 45km driven (people of driving age 18+ only). The diversion rate for additional mode shift to PT could not be directly implied from this statistical relationship, and complementary travel behaviour change measures would be required to sustain this level of mode shift.

This research resulted in the development of an evaluation tool[5], which incorporates the findings from studies of travel behaviour in New Zealand and internationally, for estimating the benefit-cost ratio of improving walking and cycling access to PT. The economic evaluation parameters remain consistent with the current valuations contained in the Transport Agency's EEM. There are acknowledged gaps in the evidence base and international values have been imported for some elements of the evaluation tool. In spite of this, the evaluation can be employed at different stages of the project evaluation process. The tool is intended to be flexible to adapt to different levels of data availability. Early in the planning process, the project analyst can fill the evaluation tool with rough estimates and default values to establish the levels of behaviour change required to generate a robust case. Once station-specific data is available, a more detailed evaluation can subsequently be produced.

The evaluation tool is designed to be used as one spreadsheet for each station or stop. It can be applied from a single bus stop to a major multimodal interchange. The evaluation tool is designed to estimate passenger impacts for a single year - either the proposed implementation year or a future-year scenario. If users want to test the impacts of integration measures combined with forecast population/employment growth, separate spreadsheets should be completed for the implementation year and any future-year scenario(s). In this way it is possible to disaggregate the impacts of the integration measures from the impacts of population/employment growth.

An alternative application of the tool is for demonstrating the benefits (particularly the health benefits) of increased PT use. For a given station and access mode profile, users can use the evaluation tool to estimate the change in total kilometres walked and cycled (as an access/egress mode) as a result of higher

5 Available on www.nzta.govt.nz/resources/research/reports/537.

PT patronage. Users will need to calculate the health benefits of this increase outside of the evaluation tool spreadsheet and are referred to the resource cost correction values as stated in section 3.8 of EEM2 (NZ Transport Agency 2010b).

8.2 Recommendations for data collection, modelling and evaluation guidelines

This research identified a number of gaps in the available information on the access and egress trips legs of PT journeys. A series of recommendations for improvements to the data collection, modelling and evaluation guidelines are therefore proposed.

8.2.1 Data collection (NZHTS)

As described in section 2.2, the definition of a walking trip in the NZHTS has been updated to remove the arbitrary minimum distance threshold. However, from a practical perspective the new definition still generates little clarity when exploring patterns of walking and PT usage. Moreover, it introduces a bizarre ideological reasoning where a 20km drive to buy a loaf of bread has significant value to the user, whereas a 50m walking trip to buy the same loaf may or may not have value, depending on whether the user walks from their origin or another shop, or whether the user crosses the street. From the perspective of the transport user, both trips fulfil the same need.

A clear rule could be that the minimum threshold should be replaced with a definition based on 'walking trips in the public realm'. In other words, walking to a car parked on the drive in front of a house would not count, but walking from a shop to a car park through publicly accessible routes would count. Similarly, walking between shops inside a shopping mall would not count (unless the pedestrian routes were publicly accessible at all times), whereas walking between shops in a public space would count. Changing the definitions in a major Household Travel Survey is difficult for obvious reasons of compatibility. In practice, in the transition period, this would require that walking trips be recorded in both a 'raw' and a 'capped' form.

In order to improve the analysis of PT trip chains, it has also been suggested that a better 'standard trip chains' definition could be developed. The work undertaken by Abley et al (2008) employed the method where time spent in one location was the sole determinant of where to break the trip chain. However, the authors acknowledged that an improved methodology would break the trip chain at certain 'anchor activities' such as employment or education.

8.2.2 Transport modelling guidelines

Chapter 4 in the New Zealand EEM2 (NZ Transport Agency 2010b) describes approaches to estimating demand for different types of transport modes, services and facilities. However, no detailed guidance on standards for mode choice modelling is specified. Furthermore there is no information on parameters for measuring the attractiveness of travel by walking and cycling. The EEM could be updated to include a set of parameters for calculating the GJT of different types of walking and cycling trips. Initially this could be based on parameters taken from international literature, with specific New Zealand parameters being added as research becomes available.

In theoretical terms, the integration of walking or cycling and PT can easily be reflected in existing transport mode choice models. There are several combinations of walking and cycling as modes to access

PT. With adequate data it would, in theory, be possible to calibrate a model of mode choice using generalised journey cost calculated for each of the PT sub-options. The crucial factor would be that the attractiveness of individual mode options is calculated in a comparable manner and expressed as generalised time or cost, as indicated in table 8.1 following.

Table 8.1 Summary of generalised journey cost elements for multiple trip stages

Journey element	Calculation of generalised journey cost
Access mode	Walking GJT, including distance, route-quality factors and appropriate penalties for crossings, etc *or* Cycling GJT including distance and route-quality factors *or* Car GJT (eg using parameters from an existing model of P&R usage)
Origin stop	Waiting time (with appropriate weighting or penalty) + Penalty for quality of facilities (eg bicycle parking) + if relevant, the cost to the user of these facilities
PT journey	PT GJT, including time and route-quality factors + fare For BoB, a set of parameters would be required to reflect the availability and quality of bicycle carriage on board
Interchange	If relevant, additional walk GJT + waiting time + interchange penalty
Destination stop	Penalty for quality of facilities (eg bicycle parking or availability of rental bicycles) + if relevant, the cost to the user of these facilities
Egress mode	Walking GJT, including distance, route-quality factors and appropriate penalties for crossings, etc *or* Cycling GJT, including distance and route-quality factors

In practice, the above parameters are far too complex for inclusion in existing mode choice models. It should be noted that for one single origin-destination movement there could be multiple PT route options, each with multiple access and egress options. The feasibility of calibrating a mode choice model to take into account all of the options and sub-options described above would be constrained not only budgetary considerations, but also the lack of data available to accurately calculate the options and calibrate the model.

However, as discussed in this report, advances in computational processing power, improved data availability through increased overlap with GIS and journey-planning applications, and shifts in the most important policy paradigms mean there is a strong chance that more complex multimodal models will become the norm over the next 10-15 years. Therefore it is essential that clear modelling guidelines are put in place to ensure that available good practice is applied from the start.

In the short to medium term, it is recommended that the impact of measures to improve the integration walking or cycling and PT should be evaluated outside of the main mode choice models.

8.2.3 Economic evaluation (value of time)

It is noteworthy that the value of time attributed to different modes of transport in New Zealand varies within individual trip purpose categories. Although the values for in-work travel are similar across modes, the values for commuting and non-work travel are significantly lower for PT passengers. However, the aggregated value for all PT passengers may be inappropriate for some situations, especially peak-time travel in urban agglomerations. Commuters on suburban rail systems (or express bus corridors) are likely to be professionals with a similar or higher value of time compared to that of car drivers. It is therefore recommended that in future value-of-time research for the EEM, it would be more useful to separate values for different PT modes.

In the UK, for example, rail and Underground passengers have a higher value of time than car drivers in both the Transport for London *Business case development manual* and the Department for Transport *Transport analysis guidance* (TfL 2010b; DfT 2011). Conversely, the value of time for bus passengers is lower than for car drivers in both sources of guidance. It should be noted that section A4.2 'Mode switching' in EEM2 (NZ Transport Agency 2010b) clearly states that for schemes where achieving mode shift to PT is the aim, PT users can be given the same value of time as car users.

As noted in section 7.3.2 of EEM2 (ibid), the publication does not include guidance on the relative perception of time for different elements of the PT chain. The evaluation tool that accompanies this research project includes a variable weighting factor where the default value is 2. It is recommended that until factors from New Zealand research are available, a default weighting of 2 could be adopted in the EEM for walking as PT access, egress or interchange.

8.2.4 Measurement and valuation of walking and cycling quality

The evaluation tool incorporates the quantitative measurement of environmental-quality variables into economic evaluation. This is a fast-evolving field of research and remains a high-priority area for further work in New Zealand. However, several elements from the evaluation tool could be incorporated into the EEM in the short term.

With regards to cycling infrastructure quality, the research by Rendall et al (2012) was based on a method that has been proven in more than one city and calibrated against empirical route choice data from New Zealand. Therefore it could be regarded as fit for purpose and incorporated into the EEM as a method of calculating GJT.

In terms of walking infrastructure quality, the CSR is a tool that is promoted by the Transport Agency and therefore reference to its principles could be made in the EEM. However, a full CSR requires significant time and resources. In order that projects can also be evaluated in an earlier stage of development, it is recommended that a simplified audit method using a 7-point scale would be a useful addition to the EEM.

Additionally, the evaluation tool adopts generalised journey penalties and weightings from a calibrated model of pedestrian movement in Central London (Colin Buchanan 2010). Clearly this method is relatively untested and therefore not strictly fit for purpose for application in New Zealand. In the short term, the EEM could propose the values contained in the evaluation tool, albeit with appropriate caveats and while stressing the importance of appropriate sensitivity tests. However, this needs to remain a priority for new research in New Zealand.

By expressing quality in terms of GJT, changes can be valued using the 'values of time' contained within the EEM. The selection of values by time of the day and journey purpose need to be consistent with EEM practice.

8.2.5 Economic evaluation (health benefits)

The sheer scale of interest in physical activity research internationally means that there is a rapidly growing body of evidence on the health benefits of active travel. As noted earlier, the work of the WHO

(2011) is the most comprehensive meta-analysis to date, and in the short term it is recommended that the EEM is updated to incorporate the findings of this work.

The WHO method estimates the relative risk reduction for all causes of mortality for adults in the population. This statistical evidence can be combined with national data on the current mortality rate for the adult population (age range 20-74) and the 'value of a statistical life' from the EEM to produce a revised set of New Zealand health benefit values.

8.3 Future research priorities

The following list summarises the research priorities identified through this project:

- A standard method for converting Household Travel Survey data into trip chains is needed. Instead of an arbitrary time threshold for all trip purposes, this would involve the definition of 'anchor activities' that automatically trigger the break in a trip chain and different time thresholds for other activities.
- There are two key gaps in the current evidence on diversion rates. Firstly, the diversion rates quoted in section A15 in EEM2 (NZ Transport Agency 2010b, from Wallis and Schmidt 2003) are derived only from 'stick measures' and do not consider the cross-elasticity of 'carrot measures', such as improvements to PT or better access to PT by walking and cycling. Secondly, the majority of studies on diversion rates focus on the main mode only. A review of the latest evidence on passenger transport demand elasticities, both from cross-sectional and time-series data, would address these two gaps.
- A standard recommendation on the weighting of walking time as part of multimodal trips, as opposed to in-vehicle time or walking time on single-mode trips, is needed in the EEM. Values for different types of walking trip can be derived from 'stated preference' or 'revealed preference' research.
- Although there is encouraging progress in research on cycling route choice in New Zealand (although further testing of the parameters on observed data from other cities would be useful), there are currently no locally estimated parameters for pedestrian route choice. A further research study could focus on collecting a reliable sample of observed pedestrian movement data; eg through manual tracking, GPS or Bluetooth technologies. This data would ideally include both single-mode walking trips and walking as part of PT trips. A pedestrian route-choice model could be calibrated from this data to take into account distance, linearity, route-quality factors, types of crossing facilities available, and the actual profile of waiting time at crossings.
- Further research to estimate health benefits, using the WHO recommendations, is needed. This will require a robust review of the evidence in light of New Zealand mortality rates in the adult population (age range 20-74).
- Research is needed to fill the following gaps in the existing evidence base regarding BoB:
    - Bike racks are being fitted to urban buses in Canterbury but it is too early to draw conclusions for other urban areas until the network-wide roll-out is complete. One issue affecting the carriage of bicycles on all PT modes is matching available capacity to demand. The disruption to cyclists if a vehicle has no capacity to carry another bicycle may be significant, in particular where service frequencies are low. In economic terms, the benefit of adequate capacity can be thought of as a value of 'certainty' of available space. This is not dissimilar to concepts used to measure passengers' preference for improved reliability and less crowded services - eg the ability to board the first vehicles that arrives, compared to savings in absolute journey time.

  - There is little evidence on the impacts of BoB on other bus passengers due to the time taken to place bikes on racks and remove them. Research is needed to find out whether the benefits of increased BoB patronage outweigh the disbenefits to other passengers (longer journey times and potentially a reduction in service reliability).
  - The currently available evidence on the carriage of bikes on buses identifies a range of the proportion of bus passengers who may adopt this service, but there is little evidence to distinguish the key target markets – eg below what overall distance threshold is cycling all the way preferred over BoB systems? Previous studies into alternative modes for cyclists to cross barriers such as rivers have looked at the relative perceived penalty for new infrastructure where the cyclist can continue to cycle; infrastructure where the cyclist is forced to dismount (eg lifts or stairs); transport modes that carry bicycles (with differing levels of perceived 'dismounting' and ease of carriage) eg roll-on/roll-off ferries; versus buses with racks. Research to identify better evidence of the dismounting impact would enable the relative attractiveness of bicycle-only trips versus multimodal bicycle trips to be incorporated into mode choice modelling.
- The research into bicycle parking, BoB and bicycle hire schemes relies heavily on international evidence. More dedicated longitudinal research on railway station and bus stop access and egress patterns in New Zealand would be extremely useful. For example, a structured monitoring framework would ideally be able to track changes in railway station access at a series of stations where changes to integration are due to take place. The monitoring would regularly measure PT patronage, number of arrivals by various access modes, and any major changes to local population and employment figures. If the railway stations monitored are geographically close, the longitudinal monitoring can additionally seek to establish patterns of trip reassignment and overall trip generation.

9 References

Abley, S (2010) Measuring accessibility and providing transport choice. *Living Streets Aotearoa (LSA) Conference*, Wellington, 2-3 August 2010.

Abley, S and S Turner (2011) Predicting walkability. *NZ Transport Agency research report 452*. 114pp.

Abley, S, M Chou and M Douglass (2008) National travel profiling - part A: description of daily travel patterns. *NZ Transport Agency research report 353*. 150pp.

Agrawal, AW and P Schimek (2007) Extent and correlates of walking in the USA. *Transportation Research Part D 12*, no.8: 548-563.

Association of Train Operating Companies (ATOC) (2012) *Cycle-rail toolkit*. Produced by ATOC on behalf of the Cycle Rail Working Group and the UK Cycling Alliance. 60pp.

Balcombe, R, R Mackett, N Paulley, J Preston, J Shires, H Titheridge, M Wardman and P White (2004) The demand for public transport: a practical guide. *Transport Research Laboratory report TRL593*. 264pp.

Barker, C (2012) Integrating cycling and public transport – a NZ Transport Agency perspective. Case study 1: the Christchurch Metro bike racks on buses trials. *2 Walk and Cycle Conference New Zealand*, 22-24 February 2012.

Boarnet, MG and R Crane (2001) *Travel by design: the influence of urban form on travel*. Oxford: Oxford University Press.

Buehler, R (2011) Determinants of transport mode choice: a comparison of Germany and the USA. *Journal of Transport Geography 19*: 644–657.

Bundesamt für Strassen (2008) *Veloparkierung: Empfehlungen zu Planung, Realisierung und Betrieb*. Switzerland: Bundesamt für Strassen. 128pp.

Burke, M and AL Brown (2007) Distances people walk for transport. *Road & Transport Research 16*, no.3: 16–29.

Cervero, R and M Duncan (2003) Walking, bicycling, and urban landscapes: evidence from the San Francisco Bay area. *American Journal of Public Health 93*, no.9: 1478–1483.

Colin Buchanan (2010) Vauxhall Nine Elms Battersea: base year pedestrian model validation report. London: SKM Colin Buchanan. Prepared for Transport for London. 46pp.

Daniels, R and C Mulley (2011) Explaining walking distance to public transport: the dominance of public transport supply. *World Symposium on Transport and Land Use Research*, Whistler Canada, 28–30 July 2011.

Department of Transport (DfT) (2004) Bike and rail: a good practice guide. *Traffic advisory leaflet 4/04*. London: Her Majesty's Stationery Office (HMSO).

Department for Transport (DfT) (2007) Decongestion benefits. *Transport Analysis Guidance (TAG) Unit 3.9.5*. 15pp.

Department for Transport (DfT) (2010) Guidance on the appraisal of walking and cycling schemes. *Transport Analysis Guidance (TAG) Unit 3.14.1*. 41pp.

Department for Transport (DfT) (2011) Values of time and operating costs. *Transport Analysis Guidance (TAG) Unit 3.5.6*. 27pp.

Dill, J (2009) Bicycling for transportation and health: the role of infrastructure. *Journal of Public Health Policy 30*: 95–110.

Ensor, M, J Slason and C Vallyon (2010) Forecasting the benefits from providing an interface between cycling and public transport. *NZ Transport Agency research report 418*. 76pp.

Greater London Authority (GLA) (2010) *Pedal power: the cycle hire scheme and cycle superhighways*. London: London Assembly Transport Committee.

Jacobsen, P (2003) Safety in numbers: more walkers and bicyclists, safer walking and bicycling. *Injury Prevention 9*: 205-209.

Jones, E (2001) Liveable neighbourhoods. *World Transport Policy and Practice 7,* no.2: 38-43.

Kingham, S, K Taylor and G Koorey (2011) Assessment of the type of cycling infrastructure required to attract new cyclists. *NZ Transport Agency research report 449*. 154pp.

Land Transport NZ (LTNZ) (2007) *Pedestrian planning and design guide*. Wellington: Land Transport NZ. 201pp.

Lu, H, P Jiao and S Yang (2003) Transfer analysis of bicycle to public transport. Paper submitted at the *Velo-city Conference,* Paris, 2003.

Mai, X, Y Wang, L Lu, X Luo and Y Hayashi (2010) *Traditional based innovation: integrating bicycles and urban rail transit in Beijing, China*. Nagoya, Japan: Nagoya University Department of Environmental Engineering and Architecture, Graduate School of Environmental Studies.

Martens, K (2004) The bicycle as a feedering mode: experiences from three European countries. *Transportation Research part D 9,* no.4: 281-294.

McClintock, H and D Morris (2003) Integration of cycling and Light Rapid Transit: realising the potential. *World Transport Policy and Practice 9*, no.3: 9-14.

Mees, P (2009) Density and transport mode choice in Australian, Canadian and US cities. *Proceedings of the 32nd Australasian transport research forum (ATRF),* 29 September–1 October 2009, Auckland.

Milne, A, S Rendall and S Abley (2011) National travel profiles part B: trips, trends and travel predictions. *NZ Transport Agency research report 467*. 94pp.

NZ Transport Agency (2010a) *Economic evaluation manual (volume 1) (EEM1).* Wellington: NZ Transport Agency. 685pp.

NZ Transport Agency (2010b) *Economic evaluation manual (volume 2) (EEM 2).* Wellington: NZ Transport Agency. 259pp.

NZ Transport Agency (2010c) *Guide to undertaking community street reviews*. Wellington: NZ Transport Agency. 51pp.

O'Fallon, C and C Sullivan (2009) Trends in trip chaining and tours: analysing changes in New Zealanders' travel patterns using the Ongoing New Zealand Household Travel Survey. *NZ Transport Agency research report 373*. 60pp.

Opus International (2010) Papatoetoe and Manurewa – walking and cycling schemes funding application. Prepared on behalf of Manukau City Council, funding application CRD00838. 73pp.

Opus and Arup (2012) *Wellington Transport Model: technical note 5B – rail intercept survey analysis*. Wellington: Opus International Consultants Ltd, prepared for Greater Wellington Regional Council. 42pp.

O'Sullivan, S and J Morrall (1996) Walking distances to and from Light-Rail Transit stations. *Transportation Research Record 1538*: 19-26.

Parkin, J, M Wardman and M Page (2008) Estimation of the determinants of bicycle mode share for the journey to work using census data. *Transportation no.35*: 93–109.

Pedal Power ACT Inc (2007) *Bikes on buses – increasing cycling and public transport usage*. Accessed 29 September 2013.
www.thinkingtransport.org.au/sites/www.thinkingtransport.org.au/files/Bike%20racks%20on%20buses%20brief%20-%20Canberra%20Jan%2007.pdf

Pitot, M, T Yigitcanlar, N Sipe and R Evans (2006) Land Use & Public Transport Accessibility Index (LUPTAI) tool: the development and pilot application of LUPTAI for the Gold Coast. In *ATRF06 Forum Papers* (CDROM and online), Surfers Paradise, 27-29 September 2006.

Policy Exchange (2009) *At a rate of knots: improving public transport on the River Thames*. R McIlveen and B Caldecott (Eds). London: Policy Exchange. 82pp.

PriceWaterhouseCoopers (PWC) (2011) *A walking strategy for NSW: assessing the economic benefits of walking*. Prepared for the Premier's Council for Active Living and the Department of Environment, Climate Change and Water (NSW). 58pp.

Pucher, J, R Buehler and M Seinen (2011) Bicycling renaissance in North America? An update and re-appraisal of cycling trends and policies. *Transportation Research Part A 45*, no.6: 451-475.

Pucher, J, J Dill and S Handy (2010) Infrastructure, programs, and policies to increase bicycling: an international review. *Preventive Medicine 50*: 106-125.

Rendall, S, P Rose and K Janssen (2012) Delivering effective cycle facilities: modelling bicycle route choice in New Zealand. *2 Walk and Cycle Conference*, Hastings, 22-24 February 2012.

Rietveld, P (2000) The accessibility of railway stations: the role of the bicycle in the Netherlands. *Transportation Research Part D 5*: 71-75.

Robinson, L (2003) Bicycle and intermodality: links with other means of transport bikes-on-buses: a north American success story! *Paper E0094 submitted at the Velo-city Conference,* Paris, 2003.

Roper, T and A Thompson (2006) *Estimating the costs of crime in New Zealand in 2003/04*. NZ Treasury Working Paper 06/04. 31pp.

Scottish Executive (2000) *Cycling by design, integration with public transport*. (This version of the online document has since been replaced by a 2010 version) Accessed 29 September 2013. www.transportscotland.gov.uk/strategy-and-research/publications-and-consultations/j185500-09.htm

Sinclair Knight Merz (SKM) (2008a) *Auckland Transport Models project ATM2: ART3 distribution and mode choice report*. Auckland: Sinclair Knight Merz. Prepared for Auckland Regional Council. 107pp.

Sinclair Knight Merz (SKM) (2008b) *Wellington Transport Strategy Model (WTSM) update 2006: user manual*. Auckland: Sinclair Knight Merz. Prepared for Greater Wellington Regional Council. 96pp.

Smart Growth America (2002) *Measuring sprawl and its impact*. Accessed 29 September 2013. *www.smartgrowthamerica.org/documents/MeasuringSprawl.PDF*

Stannard, A (2011) *Building the best public cycle hire scheme in the world*. Accessed 26 July 2012. http://community-bike.com/photos/2011/04/barclayscycleHire110303.pdf

Sustrans and CTC (2004) *Cycle parking: information sheet FF37*. Accessed 29 September 2013. www.tfw.org.uk/documents/SustransCycleparkingsheetFF37_000.pdf

Taylor, SB (1996) Bike and ride: its value and potential. *Transport Research Laboratory report 189*. 31pp.

Traffic Design Group and MVA (2008) *Christchurch Transportation Model update (2006 Census): model calibration and validation report - part 1 calibration final report*. Christchurch: Traffic Design Group. Prepared for Transit New Zealand, Environment Canterbury, Christchurch City Council and Waimakariri District Council. 226pp.

Traffic Design Group and MVA (2009) *Christchurch Transportation Model update (2006 Census): model calibration and validation report - part 2 validation final report*. Christchurch: Traffic Design Group. Prepared for Transit New Zealand, Environment Canterbury, Christchurch City Council and Waimakariri District Council. 119pp.

Transport for London (TfL) (2010a) *Measuring PT Accessibility Levels: PTALs – summary*. Accessed 5 February 2012. http://data.london.gov.uk/documents/PTAL-methodology.pdf

Transport for London (TfL) (2010b) *Business case development manual*. London: Transport for London Investment Programme Management Office. 256pp.

Transport for London (TfL) (2010c) *Travel in London report 3*. London: Transport for London. 290pp.

Transport for London (TfL) (2012) *Valuing urban realm toolkit*. (Online toolkit that requires registration to use.) http://urbandesign.tfl.gov.uk/Valuing-Urban-Realm/Toolkit-MKII.aspx

Transportation Research Board (TRB) (2006a) Guidelines for analysis of investments in bicycle facilities. *National Cooperative Highway Research Program report 552*. 135pp.

Transportation Research Board (TRB) (2006b) Guidelines for providing access to public transport stations. *Transit Cooperative Research Program (TCRP) report 153.* 146pp.

Victoria Transport Policy Institute (2013) Bike/transit integration, TDM encyclopaedia. Accessed 29 September 2013. www.vtpi.org/tdm/tdm2.htm

Wallis, I and N Schmidt (2003) *Australasian travel demand elasticities: an update of the evidence.* In *ATRF26 Forum Papers* (online), Wellington, 1-3 October 2003.

Wibowo, SS and P Olszewski (2005) Modeling walking accessibility to public transport terminals: case study of Singapore Mass Rapid Transit. *Journal of the Eastern Asia Society for Transportation Studies 6*:147–156.

World Health Organisation (WHO) (2011) *Health economic assessment tools (HEAT) for walking and for cycling: methodology and user guide - economic assessment of transport infrastructure and policies*. Copenhagen: World Health Organisation. 40pp.