Development of a public transport investment model

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Nick Allison, Logic Partners, Wellington
David Lupton and Associates, Wellington
Ian Wallis Associates Ltd, Wellington

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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

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Abbreviations and acronyms

GPS	Government Policy Statement
MC	marginal cost
MSC	marginal social cost
NZTA	New Zealand Transport Agency
NUV	non-use value
PT	public transport
OV	option value
STCCS	Surface Transport Costs and Charges Study
EEM	Economic Evaluation Manual
WRTM	Waikato Regional Transport Model
EW	Environment Waikato (now known as Waikato Regional Council)

Contents

Executive summary

The primary purpose of this research was to develop an economic modelling tool that could assist the NZ Transport Agency (NZTA), regional councils and Auckland Transport in making public transport (PT) investment decisions. This report covers the development and testing of an investment model for estimating optimal PT regional subsidies, and a flexible software platform that can be used to incrementally model changes to regional PT services arising from changes to 'prices' (fares and subsidies). Data from the Waikato region was used to test the model, with a view to possible expansion to other regions. This research was carried out between September 2011 and March 2013.

The economic model we developed incorporated the interactions between prices, service levels and patronage for public transport (bus, initially) and private car, and this is provided in a separate Excel workbook.

Methodology

The economic argument for PT subsidies is based on the concept of allocative efficiency, which occurs where resources are allocated in a way that ensures society gains the greatest overall net benefit. The policy rationales for subsidising PT principally concern identification of reasons for departures from full cost recovery (which would imply average cost pricing) in order to achieve allocative efficiency. A commonly cited reason for subsidising PT is to redress the imbalance in demand that results from suboptimal pricing of road use. This is called 'second-best' pricing and provides a justification for public transport subsidies that is independent of the 'social' or 'equity' arguments often put forward. Another economic justification is the existence of user economies of scale in the provision of PT services (the so-called Mohring effect). The Mohring effect could be seen as the economist's rationalisation of 'social' subsidies for PT.

The approach taken in the development of this model was to estimate the optimum public transport price by including the:

- demand for each mode (ie person trips, person-kilometres)
- marginal costs (including externalities) of each mode, estimated from previous research
- price (charges) for car travel
- price elasticity of demand for each public transport mode and the cross-price elasticity of demand between public transport and car travel.

This approach followed previous work by researchers Glaister and Lewis and Parry and Small. The Glaister-Lewis second-best pricing approach to estimating optimum fare and subsidy levels for urban public transport has been applied in London, several Australian cities and New Zealand. A more recent variation of the approach was applied by Glaister in London and by Parry and Small in Los Angeles, Washington and London, extending the original model to include 'first-best' warrants for public transport subsidy, in particular the 'Mohring effect'.

The Mohring effect refers to positive externalities or network spillover effects for existing users from, for example, a change in frequency. Its inclusion enables the incorporation of an important economic justification for public transport subsidy that is relevant to New Zealand, where patronage levels can be low compared with the major cities studied internationally.

The investment model

As indicated above, government intervention ('investment') in the public transport sector may be justified if the economically or socially optimal fares or prices differ from the average cost of production. The investment model developed in this research determines the optimal deviation of price from average costs. It was designed to assess *incremental* changes and was not intended to evaluate complete service withdrawal situations where option values or other policy considerations may be relevant. The model is presented in two formats to produce a range of outputs relevant to investment policy. It can be used to:

- identify the optimum fare for each market segment (eg education or work trips) and time period (we refer to this as the 'Glaister-Lewis' analysis)
- show the effect of a one cent change in fare on subsidies, bus users, car users and the environment (we refer to this as the 'Parry-Small' approach).

A number of supply-side policy responses to changes in patronage can be selected. The model currently provides for changes in frequency, route density, vehicle size and occupancy, and combinations of these factors. The model's estimates for optimal fares are quite sensitive to the policy responses adopted. Thus the model does not provide a single absolute result. Rather the model is a tool that allows many different policies to be tested and the likely outcomes to be evaluated. This feature should be of particular interest to local authorities interested in testing different policy settings for their PT networks.

By showing the distribution of the benefits from a change in fares or charges, the model provides a useful guide to investment decisions. In particular, it shows the redistribution of benefits and costs across users of different modes and public transport customer segments, including existing and new passengers.

The investment model outputs are sensitive to the 'own-' and 'cross-elasticities'. The own-elasticity measures the change in patronage of a mode when its own price is changed. The cross-elasticity measures the change in patronage when the price of a competing mode is changed. The data on elasticities for New Zealand cities is relatively sparse, particularly for cross-elasticities. These price elasticities can be expected to vary between cities depending on the current level of fare recovery, the degree of competitiveness between modes, and other factors affecting mode choice such as route frequencies and public parking availability and price.

We investigated the idea of using coefficients drawn from a calibrated transport model to calculate the implied elasticities. This would take advantage of the extensive cross-sectional data collected for such models, and then would ensure consistency with the study results as the model is expanded to cover other regions. For this study we therefore investigated using the Waikato Regional Transport Model (WRTM), which was able to provide useful data on mode shares, travel time sensitivities and transport externalities. However, data limitations in the WRTM meant that its elasticity calculation could not be used. Hence the investment model contains own-elasticities based on previous New Zealand studies and international experience. As a consequence, care is needed in interpreting model results and in drawing firm policy conclusions.

Application to Hamilton

Preliminary work using the model showed the importance of the average occupancy of a PT network and assumptions on the way the service is adjusted when patronage changes. As a key component of the optimal price is the operating cost per passenger, the average occupancy (passenger-kilometres per vehicle-kilometre) plays a central role. Occupancy in Hamilton was low, reflecting a policy decision to promote public transport by proving good network coverage and frequencies. In particular, frequencies in the peak and off-peak were generally similar. The model demonstrated how the way service level was changed in response to changing patronage impacts on the optimum price as calculated by the model. At one extreme we could address the low occupancy by reducing bus sizes and frequencies to better match supply to demand – in this case the optimum fare was quite high but the subsidy required was minimised. At the other extreme we could cut prices to better match demand to the service provided – this resulted in low fares but had a high subsidy requirement. The end decision would depend on the importance given to the policy outcomes sought and the effect of budgetary and other constraints.

Investing for outcomes

Investment for outcomes relates payments to the policy objectives the funding is intended to achieve. There should be a clear link between the government's rationale for funding, the objectives that the NZTA wants to achieve, and the expected measures that demonstrate achievement of these objectives. From the allocative efficiency perspective taken in the investment model, the primary policy objective is to ensure that subsidies are allocated to areas and transport modes where the marginal national benefit of an additional dollar of subsidy investment is the greatest. The investment model would complement an 'investing for outcomes' approach by providing the NZTA with guidance on where to invest additional dollars in PT, and by how much.

Further model development

We concluded that although the use of regional transport models to provide improved estimates of the elasticities has considerable potential, they were unlikely to provide satisfactory results in their current form. Further work on the calibration of the transport models would be needed before the results could be used with confidence for guiding PT investment nationwide. This relationship between the regional transport models and observed data on service elasticities should be further investigated to assess whether it can be resolved. The alternative is to rely on existing estimates of elasticities and to make informed judgements on the likely range in the variation of elasticities between regional transport networks. This pragmatic approach would result in using the model to estimate a range of optimal subsidy levels for each region that are sensitive to local factors such as occupancy levels and fare recovery. These other factors could be benchmarked across regions and used to help interpret model outputs to draw policy conclusions.

There are several other significant tasks in expanding and calibrating the model:

- assessing the logical subregional network configurations for Auckland and Wellington
- introducing the trade-off between bus and train
- expanding the model to simultaneously optimise both fares and service levels
- taking account of different fares and associated demand elasticities for different customer segments if this information is available in other regions.

Auckland and Wellington both contain unique network corridors that are distinguished by their geography, different mixes of PT modes (rail/bus), and disposable household incomes. Treating these corridors in the model as part of a citywide network analysis would provide only generalised results of limited policy value. Also, in the context of adding rail, the issue of cross-elasticities would become more critical.

More generally, the investment model contains a range of input measures, including patronage, passenger-kilometres travelled, occupancy and operating costs that are relevant to benchmarking both across and within regions, and to taking an 'investing for outcomes' approach. Thus the model itself could be developed and configured in a manner that enables benchmarking of such performance indicators. This would influence configuration of the Excel workbook and presentation of model outputs.

Abstract

This research was the first stage in developing an investment model aimed at assisting regional authorities and the NZ Transport Agency to make public transport investment decisions. The approach assumed that public transport (PT) subsidies should be invested to maximise allocative efficiency – ie in a way that ensures society gains the greatest overall net benefit from PT.

To do this, the investment model applies a second-best pricing method to estimate optimum fare and implied subsidy levels for urban public transport. The model takes into account operating costs and externalities of alternative transport modes (cars and PT), including safety and congestion effects. It also incorporates network spillover effects for existing PT users from changes in frequency. The result is an economic model that incorporates the interactions between prices, service levels and patronage for public transport (bus initially) and private car, and associated performance indicators.

The model was developed initially only for Hamilton and detailed in a separate Excel workbook that is capable of expansion to include rail and other cities. The model shows that the costs of public transport are high in Hamilton, and that plausible alternative policy responses include significantly reducing fares or cutting services, with dramatically different budgetary implications. It shows that the idea of a single optimum solution is overly simplistic.

1 Introduction

1.1 The project

This research report describes the development of a public transport investment model. The research was undertaken between September 2011 and March 2013 by Nick Allison from Logic Partners, in association with David Lupton and Associates and with Ian Wallis Associates.

The purpose of the research was to:

- develop and document a robust theoretical model for estimating optimal public transport (PT) regional subsidies, and to provide information relevant to the NZ Transport Agency's (NZTA's) 'investing for outcomes' approach
- build the theoretical model into a flexible software platform that could be used to incrementally model changes to regional PT services arising from changes to 'prices' (fares and subsidies)
- use the Waikato region to test the model, with a view to possible expansion to other regions.

The intention was to provide a flexible platform that would be capable of being extended, with additional functions, to meet the needs of specific policy requirements in future.

The extension of the model to other regions, incorporating rail (Wellington and Auckland) and possible interfaces with regional network models within regions, and other additional modelling capabilities, would be the subject of future research.

1.2 Structure of the report

The report begins by outlining the economic theory, relevant literature and past experience. The formulation of the investment model, including outputs and various parameters, is documented in chapter 3. Chapter 4 then describes the data sources and comments on the use of regional transport models, and chapter 5 provides guided instructions for using the model and the provisional results from applying the model to Hamilton.

Chapter 6 outlines how the investment model might inform the NZTA about the outcomes it seeks to achieve with its funding, and chapter 7 discusses the issues for further model development.

A glossary of terms is provided at the end of the report.

2 Theory and past experience

2.1 Efficiency rationales for subsidies

The economic argument for public transport (PT) subsidies is based on the concept of allocative efficiency. Allocative efficiency occurs where resources are allocated in a way that ensures society gains the greatest overall net benefit from them, or they are valued the most highly. The policy rationales for subsidising PT principally concern identification of reasons for departures from full cost recovery (which would imply average cost pricing) in order to achieve allocative efficiency. This provides a justification for PT subsidies that is independent of the 'social' or 'equity' arguments often put forward.

Allocative efficiency is maximised when the price charged for a good is equal to the marginal social cost of its production and consumption. The use of the term 'social' relates to all costs and benefits to society of transport modes and should not be confused with social equity, which is about the *distribution* of costs and benefits. The social marginal cost may diverge from the average cost of production for a number of reasons (see Gwilliam 1987), the most common being:

- producer economies of scale
- user economies of scale
- externalities
- second-best considerations
- option values.

We discuss these rationales below and identify which ones were incorporated into the investment model.

2.1.1 Producer economies of scale

Producer economies of scale occur where the cost of carrying additional passengers is less than the average cost per passenger. This is usually attributable to the existence of fixed costs (ie costs that are largely independent of the number of passengers). These can represent a significant proportion of the total costs, especially for urban rail systems. Allocative efficiency is maximised if the price is set equal to the marginal cost, but if this is done when there are economies of scale, PT operators will incur a loss.

An argument against using subsidies in a decreasing-cost scenario is that operators can price discriminate – setting variable prices or two-part tariffs. However, the scope for discriminatory pricing is limited where services are subject to competition. An example is when rail is competing directly with buses. If the marginal cost for rail is lower than the marginal cost by bus, but the average cost by rail is higher, an integrated transport solution would favour rail in order to minimise the total transport cost. However, requiring rail and bus to achieve the same cost recovery would require rail fares to be higher than bus fares, leading to a loss of patronage to bus. But this would further increase the rail average cost and the ultimate outcome would likely be closure of the rail service.

2.1.2 User economies of scale

A related rationale is that passengers take account of the value of the trip to themselves, but not the value of their trip to others on PT networks. Greater use of a PT network can convey benefits to others through, for example, enabling the frequency of services to increase, and accordingly the service waiting times of existing passengers to reduce. This is a positive externality or network spillover effect, and the associated user economies of scale are often referred to as the Mohring effect.

2.1.3 Externalities

The third rationale is the presence of externalities. These are costs borne by people other than the person who makes the decision to travel by a certain mode. For example, automobile use increases air pollution, congestion and noise, and may have road safety impacts. This imposes costs on other vehicle users as well as people who are not transport users. Allocative efficiency would be maximised by charging transport users for the externalities they generate. These can be significant in the case of automobile use at peak times.

2.1.4 Second-best considerations

In a 'first-best' world, efficient (first-best) pricing across the urban transport sector would involve users of all travel modes paying the marginal social costs (including externalities) associated with their travel.

The second-best pricing argument is that if prices cannot be set to equal marginal cost for whatever reason (practical or political), allocative efficiency is maximised if the *relative* prices reflect the *relative* marginal costs.[1] This leads to the 'theory of the second best', which plays a central role in the development of the investment model. As long as road use is not priced according to its full social marginal cost, there is an argument for subsidising its substitute – public transport – so that the relative prices reflect the relative marginal costs. A subsidy for PT thus enables a correction in the relative prices of the different transport modes, in order to maximise allocative efficiency.

Government funding of PT is promoted as a second-best solution to the social costs of peak-period travel in urban conurbations. In New Zealand cities – as in most cities world-wide – the charges incurred by road (car) users are average costs based on an allocation of national infrastructure costs between users. They are typically less than the social costs that the travel imposes on society in congested traffic conditions. Hence a case can be made on economic efficiency grounds for PT users to also be charged less than the full economic costs of their travel at these times. This would redress the imbalance in demand that results from suboptimal pricing for road use, and in so doing would reduce the social costs from congestion and/or the provision of road infrastructure. This is the basis for second-best pricing policies, and is a key assumption in setting the economically optimum subsidies and prices for PT travel.

2.1.5 Option values

People may value the option of having a PT network available should they need it (eg if the car breaks down or in the event of a major disaster), even though they may not be PT users today. It is recognised that such 'option values' incorporate economic benefits that are additional to the direct user benefits assessed in conventional social cost–benefit appraisals. A recent NZTA research report titled *The benefits of public transport – option values and non-use values* (Wallis and Wignall 2012) distinguishes between:

- option value (OV), which represents the willingness to pay for the option of having a service available for possible use at some time in the future if required, even though the option may never be taken up
- non-use value (NUV), which represents the willingness to pay for the continued existence of a good or service that the individual does not directly consume themselves, and never intends to consume.

[1] This is a slight oversimplification. The full formulation is given in chapter 3.

Wallis and Wignall concluded that in the field of public transport, OVs and NUVs were likely to be most significant in situations where substantial changes to the available transport services were being contemplated. This would particularly apply to situations where services may be threatened by closure, or where a new service might be introduced where none currently exists. The investment model, however, was designed to assess incremental changes to existing services and was not intended to evaluate complete service withdrawal.[2]

We therefore concluded that option values were not relevant to this analysis.

2.2 Social equity rationales

The investment model shows the distribution of the benefits (eg a reduction of externalities for car users or increased frequency benefits for PT users) from a change in fares or charges, and in particular the redistribution of benefits and costs across users of different modes and PT customer segments.

A widely used argument for subsidising PT is the redistribution of income to certain less privileged groups. This transfers real income in the form of cheaper PT services, rather than through lower taxes or benefit payments. Those groups in society that depend on PT would benefit from this subsidy. Among these groups are children, the poor, the disabled and the elderly.

The counter-argument is that subsidies have limited effect in achieving equity objectives. Success depends on the extent to which these groups use PT, and the degree to which subsidies accurately target the intended recipients. There are likely to be substantial deadweight losses in using PT subsidies for income redistribution purposes, although very targeted subsidies, such as for transport for the disabled, may be an efficient way of addressing a very specific social equity issue.

2.2.1 Concession fares

Concession fares is an area where social equity and efficiency rationales often become muddled. It is not uncommon for commercial services, including cinemas, airlines and coach companies, to price discriminate, offering elderly, student or family discounts in order to maximise their revenues. The objective of these discounts is to attract patrons who could not otherwise afford the service, without diluting the ordinary revenue of the service.

Our preliminary model was constructed using average fares and elasticity values, although it did identify education trips separately. In case of Hamilton, there was insufficient information to enable fares to be calculated for different beneficiary groups. In principle, the model could be developed to take account of different fares and associated demand elasticities for different customer segments if this information is available in other regions.

2.2.2 Taking account of accessibility in the investment model

A social rights-based argument concerns ensuring access opportunities for citizens, including access to public facilities such as hospitals and schools. Accessibility is another policy area where social equity and efficiency rationales often become mixed.

Accessibility is a function of frequency, route choice and density, and affordability. From an economic point of view, the existence and the nature of user economies of scale (see section 2.1.2) means that a

[2] The model could be used to test setting fares at a commercial level, which may be an option in the large cities. However the elasticities on which the model was based measured the effect of small changes in fares. Using the model to investigate large changes in fares would be unlikely to give reliable results.

commercial operation would under-provide accessibility from a societal point of view. This scale effect has been addressed explicitly in the model. However, some other aspects of accessibility were not addressed; eg:

- Affordability is a relative concept that depends on income, income redistribution policies, and individual consumption choices and patterns. It was not included in the investment model, but it is argued below that perhaps the biggest single lever that the NZTA has for improving affordability is to focus on efficiency and reducing service operating costs per km.
- Some aspects of route choice and density are often achieved though regulation, procurement rules or local transport policies, rather than through a subsidy instrument. Such policies may have added costs, which are then met by an increased level of subsidy or higher fares to fund uneconomic services, and this may have distortionary impacts. For example, requiring bus routes to be within a particular distance from all households in the area may slow down trips times to the extent that many passengers switch to more convenient transport modes.

Indeed, a recent empirical study of regional transport subsidisation in Sweden (Holmgren 2010), which used a second-best modelling approach, found fares above the efficient optimal level were probably caused by Swedish decision makers emphasising service levels more than low fares. Swedish authorities appeared to have strived to sustain at least minimum service levels in low-demand areas, in combination with an unwillingness to differentiate between peak and off-peak fares. Holmgren concluded that more efficient pricing and lower service levels could increase trips in aggregate across regions by 2.3%.

In our model, accessibility rules and policies are external parameters that influence model inputs such as the operating cost per passenger-kilometre, the access time and the waiting time. Route density and frequency can be varied at a very broad level. If all New Zealand regions are included in the model in the future, it may be possible to deduce the impacts of minimum service level policies, assuming significant variance in these between regions.

2.3 Previous research and applications

2.3.1 Previous work

Internationally, the development and application of first-best and second-best pricing models to estimate the optimum fare and subsidy levels for urban PT goes back some 30 years. The following provides a brief overview of key PT pricing studies that have been undertaken worldwide, with an emphasis on the Australian and New Zealand studies. A number of relevant pricing and funding studies are summarised in table 2.1.

Several important conclusions emerged from these studies and the wider literature:

- The total value of externalities associated with car use, or the total value of the externalities avoided by use of PT, are not pertinent to establishing the level of subsidy and fares for PT.
- A sound technical approach (second-best pricing and the divergence between average and marginal cost for PT use) is available to determine the optimum subsidy and fares for PT, given suboptimal pricing for road use.
- All the studies that followed a mathematical approach to the issue applied variations of the approach first adopted by Glaister and Lewis (1978).

The later work by Glaister (1987) and by Parry and Small (2009) appeared to have significant relevance to the New Zealand transport context, where patronage levels can be low. Although similar in approach to the seminal work by Glaister and Lewis, the later studies addressed all the social cost impacts of transport use, and in so doing identified the importance of first-best as well as second-best pricing considerations. In particular, they included the Mohring effect, which is the main economic justification for PT subsidy where patronage is low.

The Mohring effect is 'within mode' and applies even if PT customers are all assumed to be 'captive'. In contrast, traffic congestion is a 'cross-mode' impact, relying on the ability of PT to attract 'choice' passengers from the private car. The Mohring effect is likely to be of greater relevance than the decongestion effect in New Zealand applications – particularly in the case of Waikato, where the proportion of 'choice' PT passengers is much lower than in (for example) London.

2.3.2 Implications for model development

We concluded from the literature that there are both first-best and second-best warrants for pricing PT at other than the average cost of production, and that calculating the socially optimum price is feasible and provides a sound technical basis for addressing the intent of the study.

The model developed incorporated an optimisation similar to that formulated by Glaister and Lewis, but also drew on the approach developed later by Glaister and by Parry and Small. The Parry-Small paper derived essentially the same model as Glaister and Lewis by a slightly different route and provided insights into the structure and mathematics of the model.

Whereas the original Glaister and Lewis paper focused on traffic congestion as the primary social impact – thus, for example they did not include any social impacts for PT in the off-peak – Parry and Small placed a much greater emphasis on the components of the social impacts. In our model we addressed this by incorporating positive externalities, including the Mohring effect.

There was another significant difference between the approach of Parry and Small and that of Glaister and Lewis – whereas Glaister and Lewis solved their equations simultaneously to calculate the optimum, Parry and Small adopted an incremental-change approach that allowed them to draw conclusions about the importance of the individual components of the equations. We believe that this is an important and attractive feature of their approach, which we applied in the development of this model.

Table 2.1 Relevant international and New Zealand PT pricing subsidy and funding studies

Reference	Application	Comments
Economic incentives to increase PT subsidy – the theory and the practice (Wallis & Gale 2001) Paper to Thredbo 7 Conference, Molde, Norway, June 2001.	• Externality benefits of switching transport mode to PT (decongestion, parking, safety, environmental benefits). • Derivation of (marginal) funding rates reflecting these benefits.	• Most useful document summarising the patronage funding project work.
Passenger transport evaluation and funding procedures (stage 2) (BAH NZ 2000) Draft final report to Transfund NZ.	• Detailed report (summarised in the Thredbo 7 paper above).	• Contains more detail on the methodology than the Thredo 7 paper.
Economic evaluation manual, vol 2 (EEM2) (NZTA 2010).	• Table 1 provides estimates of economic benefits associated with improvements in PT services, expressed per additional passenger boarding. Rates cover benefits to both PT users and to road users. • Separate rates given for peak/off-peak and by region.	• For use as simplified procedures only (where detailed assessments are not available).
Surface transport costs and charges study: (i) *Main report* (2005) (ii) Working paper – Costing urban PT operations (draft 6, 2004) BAH for MoT.	• Table 3.4 in main report provides full set of marginal social cost (MSC) estimates for urban PT (car/bus/train, Auckland/Wellington). • Urban passenger transport working paper provides derivation of marginal PT operating and capital costs and of user economies-of-scale effects.	• Provides the most recent New Zealand set of urban transport MSC values – should be a key input to pricing analyses.
*The subsidisation of urban transport services: (i) Stage 1 report, vols 1 & 2 (*1987) (ii) *Stage 2 report* (1988) Travers Morgan for Urban Transport Council. *Research on urban transport subsidies in New Zealand* (Bell and Starrs 1988) Paper for Australasian Transport Research Forum, Christchurch, July 1988. *The calculation and delivery of urban transport subsidies in New Zealand* (Baxter & Starrs 1989) Paper for Australasian Transport Research Forum 1989.	• Project estimated warranted UPT subsidies for (i) producer economies of scale, (ii) user economies of scale, (iii) road congestion (second-best pricing), (iv) mobility of the transport disadvantaged (concession fares). • The second-best pricing assessment applied a development of the Glaister-Lewis model (developments relating to inclusion of PT frequency benefits and bus congestion effects). This was applied to estimate optimum peak and off-peak fare level and subsidy for Auckland, Wellington, Christchurch, Dunedin, Invercargill.	• Centrepiece of project was estimation of optimum PT fares and subsidy levels, reflecting second-best pricing of roads, and using an enhanced version of the Glaister-Lewis model. • Also addressed the allocation of funding responsibility between central and regional/local governments.
An integrated fares policy for transport in London (Glaister and Lewis 1978) *Journal of Public Economics 9*: 341–355.	• Establishment of the optimum fares and hence patronage and subsidy levels for PT in London. • Involves second-best pricing approach. • Contains separate analyses for peak and off-peak periods.	• The original development and application of the Glaister-Lewis second-best pricing model.

Reference	Application	Comments
Putting our money to good use: can we attract more passengers without increasing subidies? (Holmgren 2010) *Research in Transportation Economics Journal.*	• Example of the application of second-best pricing techniques for the estimation of optimal pricing and service levels.	• Relevant to New Zealand investment model development, as cross-regional comparisons are made.
Allocation of urban public transport subsidy (Glaister 1987) Pp27–39 in *Transport subsidy – Policy Journals.*	• Updates the original model that explicitly takes account of Mohring effect, etc. • Traces the effect of changes in PT fares and service levels on the transport systems in each of the UK's main urban areas.	• Could be considered to pre-date Parry and Small, although still essentially a simultaneous equation model.
Value of city rail externalities and optimal government subsidy (CRAI 2008) Report for the Independent Pricing and Regulatory Tribunal. *An empirical estimate of CityRail's marginal costs and externalities* (Smart 2008) Report for the Independent Pricing and Regulatory Tribunal.	• Established the optimum fares and hence patronage and subsidy levels for CityRail New South Wales services. • Applies mathematical optimisation methods similar to those used in the Glaister-Lewis model. • Does not analyse peak and off-peak separately (all input functions appear to be all-day averages).	• Use of daily average figures is a substantial weakness.
Value of Sydney bus externalities and optimal government subsidy (Smart 2009) Draft report for the Independent Pricing and Regulatory Tribunal.	• Same approach as for CRAI/LECG CityRail reports (above). • Again, analyses undertaken only for all-weekday average parameters.	• Use of daily average figures is a substantial weakness.
Public transport subsidies in Adelaide (Amos & Starrs 1984) Paper for the Independent Pricing & Regulatory Tribunal, Adelaide.	• Application of enhanced Glaister-Lewis model to estimate optimal prices and PT subsidy levels in Adelaide. • Assessment covers producer economies of scale, decongestion (second-best pricing) and social/transport-disadvantaged aspects.	
Subsidies and the social costs and benefits of public transport (CIE 2001) Report for the Independent Pricing & Regulatory Tribunal.	• An exploratory study into pricing principles and the role of subsidies in the context of urban PT services. • Discusses all the components needed for a second-best pricing optimisation, but does not include the optimisation methodology.	• Useful discussion of second-best v first-best issues, but otherwise primarily a background document.
Should urban transit subsidies be reduced? (Parry & Small 2009) *American Economic Review 99*: 3.	• Develops mathematical formulation to assess the economic welfare effects of fare adjustments and optimal fares for peak and off-peak urban rail and bus services. Formulation covers congestion, pollution, accidents, scale economies and producer/user economies. • Applies methodology to estimate optimal UPT price and subsidy levels for Washington DC, Los Angeles and London.	• Develops a model for assessing impacts of fare adjustments, different from the Glaister-Lewis model. • Appears to be an excellent contribution, includes extensive sensitivity testing on key inputs.

Reference	Application	Comments
Valuing the benefits the community derives from CityRail services (Hensher et al 1994) Report to CityRail.	• Examines relationships between rail fare levels and net welfare benefits associated with CityRail's services: evaluated 3 fare scenarios and rail system closure cases. • Covers peak services only, two modes only (rail, car) and assumes fixed travel demand in each corridor.	• Not an optimising model, hence not directly relevant to the issue of optimisation of fares and subsidy.
Value of CityRail to the NSW community (Karpouzis et al 2007) Market Development and Research economic information paper.	• Comparison of net welfare benefits associated with the NSW CityRail system, relative to the 'no rail' scenario. • Takes account of the inter-relationships between rail and bus services.	• Relevance of this approach is arguable – may be of some relevance to investment decisions.

3 Model formulation

3.1 Model formulation and key parameters

As noted in chapter 2, the economic rationale for PT subsidies is based on achieving allocative efficiency – ie using resources in a way that maximises the net social benefit. Allocative efficiency can be shown to be maximised when relative prices reflect the relative social marginal cost. The social marginal cost of PT use includes:

- the (marginal) operating cost for providing the service
- externalities from PT use (congestion, pollution, noise, safety)
- user benefits from improved access and frequency.

In a simple world, the allocative efficiency rule for pricing transport services is thus:

$$P = MC \qquad \text{(Equation 3.1)}$$

where *P* is the price and *MC* is the social marginal cost – ie it includes all the costs enumerated above. Pricing PT on this basis would require subsidy because the social marginal cost is less than the average cost, due primarily to producer economies of scale for rail and user economies of scale for bus travel.

However, it is not a simple world. Allocative efficiency will still not be achieved if the main competing form of transport is not charging its social marginal cost. Since this is the case, the optimum PT fare must also take into account the price and social marginal cost of car travel.

If bus and car were not competing modes, their relative cost would not affect their use and we could ignore cars when setting bus fares. The degree to which they compete (ie can be substitutes) is measured by the cross-elasticity. The larger the cross-elasticity, the bigger the effect of bus fares on car use and thus on allocative efficiency. Thus in setting bus fares we need to know:

- price (charges) for car travel
- social marginal costs (including externalities)
- the cross-price elasticity of demand between modes.

The simple efficiency rule needs to be modified by adding terms that equal the difference between the price and the social marginal cost for substitute modes, multiplied by a term that measures the degree of substitutability between the modes (ie that measures the cross-elasticities).

The mathematical formula for determining the optimum price of one good (i) given the price of the alternative goods (j) is:

$$P_i = MC_i - \sum_{i \neq j} \left[\left(\frac{E_{ij}}{E_i} \right) * \left(\frac{Q_j}{Q_i} \right) * \left(P_j - MC_j \right) \right]$$

(Equation 3.2)

where:

Pi, MCi and *Qi* are price, marginal cost and quantity of good *i* (say bus PT)

Pj, MCj and *Qj* are price, marginal cost and quantity of good *j* (say car transport)

Eij is the cross-price elasticity of demand for good *j* with respect to the price of good *i*

Ei is the 'own' price elasticity of demand for good *i*

MCj is the social marginal cost – ie it includes external costs.

Two modes (car and bus) and two time periods (peak and inter-peak) were considered in the model we developed – ie peak car, inter-peak car, peak bus and inter-peak bus.

This mathematical relationship underlies both the Glaister-Lewis and the Parry-Small approaches to objectively reviewing PT fares. It was originally proposed that this study would concentrate on the Parry-Small approach. However in developing the model it became apparent that both approaches use the same basic data and simply represent different ways of displaying the results. Hence the model developed includes both outputs.

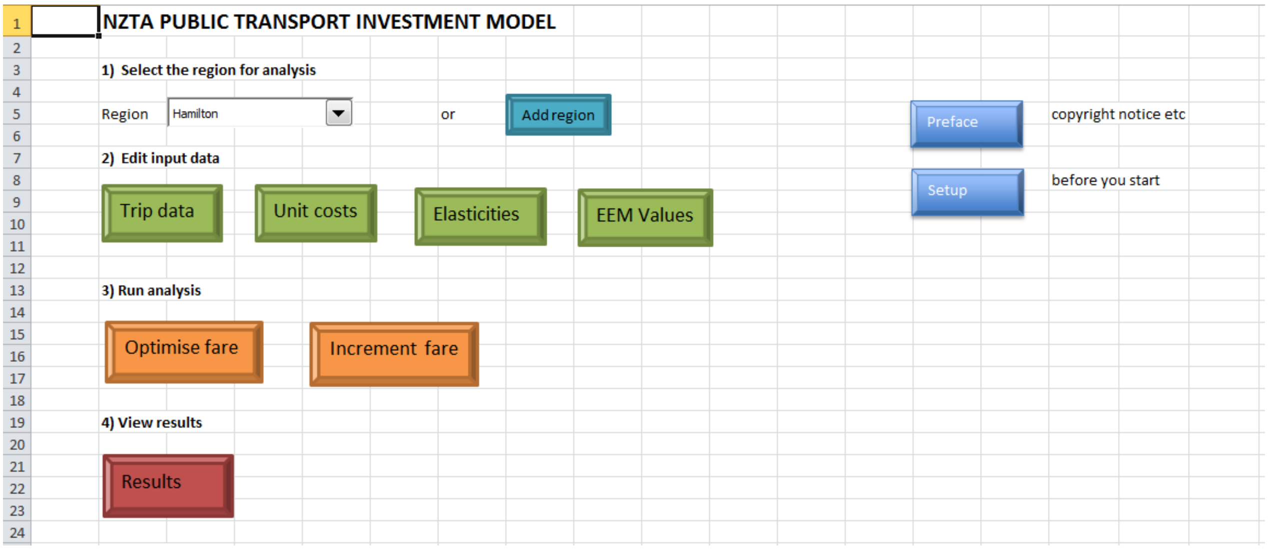
3.2 Model structure

The model is presented in the form of a Microsoft Excel workbook. It comprises a number of worksheets to process the input data depending on user-specified parameters, and three main output worksheets.

The main input and analysis sheets are described in this chapter. The data requirements are described in more detail in the next chapter.

A home sheet (figure 3.1) allows the user to select the region (only Hamilton is currently active) and navigate around the workbook. In particular, the user can review or edit the input sheets, activate the analysis sheets, or print out the main assumptions and results from a particular analysis.

Figure 3.1 Home sheet



The home sheet also provides access to a preface/copyright statement and a set-up guide for those whose computers are not set up to run Excel macros or the 'solver' add-in.

3.3 Inputs

This section describes the input requirements of the model. The description relates primarily to Hamilton data. The model is designed to allow it to be generalised and applied in other centres. However extension of the model depends on region-specific analysis and on the feasiblity of gathering regional data.

There are three main input sheets:

- trip data (envisaged as a region-specific sheet)
- unit costs (envisaged as a region-specific sheet, but with national default values for some parameters such as car operating costs)
- elasticities (designed as a single sheet with data for all regions, from which the relevant region is selected).

3.3.1 Trip data

This is an input sheet, with the main operating data for the transport network. It is region specific, but could be standardised to facilitate referencing of data by other sheets, should further regions be included.

There are two main sources: Environment Waikato for bus operating and financial statistics, and Waikato Regional Transport Model (WRTM) for daily travel data, by time period and travel purpose.

The bus operating data is used to derive the average occupancy for buses used in the unit cost sheet and the base data for fare recovery and subsidy statistics used in the Glaister-Lewis sheet.

The WRTM data is primarily used to calculate the fare elasticity. It is also used to split the EW (Environment Waikato, now known as Waikato Regional Council) data between peak and inter-peak and to provide trip length data by market segment.

3.3.2 Unit costs

This sheet estimates the operating cost, social costs and social benefits for each mode and time period. Again it is region specific, but could be standardised to facilitate referencing of data by other sheets. The unit costs are primarily based on the *Surface transport costs and charges study* (STCCS) (Booz Allen Hamilton 2005) but are updated or modified where Hamilton-specific information is available. The workings for making these estimates can be placed in a 'scratch' area to the right of the main data. The scratch section is free format and will vary between regions. The base STCCS data is included on a separate sheet and can be used as default values.

The upper part of the sheet provides unit costs per vehicle-kilometre and it is these that will generally be modified. The lower figures are per passenger-kilometre and are calculated based on vehicle occupancy.

We used the current occupancy levels for the Hamilton data. The level of occupancy can be varied incrementally by the assumptions adopted when running the model.

3.3.3 Elasticities

This sheet derives the 'own' and 'cross' elasticities for each region. The Hamilton values are based on the mode-share data from the WRTM, using the formula set out in section 4.2. Users would not normally need to change this sheet, but the parameters can be changed to ensure that the resulting elasticities are consistent with known data from other studies. In the case of Hamilton, the elasticities were calibrated to be in a range consistent with known New Zealand studies.

3.4 Analysis

The model is structured in two formats to produce two types of analysis. The model can be used to:

- identify the optimum fare for each market segment and time period – we refer to this as the Glaister-Lewis analysis

- show the effect of a one cent change in fare on subsidies, bus users, car users and the environment – we refer to this as the Parry-Small analysis.

3.4.1 Glaister-Lewis analysis

The model can identify the optimum fare for each market segment and time period. The market segments we considered were i) frequent travellers (peak and off-peak); ii) education (peak); and iii) infrequent (peak and off-peak). We extended the scope of the original Glaister-Lewis analysis somewhat so that:

- the model can be run with different parameters (ie different policy responses) to understand the effect of different policy assumptions
- it is possible to incorporate financial and other constraints
- it would be possible to change the objective – eg to maximise operating efficiency or passenger-kilometres.

The optimisation sheet, referred to as the 'Glaister-Lewis' in the Excel workbook, undertakes the basic Glaister-Lewis analysis. The mathematical formulation shown as equation 3.2 above is solved for all prices simultaneously, using the Excel 'solver' function. The solver function has been included in a visual basic subroutine that is called by clicking on the button. Note that the cell addresses for solver are not automatically updated if the locations referred to are changed. Hence any re-formatting of the sheet that changes the location or address of cells used for solver may mean that it will no longer work. Users may need to install the relevant Excel functions and add-ins.

Unlike the original Glaister-Lewis analysis, which only considered the congestion externality, this analysis has been designed to enable the inclusion of other externalities such as the Mohring effect and environmental and safety impacts. These effects can be included/excluded as desired to show their impact on the optimum price. The settings are changed using the drop-down boxes.

To run the Glasiter-Lewis model, users move through the following steps:

1 (a) The amount of any change in patronage that will be absorbed by a change in occupancy is defined, as shown in figure 3.2.

Figure 3.2 User assumptions on patronage change absorbed by occupancy

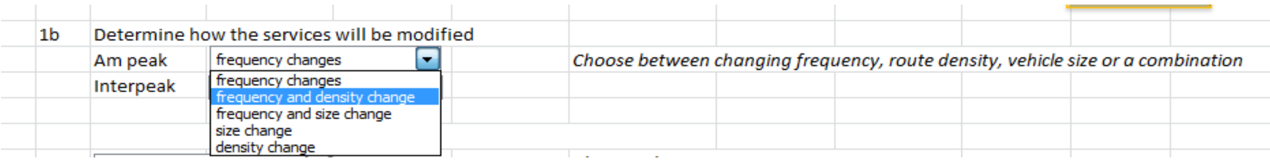
1a	Determine the amount of the patronage change absorbed by a change in occupancy		
	Am peak	40%	*Zero means any new passengers will require extra services*
	Interpeak	60%	*100% means the number of services will not change*

(b) The means by which the remainder of the change will be catered for is defined, as shown in figure 3.3. This can be

- frequency changes
- route density changes
- bus size changes
- a combination of these.

The impacts box allows the user to define which impacts to include in the optimisation.

Figure 3.3 User assumptions on frequency and size

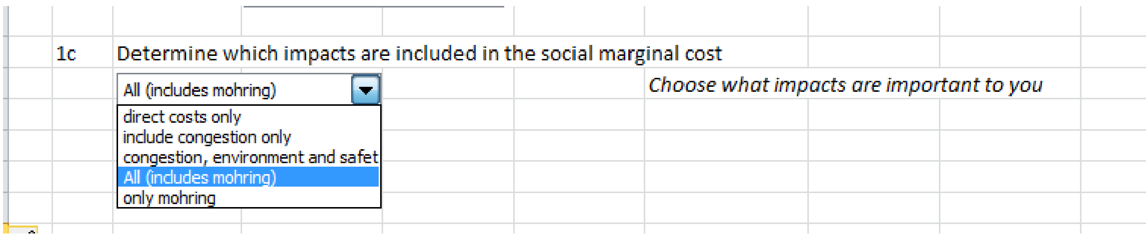


(c) The user can choose the impacts to include, as shown in figure 3.4. This can be

- congestion only
- congestion plus environment and safety
- all, including the Mohring effect
- only the Mohring effect.

While all impacts are equally valid from an economic perspective, this box enables the effect of pursuing particular policy objectives to be explored. Including direct costs only approaches a 'commercial' regime.

Figure 3.4 User selection of externalties for inclusion in social marginal cost



2 It is possible that the prescribed fares resulting from the optimisation could result in an unsustainable subsidy level, or one that is inconsistent with other policy objectives of the NZTA or the regional council. This can be addressed by specifying a number of constraints on the spreadsheet. Constraints can be set in the constraints fields, as shown in figure 3.5.

Figure 3.5 User instructions for setting contraints fields and running optimisation

Constraints		annual (million)	
Subsidy	<=	13	million
max child fare	<=	1	adult
off peak fare	>=	0	peak
fare recovery	>=	0%	

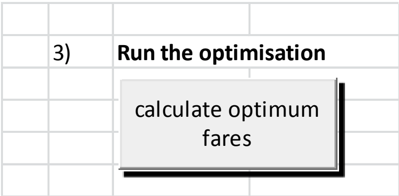
The user can specify:

- the maximum annual subsidy
- the maximum child fare as a proportion of the adult (a value of 0.5 would require the child fare to be 50% of the adult fare)
- the inter-peak fare as a proportion of the peak (a value of 1 wouldensure no discount for inter-peak travel)
- the fare recovery ratio.

Other constraints could be added by augmenting the macro code if required by users.

3 The optimisation is undertaken by clicking the ‘calculate optimum fares’ button, which invokes the Excel add-in *solver* (figure 3.6). (If solver fails to run, refer to the set-up instructions on the home sheet.)

Figure 3.6 View results



4 The results panel shows the main results, as shown in figure 3.7. This shows the current fare, the optimised fare and the percentage change. It also shows key performance measures and indicates whether any of the constraints are active. The user can also choose to go to the report sheet, where the assumptions and the result are displayed and can be printed out.

Figure 3.7 Results view

4)	View results			
		current fare	revised fare	change
home based work trips			(cents/km)	
	peak car	17.0	17.0	0%
	off peak car	17.0	17.0	0%
	peak bus	25.7	51.2	100%
	off-peak bus	27.4	14.9	-46%
education				
	peak car	17.0	17.0	0%
	peak bus	33.9	49.4	46%
other				
	peak car	17.0	17.0	0%
	off peak car	17.0	17.0	0%
	peak bus	45.1	55.6	23%
	off peak bus	39.5	21.6	-45%

	current	revised	
pt revenue	5.20	5.1	
gross cost	17.31	17.1	
subsidy	12.12	12.0	Active constraint
fare recovery	30%	30%	
bus-km	4.63	4.87	
pax-km	29.50	32.00	
occupancy	6.37	6.58	
Congestion	225.01	225.0	
PT share	1.17%	0.99%	

3.4.2 Parry-Small analysis

The incremental (Parry-Small) analysis shows the effect of a one cent reduction in the price per kilometre of each mode and shows its impact on the government, bus users, car users and the environment.

As before, the user specifies the policy response to the change in patronage – by increasing occupancy, service frequency, service density or vehicle size.

The Parry-Small analysis estimates the marginal benefit *MBi* as the benefit from a one unit change in the price of mode *i* as follows:

$$MB_i = \Sigma E_{ij} Q_i * (P_j - MC_j) \quad \text{(Equation 3.3)}$$

If the price is optimal, a unit change in price would have zero benefit. Putting *MBi = 0* in the Parry-Small equation results in equation 3.2 presented above – ie the Parry-Small formulation is, in effect, simply a rearrangement of the optimising formula.

Equation 3.3 gives the change in social benefit from a unit change in the price of mode i. This expression is evaluated for each market segment, mode and time period in tabular form, showing the contribution of each component rather than just giving the ‘answer’ as in the case of the Glaister-Lewis analysis.

There is no 1(c) step specifying the impacts to include (as in the Glasiter-Lewis worksheet), as all of the components of the impact are shown. The components identified are:

- car: the direct benefit (benefit to new users minus infrastructure and vehicle operating costs and externalities (congestion, pollution and safety impacts caused by cars)
- bus: direct benefit, access (ie the Mohring effect) and other externalities (congestion, pollution and safety impacts caused by buses).

A more detailed disaggregation is possible if required.

The output of this analysis is illustrated by an extract from the spreadsheet in figure 3.8 on the next page.

The first-order effect of the change in fare is a transfer between the government or regional government agency and users. Because this is a transfer, it is not included in the calculation of the economic benefits. The second-order effects result from a change in travel patterns consequent upon the fare change.

Each row of the spreadsheet shows the incremental economic benefit (in cents per peak or off-peak period) of a one cent decrease in the fare or charge. The benefit or disbenefit is the sum of a number of components, as follows:

- For car users, the charge paid per kilometre exceeds the production cost by 2.48c/km. Thus each additional car user results in a direct operating benefit of 2.48c.[3] However, additional car users (ie driver plus passenger) create externalities (congestion, environment and safety disbenefits) of 9.1c/km in the morning peak.
- For bus users, the charge per kilometre is more or less than the cost of production, depending on the fare paid and the time of day, and the direct benefit is accordingly positive or negative. In the example shown, which is for 'Home-based work trips' (ie trips between home and work), the cost of provision exceeds the price paid, so there is a direct economic loss of 34.3c/km from gaining passengers.

Additional bus users generate negative externalities similar to those generated by car use, and the relative size of these depends on bus occupancy assumptions. In this case it is 3.8c/km in the peak. For bus users, we have also included an 'access' externality, which reflects the user economy of scale or 'spillover' effect whereby additional users reduce the access cost for existing users. This provides a saving of 8.9c/km.

Thus, for example, when leaving everything else the same, a decrease in the peak car 'fare' (ie the fuel tax) has a positive impact on direct benefits for cars, but results in a large increase in the externality (ie is a disbenefit). It results in a reduced bus subsidy (a positive) and a loss of access benefits for bus users (a negative), but has a positive congestion and safety impact. It also impacts off-peak car users. The impact of peak car costs on the off-peak bus users is assumed to be negligible.

This analysis can be used to understand the distribution of the benefits from a change in fares or charges, which could be a useful guide to funding policy.

[3] This is an economic benefit because the additional users must perceive a benefit at least equal to the price paid, while the resource cost is equal to the cost of production.

3.5 Reporting results

A separate reports sheet summarises the input assumptions and presents the key results. The sheet has been designed to provide the key data on two pages. It can be tailored to the user's requirements.

Sample graphs from the results sheet are shown in chapter 5, which provides further guidance on using the model and summarises some indicative results for Hamilton.

Figure 3.8 Extract from the Parry-Small analysis

2)	**View the effect of a one cent reduction in price**				*(scroll down)*		***ALL VALUES IN CENTS***							
		Period >	Peak					Interpeak					Total	Revenue
		Mode >	car		bus			car		bus			benefit	loss
		Impact type>	resource	externality	resource	access	externality	resource	externality	resource	access	externality	(cents/period)	
Mode/period														
Home based work trips		**cents/trip-km>**	-2.48	9.09	34.27	-8.88	3.80	-2.41	9.62	-8.91	-6.56	2.69		
car	peak		8,001	-29,371	3,558	-922	394	-1,210	4,832	0	0	0	-14,718	914,901
	off peak		-800	2,937	0	0	0	12,099	-48,317	-140	-103	42	-34,283	311,819
bus	peak		-206	755	-4,115	1,067	-456	0	0	-51	-38	15	-3,028	13,539
	off peak		0	0	386	-100	43	-30	121	480	353	-145	1,107	3,213

4 Data requirements for the model

4.1 Input data

The main input data requirements are the:

- costs and charges associated with transport use, which determine the relationship between the cost to society and the cost to the user
- demand elasticities, which indicate the effect of prices on the demand for each mode.

The costs and charges are analysed as follows:

- costs and charges for road infrastructure
- externalities relating to road use
- PT operating costs and fares
- externalities relating to PT use.

Where possible the data used should be derived from, or be consistent with, values presented in the *Economic evaluation manual* (EEM) (NZTA 2010) or the STCCS (BAH NZ 2004) (or both, since some EEM values are derived from the STCCS).

4.1.1 Market segmentation

The input data was, to the extent possible, collected at a disaggregated level, reflecting the market segmentation possible within the model. The data available from the WRTM segments travel by trip purpose. The surveyed trip matrices were derived from household interview survey data for each purpose and time period.

The purposes surveyed for the WRTM are shown in table 4.1 (all information sourced from the WRTM).

Table 4.1 WRTM segments, by trip purpose

Home to work	Work to home
Home to education	Education to home
Home to business	Business to home
Home to shop	Shopping to home
Home to social/recreation	Social/recreation to home
Home to other	Other to home
Non home-based trip	

However, the WRTM mode-split model has only been estimated for six trip purpose/time period combinations, as shown in table 4.2.

Table 4.2 Trip purpose time period combinations

AM peak	Inter-peak
Home to work	Home to work
Home to education	Home to other
Other purposes	Non home-based trip

This information enabled us to separate the market into three segments:

- adult frequent traveller
- adult infrequent traveller
- education traveller.

Thus the model can, in theory, provide guidance on the appropriate fares for multitrip fares, ordinary fares and school fares, both peak and off-peak. The model was developed with this division in mind. However, data limitations meant that not all data was able to be disaggregated to this level of detail.

There was insufficient information to enable fares to be calculated for different beneficiary groups. However a traditional argument has been that while the economic logic for lower fares off-peak has been long recognised, its implementation is normally limited to pensioners and other needy groups for financial reasons (hence off-peak concessions for pensioners).

4.1.2 Costs and charges for road infrastructure

The costs and charges per vehicle for road infrastructure use were adapted from the STCCS. Per-person costs for cars were estimated based on vehicle occupancy in the peak and inter-peak of the WRTM. This gave a peak occupancy of 1.40 and an inter-peak occupancy of 1.33. An average bus occupancy of 6.96 was provided by EW. This did not differentiate peak/off-peak, but it is normal for average loads to be similar in the peak to in the off-peak.

Table 4.3 Estimates of cost and charges of road infrastructure (Source: STCCS/EW)

	Per car (cents/km)		**Per bus (cents/km)**	
	Peak	Off-peak	Peak	Off-peak
Road maintenance	0.10	0.10	5.0	5.0
Fuel duty	3.8	3.3	9.5	8.2

4.1.3 Externalities relating to road use

The main externality relating to road use is congestion in the peak period. This externality was assessed by specifying a run of the WRTM with a reduced number of vehicles, and comparing the travel time cost per kilometre with a standard run.

In order to assess the effect of the different travel market segments, several runs were specified, as follows:

- am peak with 10% fewer home-based work trips
- am peak with 10% fewer home-based education trips
- am peak with 10% fewer ‘other purposes’ trips
- inter-peak with 10% fewer home-based work trips
- inter-peak with 10% fewer other home-based work trips
- inter-peak with 10% fewer ‘all other’ trips.

Unfortunately, due to problems with the WRTM data, the results from these runs were inconsistent. It was thought that the data problems arose because of the relatively small sample size. Similar problems were found in the calibration of the mode-split models. As a consequence, the decision was made to not attempt to differentiate the congestion cost by type of trip. The analysis was undertaken using average values for the externality, differentiating only between peak and inter-peak.

The calculation is summarised in table 4.4.

Table 4.4 Congestion externality calculation (Source: WRTM)

	AM base	Minus 10%	IP Base	Minus 10%
Total trips	223,277	201,763	207,286	187,459
Total time	2,834,540	2,508,218	2,871,840	2,568,070
Distance	2,658,623	2,408,663	2,767,238	2,515,577
Av time	12.7	12.4	13.9	13.7
Av dist.	11.9	11.9	13.3	13.4
Av speed	56.3	57.6	57.8	58.8
		AM peak		Inter-peak
Externality – minutes per km		0.24		0.17
– cents per km		7.58		6.08

Road safety externalities were based on the STCCS. Some road safety costs, such as the risk of vehicle damage and personal injury, are private costs paid for or taken into account by the vehicle driver. Other costs, such as injury to others, are arguably not taken into account by the driver and are thus classified as externalities. In free driving conditions, additional vehicles increase the risk of crashes. However in congested conditions, additional vehicles slow the traffic stream, reducing the severity of crashes, hence the negative value determined by the STCCS. The road safety cost in the peak may vary by market segment due to the congestion effect, but we did not attempt to incorporate any differentials.

Other external costs are noxious gases and greenhouse gases. In theory these may also vary slightly between segments, but the differences are expected to be negligible. These are based on EEM values.

Table 4.5 shows the road externalities included in the model.

Table 4.5 Model road externalities per vehicle km (Source: STCCS/EEM)

	Private car (cents/km)		Bus (cents/km)	
	Peak	Off-peak	Peak	Off-peak
Congestion	7.6	6.1	23	18
Environment	9.0	9.0	38	27
Safety	-3.0	2.3	-12.2	5.9

4.1.4 Public transport (PT) operating costs and fares

The effect of a marginal user on PT operating costs depends on the policy or supply-side response assumed for responding to changes in patronage.

If patronage increases, it may be possible to accommodate the increase by increasing the load factor, and not provide any additional resources. In that case, the only cost is the effect of more boardings on travel time for the bus operator and existing users.

The model has a drop-down menu that allows the user to determine the proportion of the change in PT demand that is accommodated through a change in occupancy – ie without any change to the service provided. The menu offers values between 0 and 100% inclusive, in units of 20%.

If additional capacity is required it can be provided by increasing service frequency or by increasing the number of routes.[4] In the first case, there are benefits to existing passengers through reduced waiting times for boarding the services. In the second case, walking time to access the routes should reduce. Additional capacity can also be provided by increasing vehicle size, in which case there are no benefits to passengers – possibly disbenefits through slower boarding and more stops – but economies of scale for the service provider. The policy response may be different for the peak and for the off-peak.

There are thus a wide range of policy options, which can be refined or extended. The results of the model are quite sensitive to the policy options adopted. For this reason, it is not possible to present definitive ‘results' from this project – rather, the output of the project is the model, which can be used to explore a wide range of policy options.

Bus operating costs in this model use a standard bus operating cost model, which was calibrated to replicate the overall Waikato bus operating costs provided by EW. This is shown in table 4.6.

Table 4.6 Bus operating costs (Source: Ian Wallis Associates)

Vehicle type	Dollars/hour	Cents/km	Dollars bus op.	/Year bus cap.	Overhead
Mini bus	21	31	2600	16,432	15%
Medium bus	23	94	5200	38,480	15%
Large bus	23	114	6240	40,456	15%

Existing bus fares are entered into the model but their primary use is to provide a point of comparison with the optimum fares that are calculated.[5] There is an approximate correspondence between the market segments as defined and the current fare types: the adult multitrip concession (ie the Busit card) would normally be used for home-based work trips, the standard adult fare for infrequent adult users, and the school concession rate for education trips. The fares in the model are those faced by the customer – ie they include GST. The model deals in fares per passenger-kilometre, whereas Hamilton has a flat fare system. The choice of passenger-kilometres as the basis for charging was made with a view to the generalisation of the model to other centres, particularly Auckland and Wellington, where longer distances will be involved.

4.1.5 Externalities relating to PT use

The values of the externalities relating to PT use also depend on the policy assumptions relating to the effect of changes in patronage. Externalities relating to the operation of the vehicle – congestion and environmental impacts in particular – vary depending on the change in bus-kilometres per passenger-kilometre, which in turn depends on the occupancy of the vehicle.

User benefits of scale occur when increasing patronage results in higher service frequency or route density, as follows:

- If increased patronage leads to increased service frequency, the waiting time for all existing passengers is reduced.
- If increased patronage leads to increased route density, the walk time to access the services reduces.
- If the increased patronage is accommodated by increased occupancy, crowding increases (a disbenefit) and journey times lengthen due to longer stop times.

[4] Service frequencies were similar on most routes in Hamilton.

[5] They are used to calculate the elasticity, but the value used nets out in subsequent calculations.

If the service frequency increases in proportion to the number of passengers, the benefit from additional passengers is just equal to the value of the average waiting time. If the rate of change of the service frequency is only 60% of the change in patronage, the benefit will be based on 60% of the waiting time. Similarly if route density increases in proportion to patronage changes, the walking time benefit will be that proportion of the current walk time. Walking and waiting time was valued using the EEM values. The bus frequencies were 4.2 buses/hour peak and 3.7 buses/hour inter-peak, while the average walk time was assumed to be five minutes.

No attempt was made to evaluate the disbenefit from crowding or of being left behind if occupancy increases. These are major issues in some international studies. We understand that these were not significant issues in Hamilton.

A summary of the benefits from user economies of scale are shown in table 4.7, assuming that in each case the entire patronage change is reflected in each benefit estimate. If this is not the case, the value of the benefit reduces in proportion to the patronage changes, which are not reflected.

Table 4.7 User economies of scale (Source: David Lupton and Associates)

User externality	Peak (cents/km)	Off-peak (cents/km)
Crowding	n/a	n/a
Frequency	-11.8	-13.1
Density	-25.9	-27.6

4.1.6 Elasticities

Elasticities are critical for estimating the impact of changes in PT fares on other users and on other modes. The elasticity measures the percentage change in patronage that results from a change in price. The ‘own’ elasticity measures the change in patronage of a mode when its own price is changed. The ‘cross’ elasticity measures the change in patronage when the price of a competing mode is changed.

The analysis was undertaken entirely in terms of optimising fares, and thus fare elasticities were used. The model can be used to draw conclusions about the appropriateness of current service frequencies, but joint optimisation of frequency and fares has not been attempted at this stage.

Previous studies reviewed as part of this research have used published estimates of ‘own’ and ‘cross’ price elasticities as inputs. These price elasticities can be expected to vary between cities depending on the current level of fare recovery, the degree of competitiveness between modes, and other factors affecting mode choice, such as route frequencies. The data on elasticities for New Zealand cities was relatively sparse, particularly for cross-elasticities and data discriminating by peak/off-peak. This is because the normal way elasticities are estimated requires extensive data on trip making before and after any change in fares or other mode costs – however, fare changes are relatively infrequent so the number of observations was small.

For this study we investigated the use of the WRTM mode-choice model to determine the elasticities. The WRTM is a standard ‘four-step’ transport model, with one of the ‘steps’ being to forecast the choice of mode for travel, based on the relative generalised costs (a weighted sum of the travel time, access time and fare). These are the same factors that lie behind the elasticity formulation, which means that it should be possible to calculate the implied elasticities from the coefficients of the mode-choice model. This proved not to be possible in practice, and it was necessary to work back from an estimate of elasticities based on previous New Zealand studies and international experience. We used an overall elasticity for bus fares of -0.23 in the peak and -0.46 in the off-peak.[6] As described in section 4.2, we then used the logit model formulation and the average mode shares indicated by the WRTM model documentation to derive the car own-elasticities and the cross-elasticities.

We had expected to be able to make further refinements to provide elasticities by market segment, as the WRTM mode-split models are calibrated by six journey-purpose/travel-time combinations. Due to data issues, deriving these directly from WRTM was not possible. However, again using the logit model formulation and the observed mode shares by market segment, we were able to calculate market segment-specific elasticities. While it could be argued that the differences between the elasticities are less than the uncertainty of the estimates, this process should ensure that the relativities between the elasticities are appropriate.

The WRTM mode-choice model does not include time-shifting in response to changes in the relative cost of peak and inter-peak travel. Nor is there much evidence in the literature on which to estimate the time-shifting elasticities. We made a judgement that the car–bus and bus–car elasticities between time periods would be zero. For the car–car and bus–bus elasticities between periods, we used the property that the own- and cross-elasticities should add up to the overall elasticity of demand for transport (Epstein and Rubinfeld 2001). In the event, we needed to set the elasticity of overall demand for transport to zero to get credible results from the optimisation (ie we assumed that the only effect of price changes was on modal shares, with no impact on total demand).

The resulting elasticities used are shown in tables 4.8–4.10.

Table 4.8. Elasticities car and bus – home-based work trips (Source: David Lupton and Associates)

Home-based work trips		**Percentage change in number of trips >**			
		Car		**Bus**	
% change in prices		Peak	Off-peak	Peak	Off-peak
Car	Peak	-0.060	0.027	0.130	0.000
	Off-peak	0.006	-0.274	0.000	0.083
Bus	Peak	0.002	0.000	-0.228	0.046
	Off-peak	0.000	0.001	0.023	-0.459

Table 4.9 Elasticities car and bus – education (Source: David Lupton and Associates)

Education		**Percentage change in number of trips >**			
		Car		**Bus**	
% change in prices		Peak	Off-peak	Peak	Off-peak
Car	Peak	-0.04		0.06	
Bus	Peak	0.00		-0.16	

[6] These correspond to a lambda (λ) of 0.001 in the peak and 0.002 in the inter-peak in the binary logit model – see the next section.

Table 4.10 Elasticities car and bus – other trips (Source: David Lupton and Associates)

Other trips		**Percentage change in number of trips >**			
		Car		**Bus**	
% change in prices		Peak	Off-peak	Peak	Off-peak
Car	Peak	-0.127	0.016	0.064	0.000
	Off-peak	0.013	-0.159	0.000	0.198
Bus	Peak	0.001	0.000	-0.309	0.062
	Off-peak	0.000	0.003	0.031	-0.617

4.1.7 Summary of data sources

Table 4.11 lists the main data inputs and sources used in the model.

Table 4.11 Main data sources

Data required	**Source**
Number of people by mode, purpose and time period	WRTM documentation
Bus operating costs/fares	EW/Ian Wallis Associates
Vehicle emission costs	EEM
Congestion externalities	WRTM model run
Road safety impacts	STCCS
Own- and cross-elasticities	Ian Wallis Associates and David Lupton and Associates

4.2 Elasticities and the use of regional transport models

This section expands on the issues raised in section 4.1.6. It contains theoretical material that is not essential for those who are only interested in the practical application of the model.

One of the main economic warrants for subsidy of PT (the only warrant considered in the original Glaister-Lewis paper) is based on the theory of the second best – ie subsidies to PT to compensate for the inability to correctly price private car use. Getting the pricing of PT right therefore requires a good understanding of the interaction between fare and service decisions for PT and the choices made by travellers.

This interaction is encapsulated in the concept of the cross-elasticity, which is the change in patronage of one mode that results from changes in the price and service provided on another. Hence the main studies reported in the academic literature – and indeed, the main practical studies undertaken to date in New Zealand and elsewhere – use estimates of the own- and cross-price elasticities as a basis for their calculations.

There are, however, some problems with the concept of price elasticity. For a start, the fundamental theoretical concept is based on users maximising their utility. Utility is a general concept in which financial impacts play only a part. It is common in transport applications to approximate the utility function by a concept called the *generalised cost*. This is a weighted sum of the travel time, access time, and effort and fare involved in making a trip. Based on conventional estimates of the value people place on travel time and time spent walking or waiting for a bus, the fare turns out to be only a small part of the total generalised cost. What fraction it is will depend on the characteristics of the city and its transit system. Thus, even if you assume that the *generalised cost* elasticity is going to be similar between cities, you would expect the *price* elasticity to vary depending on the current fare recovery ratio, the average service frequency, the density of the route system and other travel attributes.

Estimating the price elasticity also raises some practical issues. Price elasticities are normally estimated from time series data covering periods with one or more fare increases. Time series data commonly exhibit problems of multicolinearity. In particular, fare increases usually keep track with inflation: fuel and other costs will have increased in a similar manner over the study period. There is always a problem of isolating short- from long-term impacts, and between perceived, nominal and real changes in cost.[7] Also, there are frequently problems in simply obtaining the necessary trip-making data. In spite of that, there is now a body of literature on observed own-price elasticities and we can be reasonably confident that the value will fall within a normally observed range. There has been much less research into cross-elasticities and the 'expected' range is much wider.

Comprehensive regional transport models need to address the same question of how users will react to changes in the relative prices and service provision by the transport modes. A typical four-step[8] transportation model will include a mode-choice step that predicts the mode shares between each origin and destination, based on the generalised costs of each mode. Mode-choice models are typically calibrated using cross-sectional data. A comprehensive travel survey is undertaken to estimate the number of trips, by mode, between each origin and destination pair. At the same time the travel times and fares for each mode are estimated for each origin-destination. Thus the dataset consists of hundreds of thousands of observations, each with potentially different observed mode shares and relative travel times and costs. This data is used to estimate the relationship between the relative generalised cost and the mode share. Thus there are far more observations than for a conventional elasticity estimation.

Using the mode-choice model has other advantages: firstly, it ensures consistency between the results of this study and the WRTM and that they reflect the observed probability of travel by car or bus; secondly, it ensures that the values of the own- and cross-elasticities are internally consistent.

The WRTM uses a nested logit model to predict mode shares. Figure 4.1 shows the structure of the model. It is a sequential model with binary choices at each level.

There is a mathematical relationship between the coefficients of the mode-choice models used in comprehensive transport models and the own- and cross-elasticities.

The general form of a binary logit model is

$$\rho_i = \frac{e^{-\lambda u_i}}{e^{-\lambda u_i} + e^{-\lambda u_j}} \qquad \text{(Equation 4.1)}$$

This expresses the probability of selecting mode *i* (ρ_i) based on the generalised cost of mode *i* (u_i) and the generalised cost of mode *j* (u_j).

λ is a constant that determines the sensitivity of the model.

e is a constant (Euler's number, not to be confused with the symbol for elasticity below).

[7] For example, a recent time series estimate of the price elasticity in Hamilton (Kennedy 2012) found that the implied price elasticity was positive – ie increasing.

[8] The four steps are trip generation, distribution, mode choice and assignment.

The elasticities can be easily calculated from the coefficients of the logit model. Using the same notation, the own-elasticity e_i expressing the change in demand resulting from a change in fare is given by:

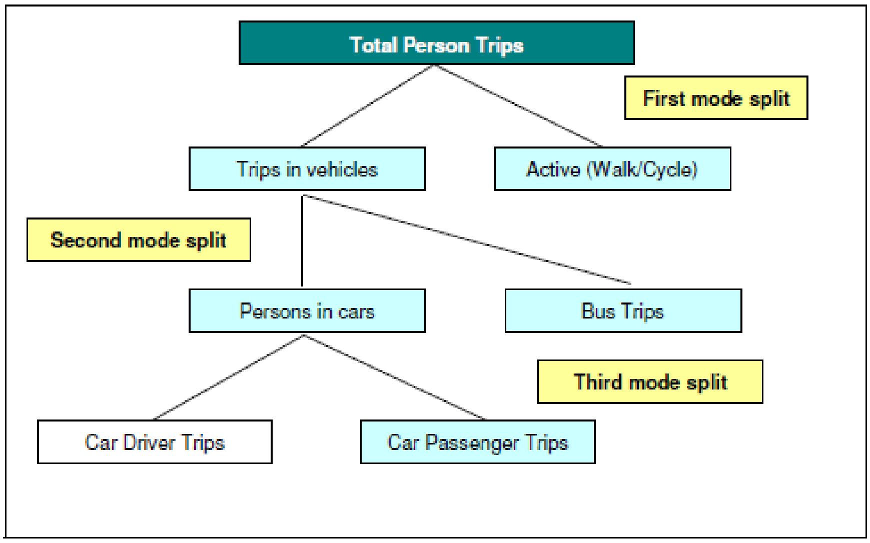
$$e_i = -\lambda(1 - \rho_i) * u_i \quad \text{(Equation 4.2)}$$

The cross-elasticity expressing the change in demand for *i* with a change in the cost of *j* is

$$e_{ij} = \lambda \rho_i u_j \quad \text{(Equation 4.3)}$$

The resulting elasticities should be consistent with international experience.

Figure 4.1 The general form of the logit model in WRTM (Source: WRTM)



Work with the WRTM identified some apparent discrepancies between the coefficients derived from the WRTM data and elasticities determined from conventional studies. Further review of the WRTM data showed that the home interview survey used to provide base data for the mode-split calibration had too few PT trips to provide reliable estimates of the coefficients – thus, although the WRTM predicts the response to changes in PT fares reasonably in aggregate, the individual coefficients were not sufficiently accurate for our purposes.

The problem arose as a result of the method used to estimate the trip matrices. Trip matrices are estimated from household interview data and passenger survey data. It is normal for this to be collected on a sample basis. Thus not all trips are observed: instead standard statistical methods are used to factor up the observed trips to give the correct number of trips in total. While this will give the correct figures in aggregate, it can result in highly inaccurate figures at the origin-destination level. In the case of the Waikato model, there were 700 zones and thus 490,000 origin-destination pairs. The household survey covered 1000 households in the Hamilton urban area of which, based on overall mode shares, less than 100 would have reported PT use. Thus the PT matrix would consist of perhaps several hundred origin-destination pairs with the observed number of trips factored up significantly to give the correct total number of trips, and half a million pairs with zero trips. Hence the calibrated coefficients were unsatisfactory for the purpose of informing elasticities used in the investment model.

As a result of our investigations, the mode-choice parameters in WRTM have been recalibrated to be consistent with expected service elasticities. This does not affect the overall results of WRTM, but will ensure consistency between the approaches. We recommend that this relationship between the regional transport models and observed data on service elasticities be investigated further.

We concluded that although the use of regional transport models to provide improved estimates of the elasticities had considerable potential, they were unlikely to provide satisfactory results in their current form. Further work on the calibration of the transport models would be needed before the results could be used with confidence.

5 Results

The analysis undertaken by using the model showed the importance of the assumptions relating to the way the service is adjusted when patronage changes.

Because a key component of the optimal price is the operating cost per passenger, the average load factor (passenger-kilometres per vehicle-kilometre) plays a central role.[9] How the service level is changed in response to changing patronage has a critical impact on the optimum price as calculated by the model.

The model thus does not provide a single absolute result. Rather the model is a tool that allows many different policies and a multiplicity of options to be tested – the results presented here are simply indicative of the outputs that are possible with the model.

The following sections provide a range of results that were obtained using the model.

Warning: Elasticities relate incremental changes in patronage to incremental changes in prices. Where the implied change in fares is large, the results will indicate the direction and relative size of any adjustment, but care should be taken in interpreting the absolute size of the adjustment indicated. Similarly, the costs used are costs at the margin. Equating fares to the marginal cost does not ensure all costs are covered.

5.1 Indicative results

In the following discussion, the input parameters for the runs are described so that the reader should be able to replicate the results by selecting the same assumptions and constraints. The options selected are shown in square brackets – eg [frequency changes]. Note that while the model gave results for the full range of fare types, only two, the peak multijourney and the inter-peak single-trip fare, have been discussed in each case, to keep the discussion manageable. The multijourney fare was calculated as the 'Home-based work trips' fare and the single-trip fare was calculated as the 'other' fare.

While the analysis was undertaken on the Glaister-Lewis and Parry-Small sheets, the annual results and the graphs can be found on the reports sheet.

5.1.1 Maintain current occupancy

For this option, the occupancy change was put at zero in both the peak and off-peak. (AM peak [0%], inter-peak [0%]) and we set the policy response in the peak and off-peak to adjust the frequency to accommodate the change in patronage [frequency changes]. This may not be considered a realistic policy option given the relatively low current occupancy, but is included in this section to show the implications of the range of policy options.

5.1.1.1 Peak multitrip

The effect of changing fares for regular commuters was calculated in the 'Home-based work trips' section of the Parry-Small analysis (Parry-Small rows 20–23). The *peak bus* line (row 22) shows the effect of reducing the peak multitrip fare by 1c/km.

The first-order effect of a reduction in fares was a loss in revenue for the operator of 13,539c/peak period (cell Y22). This is shown at the right-hand end of the *peak bus* line and also on the report sheet, where it is annualised and shown as $67,693 per year (cell C58). There was a corresponding benefit to existing

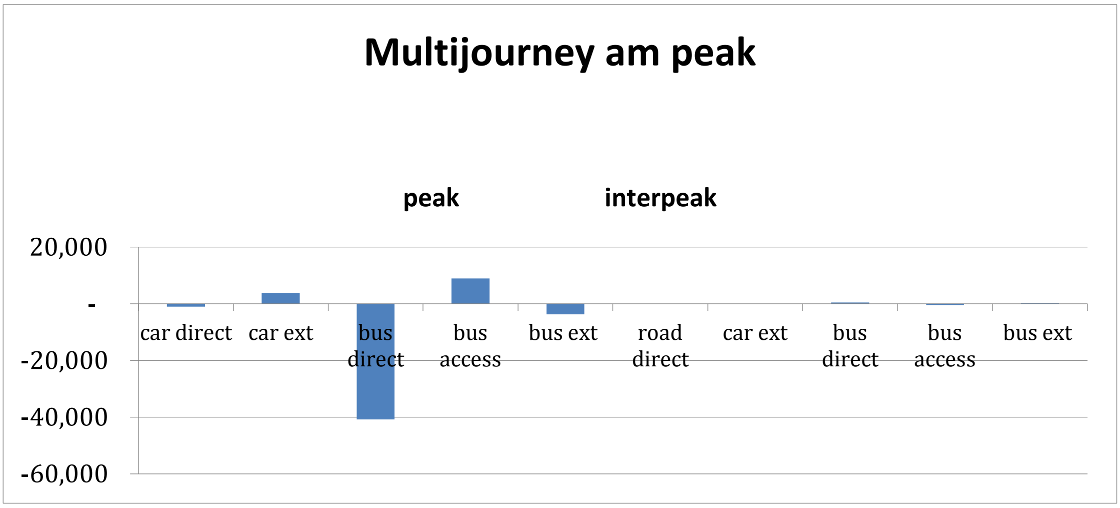
[9] The average load factor in Hamilton was low, reflecting a policy decision to promote PT by providing good network coverage and frequencies. In particular, frequencies in the peak and off-peak were generally similar.

passengers of $67,693 per year: from an economic point of view, this was a transfer payment and the net economic impact was zero.

The *peak bus* line also shows that the fare reduction generated a net benefit of minus 6579c (cell X22), which (as shown on the report sheet) was equivalent to a disbenefit $32,893 per year (cell C59).

We were interested in the distribution of the benefits resulting from the change in patronage, which is shown in figure 5.1. It can be seen that although there were benefits from the reduction in car externalities and improved bus frequency, these were swamped by the negative bus operating benefits, which measured the benefit to the new passengers less the increase in costs to carry them. Thus the Parry-Small analysis indicated that a decrease in the peak fare would *decrease* net benefits.

Figure 5.1 Distribution of benefits: am peak fares[a]



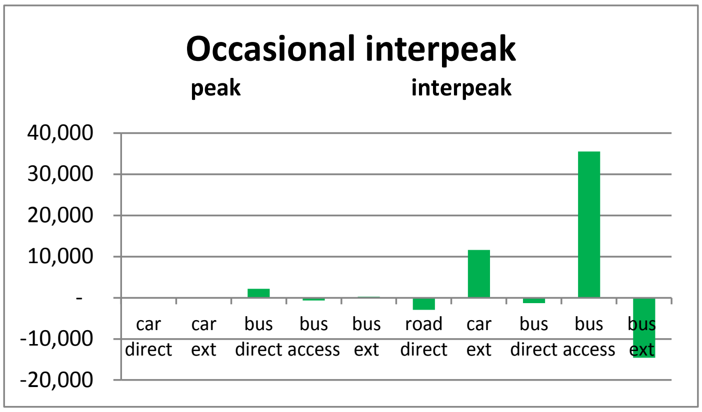
a) Ext = 'externalities'.

5.1.1.2 Inter-peak single trip

The single ticket prices were calculated in the 'Other' section of the Parry-Small analysis (rows 30–33). The *bus off-peak* line (row 33) shows the effect of reducing the inter-peak single trip fare by 1c/km.

The totals at the right-hand end of the *bus off-peak* line show that a decrease in this fare would cost the operator 17,341c/period (cell Y33)–$138,728 per year (report sheet cell C94) – and generate a net benefit of 3768c (cell X33)–$30,143 per year (report sheet cell C95). Thus on balance, a decrease in off-peak fares would be economically justified although it would have a financial cost. The change would result in benefits from the reduction in car externalities and in frequency benefits for PT users, while the main disbenefits would be negative operating benefits (ie the increased costs would slightly exceed the direct benefits to the new passengers) and an increase in the externalities caused by the extra buses, as shown in figure 5.2.

Figure 5.2 Distribution of benefits: inter-peaks[a]



a) Ext = 'externalities'.

The Glaister-Lewis analysis provided an alternative but internally consistent way viewing these results. The Glaister-Lewis analysis was run by:

- selecting the occupancy and frequency response assumptions (these carry over between sheets)
- selecting the impacts to be included (rows 12 and 13)
- then running the optimisation by clicking the [calculate optimum fares] button
- selecting the option of only including direct costs in the optimisation ([direct costs only]) results in an increase in the recommended peak multitrip fare from 26c/km (cell L32) to 95c/km (cell M32) and the off-peak fares from 40c/km (cell L41) to 42c/km (cell M41).

This resulted in the fare recovery increasing from the current 30% (cell Q31), as calculated based on EW data, to 64% (cell R31), and the peak PT mode share reducing to less than 1%.

At first it seemed strange that charging what should be the commercial fare resulted in such a low cost recovery. This was because at the time of writing, the revenue per passenger actually recovered was only about half of that charged, and we assumed that this situation was maintained. There may be a good reason for this situation, or it may be an issue that needs further investigation by EW. If this can be resolved, the 'revenue factor' applied in the model (I7 on sheet 'hamilton_tripdata') could be updated accordingly.

If the Mohring effect was included in the optimisation (changing the impact at row 13 to [only Mohring]) – ie taking into account the user economies of scale in the bus sector (effectively the 'social service' benefit) – the recommended peak fare dropped to 81c/km (still an increase on the current peak fare) and the inter-peak fare fell to 25c/km. Fare recovery dropped to 43%.

Including the second-best pricing impacts on road users [all (includes Mohring)] reduced the optimum peak fare further to 79c/km, but the inter-peak fare rose slightly to 26c/km with an overall cost recovery of 43%. As indicated by the Parry-Small analysis, even when all the interactions were taken into account, the optimum peak fare was greater than the current peak fare.

5.1.2 Allow occupancy to increase

At the time of this research, occupancy on the Waikato region's services averaged just under seven passenger-kilometres per bus-kilometre, which was low by comparison with the other main centres, which were generally averaging about 10 passenger-kilometres per bus-kilometre.

This had the following consequences in our analysis:

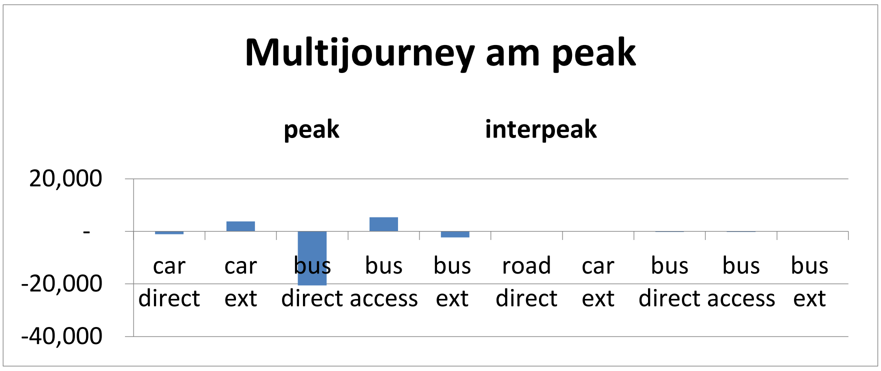
- It increased the average cost per passenger. If, as in the previous subsection, we assumed that the quantity of service offered was adjusted proportionally with the number of passengers [frequency changes], this would result in the marginal cost per passenger-kilometre also being high and this would be reflected in a higher calculated optimum fare.
- The low occupancy increased the externalities per passenger from the bus itself.
- The higher frequency implied by low occupancy reduced the frequency benefit from additional passengers.

It seems likely that at least some of the passengers that would result from reducing fares would be accommodated through an increase in occupancy. Furthermore it seems likely, given that Hamilton City frequencies were almost as high off-peak as at peak, that there would be more scope for occupancy increases in the inter-peak period.

The model allows the user to specify the proportion of the change in patronage that is accommodated through changes in occupancy. For illustrative purposes we made the assumption that 40% of the change in peak patronage would be accommodated by change in occupancy (AM peak [40%]) and 60% of the inter-peak (inter-peak [60]). This reduced the peak marginal operating cost from 94c to 60c/passenger-kilometre (Parry-Small sheet cell D10), and the inter-peak marginal operating cost from 40c to 19c/passenger-kilometre (Parry-Small sheet cell D11).

Looking at the Parry-Small analysis and still assuming that the rest of the patronage increase would be catered for by increasing the frequency [frequency changes], the cost to the operator of a one cent reduction in fare remained the same as in the previous example ($67,693 peak, $138,728 inter-peak). However the negative net benefit resulting from the increase in patronage was much lower because the increase in bus-kilometres required was lower. Nevertheless, the overall net benefit in the peak was still negative (-15,142 per year), implying that the optimum policy was still an increase in the peak multijourney fare. The output of this analysis is shown in figure 5.3.

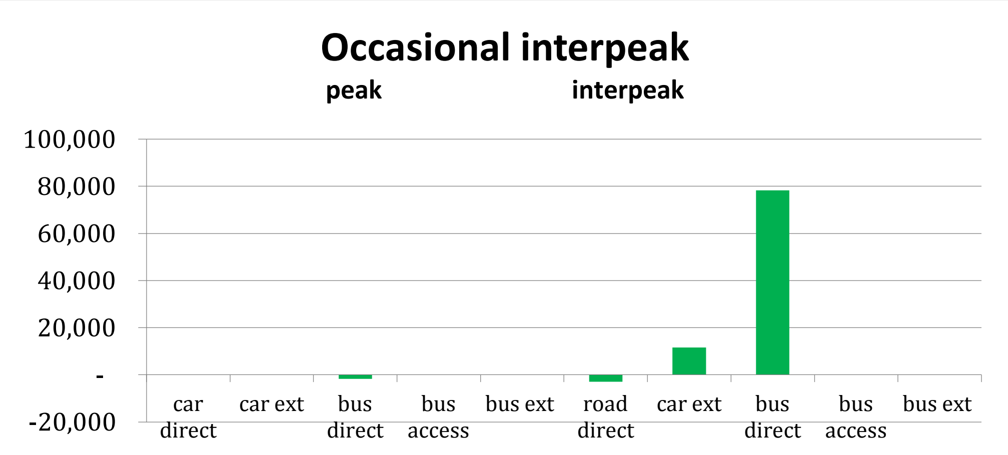
Figure 5.3 Distribution of benefits with occupancy increase: peak[a]



a) Ext = 'externalities'.

For the inter-peak, there was now a net operating benefit from the change in patronage – ie the benefit to the additional passengers was greater than the increase in operating cost (figure 5.4). What is more, the bus externality cost per passenger-kilometre was lower again because fewer new bus-kilometres were required. Hence, overall there was a net benefit from reducing the inter-peak fare.

Figure 5.4 Distribution of benefits with occupany increase: inter-peak[a]



a) Ext = 'externalities'.

Again these results were borne out by the Glaister-Lewis analysis.

Optimising fares but only considering direct costs [direct costs only] resulted in a peak fare of 58c/km – still an increase, but a smaller one – and an inter-peak fare of 17c/km. Fare recovery was 30%. Including the Mohring effect but ignoring the effect on car use [only Mohring], resulted in fares of 49c and 1c/km respectively, while including the second-best pricing impacts [all (includes Mohring] resulted in a peak fare of 45c/km peak and 7c/km inter-peak, with fare recovery dropping to 20%.

5.1.3 Exploring economies of scale

There are a number of other policy responses to changes in patronage that can be selected. The model currently provides for the following options that can be set on either of the analysis sheets:

- [frequency changes]
- [frequency and density changes]
- [frequency and size changes]
- [size changes]
- [density changes].

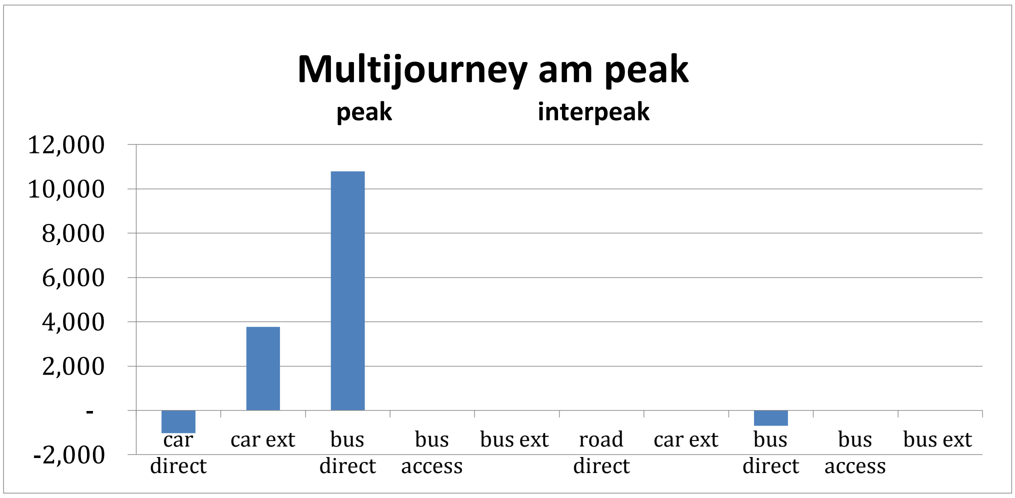
Currently the combination options are set at 50:50, but other combinations could be provided for in the model.

While it is generally considered that the economies of fleet size are small, capital and operating cost per seat-kilometre reduce with increasing vehicle size. Clearly, adjustments in vehicle size cannot be made overnight. However, there has been a trend towards larger buses in New Zealand's main centres and this provides a way of accommodating additional patronage.

Taking as a starting point the occupancy assumptions from the previous subsection (AM peak [40%], inter-peak [60%]), we set the policy assumption to [size changes]. On the assumption that the same fleet was used in the peak and inter-peak, we set AM peak and inter-peak to be the same.

As before, the cost of a 1c/passenger-kilometre fare reduction for multijourney tickets was $67,693 per year, with an equal benefit to existing users. As seen in figure 5.5, the main benefit from the change in patronage was now the net operating benefit, as the benefit to new users exceeded the additional operating costs. The other significant benefit was the reduction in car externalities. The net benefit from a one cent fare reduction was $12,851 per year.[10]

Figure 5.5 Distribution of benefits: size increases – peak[a]

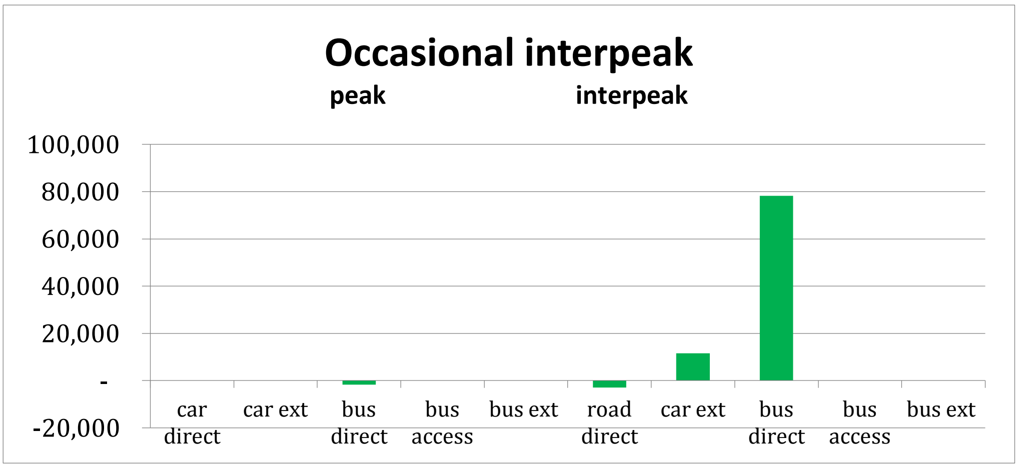


a) Ext = 'externalities'.

As for the occasional off-peak fare, the annual cost was, as before, $138,728 per year but the net benefit was now $85,295 per year, with again the main benefit being the net operating benefit (the difference between the benefit to new users less the increase in operating cost), followed by the reduction in car externalities, as presented in figure 5.6.

This implies that the optimum strategy under this scenario would be to lower the bus fares.

Figure 5.6 Distribution of benefits: size increases – inter-peak[a]



a) Ext = 'externalities'.

As before, this result was confirmed by the Glaister-Lewis analysis. In all cases, the optimum fares were very low, which resulted in very low fare recovery ratios. This scenario resulted in the largest variance between average and marginal cost, and thus the largest subsidy requirement if charges were to be set at

[10] Note that these results provided information on the benefits of subsidies to reduce fares if larger vehicles were used, but not on the benefits of using larger vehicles per se, given that that option would almost certainly lead to changes in service levels. It would take a full cost-benefit analysis to reach conclusions on that option's desirability.

the economically efficient level. The low marginal operating cost was the main driver for the optimum fare, with the selection of which social costs to include (congestion, Mohring, etc) making relatively little difference. The Mohring effect was, in any case, zero because frequencies were not adjusted in this option.

The extremely high subsidy requirement makes this option rather unrealistic. A more realistic option would be to assume that patronage is accommodated by a combination of size and frequency increases. [frequency and size increase]. With all other assumptions as before, this gives a peak multitrip fare of 21c/km and an inter-peak fare of 2c/km.

5.1.4 Constraints

Use of the Excel function 'Solver' to calculate the optimum fare (rather than using matrix algebra to solve the simultaneous equations, as was done by Glaister-Lewis) enabled the optimisation to be undertaken subject to constraints.

In particular, the optimisation in the last section [frequency and size increase] resulted in an estimated subsidy of $16 million compared with the current subsidy of $12 million. If this was judged unaffordable, it would be possible to re-run the optimisation subject to a maximum subsidy criterion. For example, the maximum subsidy could be left at $12 million, and the model re-run to show how the fares might be adjusted to more closely match the economic optimum within the current budget constraint.

This analysis was undertaken entirely with the Glaister-Lewis sheet. Undertaking the optimisation taking into account the impact on car travel [all (includes Mohring)] resulted in a recommended fare of approximately 26c/passenger-kilometre in the peak and 33c in the off-peak. The resulting fare recovery was 33%, a slight increase on the current level. However, a word of warning – the peak single fare was particularly high in this example and this seems unlikely to be acceptable. While the model can provide guidance on moving from the optimum fare to meet budget constraints, careful judgement of the real-world validity of the results is required.

Other constraints that could have been imposed were on the fare recovery ratio, on the relationship between the child and adult fare, and on the relationship between peak and off-peak fares. All the above analysis left these factors unconstrained. Other constraints could easily be added to the optimisation process.

5.1.5 Alternative optimisation measures

Consistent with the objective of this study to show how socially optimal bus fares can be determined, we only tested the model using maximisation of net social benefits as the criterion. However, in theory any objective could be maximised (or minimised as appropriate), as long as it can be expressed numerically and any measurable consequence can be included as a constraint.

5.2 Conclusions

These preliminary results showed the importance of the 'policy' assumptions that were defined within the model. In particular they indicated that with the current low level of occupancy, the bus service was expensive per passenger to operate, and that in the peak in particular, the indirect benefits appeared insufficient to justify the current level of subsidy.

If this was a structural problem caused by (for example) the highly peaked and unidirectional nature of the demand, it may not be possible to assume that any new patronage would be absorbed by occupancy increases, at least in the peak. In this case, the conclusion was that reducing bus fares would be an inefficient way of encouraging car drivers to leave their cars. The inefficiency took two parts – first, the cost per diverted passenger was very high, and second, the congestion and externality relief from the transfer was small: a bus with seven passengers had almost the same congestion and externality impact per passenger as a car with driver and passenger. The optimum fare policy appeared to be a combination of higher peak and lower inter-peak fares. However, other options could be tested, such as increasing bus sizes.

Yet if indeed there was spare capacity at the peak, and passengers could therefore be attracted at low cost, the picture would be somewhat different. In this case the economic efficiency argument would be for low peak fares in order to attract additional passengers, who could be carried at minimal extra cost and whose transfer from the roads would provide congestion-relief benefits. Even though the current fare recovery is low, the optimum policy could be to actually increase the level of support.

This highlights one of the issues with optimum prices – that they often run against a budget constraint. The model has been designed to allow a budget constraint to be specified, but it does not directly address the potential for the bus company to price discriminatorily so that economically efficient prices can be offered to new users without risking the loss of existing revenue. One option could be a two-part tariff, with an ‘entitlement’ card sold to Hamilton citizens entitling them to use the buses at the optimal fare. The level of that optimal fare would depend on other policy options that could be tested by EW via the model.

There is a third alternative. The model as it stands optimises by changing the fares. With only fares as a policy variable, it appears that increasing occupancy by reducing fares is the economically optimal, if not the fiscally responsible, course. But another way of increasing occupancy would be by reducing frequency. This option is implied by the model results, and could be explored by further research.

6 Relationship between the investment model and the NZTA's 'Planning & investing for outcomes' project

6.1 Introduction

The NZTA wants to become a smart investor and is in the process of implementing a 'planning and investing for outcomes' approach to how it invests the National Land Transport Fund, including for PT. It is interested in how the investment model might inform or assist in the understanding of how outcomes are being met, or will be met, by investment in PT. In theory, 'outcome-based' funding relates subsidy payments to the policy objectives the funding is intended to achieve, and would support a smart investor approach.

The extent to which the investment model can assist with the development of an outcome-based funding methodology depends on the degree of overlap between inputs and outputs used in the approaches, and how the objective functions of the models might align. The investment model aims to ensure prices are equated to social marginal costs across all modes, and accordingly estimates the implied subsidies needed to achieve this result. The investment model has its roots in economic rationales for government subsidising PT with an objective focused on achieving allocative efficiency in the use of transport resources, including consideration of externalities. In this section we explore how the outcomes the NZTA is seeking to achieve relate to the investment model.

6.2 Alignment of NZTA outcomes and the investment model

The NZTA's investment of the National Land Transport Fund is guided by the Land Transport Management Act (LTMA) and the Government Policy Statement (GPS). The Act has broad and multifaceted purposes promoting an 'affordable, integrated, safe, responsive and sustainable land transport system'. Under the Act's operating principles, the NZTA must, in meeting its objectives and undertaking its functions, use revenue in a manner that seeks value for money.

For the NZTA to gain the most from the development of the investment model, it would be useful for it to take account of the outcomes that the NZTA is trying to achieve.

6.2.1 Government Policy Statement and NZTA objectives

The GPS outcomes sought from the investment in land transport generally can be summarised as:

- contributing to increasing economic growth and productivity
- providing a sharpened focus on value for money
- improving road safety.

The key outcomes the NZTA seeks from the investment in PT to help achieve these GPS outcomes are:

- easing congestion in major urban areas at peak times
- optimising investment in PT services and infrastructure to deliver increased effectiveness.

The investment model aligns well with the first of these policy objectives, as it includes the value of congestion externality savings, which will flow on to improved productivity. It may also align with the second optimisation objective, depending on how 'increased effectiveness' is measured. Effectiveness measures assess the match between stated objectives or outcomes and their degree of achievement. The investment model concerns optimisation of prices, inclusive of subsidies, and guides the NZTA in terms of where increases or decreases in subsidies might be economically warranted. It may be less helpful in optimising the effectiveness of other policies; eg policy outcomes such as accessibility, affordability or sustainability issues.

However, as discussed above, what can be included in the model does depend on specific definitions of the NZTA's policy objectives. For example, accessibility is improved through frequency increases and the investment model takes account of the associated economic user benefits.

Other important outcomes that the NZTA seeks from PT investment are:

- more transport mode choice in major urban areas
- reductions in deaths and serious injuries from traffic collisions
- reductions in adverse environmental effects from land transport
- a resilient and secure transport network
- better use of existing transport capacity
- easing of severe urban congestion
- improvements in journey time reliability
- better access to markets and employment
- contribution to positive health outcomes.

Road safety impacts and environmental effects (vehicle emission costs) are included in the model, whereas the value of transport choice (potentially an option value as discussed above) is not. Journey time is a key input, particularly the impact of PT investment on the journey times of road users. Access to employment opportunities is not explicitly modelled, although improvements to the frequency and density of PT networks and to peak vehicle journey times, which together would improve access to employment, are modelled.

The investment model values the benefits and costs using values from, or consistent with, the EEM. If different weightings were sought, these could be reflected in the model.

6.2.2 Value for money

The NZTA has defined 'value for money' in its Investment and Revenue Strategy as selecting the right things to do (strategic fit), and implementing them in the right way (effectiveness) at the right time and for the right price (economic efficiency). In making decisions on funding requests from regional councils and Auckland Transport, the NZTA assesses value for money by considering:

Strategic fit + Effectiveness + Economic efficiency.

The economic efficiency assessment considers how well the proposed solution maximises the value of what is produced from the resources used. The benefit-cost ratio is used to provide a basis to rate the economic efficiency for improvements and new initiatives. The investment model developed in this research lines up well with the economic efficiency objective, indicating the likely incremental increase or decrease in subsidies might be warranted, given the incremental benefits and costs (expressed in cents per passenger-kilometre).

Potential areas for indicators that are relevant to tracking the achievement of outcomes are listed in table 6.1 below. These indicators were provided by the NZTA. We have provided information on whether they are taken into account in the investment model, what strategic NZTA GPS objectives the indicators may relate to, and whether the EEM covers issues relevant to the indicators.

Table 6.1 shows the performance indicators suggested by the NZTA:

- broadly align with parameters used in the investment model, other than indicators ‘key routes congestion’ and ‘accessibility to specific community services’
- cover all of the NZTA strategic objectives and with emphasis on congestion and mode share objectives
- are taken into account in the EEM procedures, which in turn use similarly sourced parameters as the investment model.

Care is needed when making comparative assessment using table 6.1. The EEM provides a set of steps and procedures for appraisal of an investment in PT. It is not itself an investment model, nor does it provide guidance on optimisation of PT investment across regions. If a model is developed that covers other/all regions, it may be able to provide guidance on optimisation of PT investment across regions.

Table 6.1 Potential measurement indicators

Indicator area	Potential measures	Investment model indicator commentary	Indicator aligned to contribution to gps/NZTA strategic objectives	Recognition of benefits in Economic Evaluation Manual (2008 values)
Congestion	Commuter and freight transit times and variability during peak periods on key routes in urban centres.	The value of congestion savings is included in the model, in accord with the EEM, but not assigned to key routes.	• Easing of severe urban congestion. • Improvements in journey time reliability.	• YES – existing road user savings, average travel time, vehicle operating cost (VOC) Auckland \$1.41/km, Wellington \$1.08/km, Christchurch \$0.10/km, EEM procedure for estimating trip reliability section 7.2 in EEM2.
Mode share	PT patronage and percentage of trips undertaken on PT during peak periods on key routes in urban centres; expressed as proportions of passenger-km per vehicle-km.	Included in the investment model at a general level, but not for specific routes.	• More transport mode choice. • A resilient and secure transport network.	• Assumed mode shares are calibrated to actual behaviour in transport models, so the generalised cost difference can be equated to the benefit associated with a change in mode share. • EEM – benefits to people changing modes valued at \$0.29/trip (2008) vehicle to PT (section 3.8 in EEM2).
Cost of PT services	Cost per passenger-km by PT mode and versus other modes.	Included in investment model, and will vary depending on operator and capacity constraints.	• Better use of existing transport capacity.	• Part of EEM evaluation procedures – resource cost adjustment for vehicle operating cost of \$0.11/km for avoided vehicle trips.
Fare box recovery	Percentage of total cost recovered from passengers.	Included in the investment model.		• No figure provided, part of evaluation.
Patronage	Public boardings per government \$ invested in PT services.	Included in the investment model.	• Value for money Statutory Mandate	• EEM procedure requires demand estimates for evaluations. Appendix A15 provides some default elasticity and cross-elasticity values.
PT safety	Reported serious accident and injury rates per passenger-km travelled, by mode.	Values included in investment model.	• Reductions in deaths and serious injuries from traffic collisions.	• EEM2 contains resource cost corrections for accident cost savings, for private vehicle motorcycle and bus taken from STCCS's, as per investment model.
Accessibility to PT	Percentage of people living within 500 metres of a PT stop in urban centres.	Route density included only in a very broad manner through change in service levels, and model provides for frequency changes that impact on accessibility.	• A resilient and secure transport network.	• Takes into account waiting and walking times in procedures. • Maybe land use accessibility benefits are, in general, captured in the monetised and non-monetised impacts described in appendix A8 of EEM1, but there may be additional benefits in particular situations.

Indicator area	Potential measures	Investment model indicator commentary	Indicator aligned to contribution to gps/NZTA strategic objectives	Recognition of benefits in Economic Evaluation Manual (2008 values)
Accessibility to basic community services/ economic centres	Percentage of basis community services/ economic centres within 500 metres of a PT stop in urban centres.	Accessibility is a central measure in the model, but is measured in terms of frequency and route density only.	• Better access to markets and employment.	• EEM2 contains provision for valuing 'community liveability' – refers to the environmental and social quality of an area as perceived by residents, employees, customers and visitors. EEM2 recommends using revealed preference techniques; eg effect on house prices of PT density.
PT impacts	Energy use, greenhouse gas emissions and local air pollutant emissions per passenger-km travelled.	Included, using average consumption and emission values.	• Reductions in adverse environmental effects from land transport. • Contribution to positive health outcomes.	• EEM uses composite value for all impacts including local air, noise and water pollution and greenhouse gas emissions in peak and off-peak periods, differentiated by private driver and passenger. See table 3.6 in EEM2.

6.3 Who should fund the subsidy?

The issue of who should pay arises in the development of funding methodology. The investment model indicates whether fares are optimal and hence what commuters should pay and what subsidies are required to achieve efficient resource allocation.

The model is, however, silent on the matter of how local and national government should share in the cost of funding the subsidy. Taken from a pure national cost-benefit lense, central government should be indifferent regarding what kind of economic benefit it funds – whether congestion savings or reduced waiting times. However, in practice there are issues of budget affordability, ensuring aligned incentives, and particular agency policy objectives to consider. The question of who should fund the cost of subsidies is then a political economy and agency issue as much as it concerns the need to develop a simple and enduring funding methodology.

6.4 Conclusion

Investment for outcomes relates payments to the policy objectives the funding is intended to achieve. Thus there should be a clear line of sight between the government's rationale for funding, the objectives that the NZTA wants to achieve, and the expected measures that demonstrate achievement of objectives. Thus from the allocative efficiency perspective taken in the investment model, the primary policy objective is to ensure that subsidies are allocated to areas and transport modes where the marginal national benefit of an additional dollar subsidy investment is the greatest. The investment model would complement such a methodology by providing the NZTA with guidance on where to invest additional dollars in PT.

7 Further model development

The first step of further model development would be the generalisation of the model to make it applicable in all main New Zealand centres, thus necessitating the inclusion of rail as an alternative form of PT. We anticipate this would raise a number of issues, particularly the need to appropriately express the degree of substitutability between rail and bus.

The cross-elasticity between rail and bus modes is important. At the time of this research, some routes in Wellington operated in competition, while other routes were exclusively bus or exclusively rail. The rail routes in Auckland were generally subject to bus competition (although proposed network changes would be likely to significantly reduce this), but very few bus routes were subject to competition. The substitutability of the modes would need to be addressed by segregating the market, as discussed further below. However, even if this is done, the issues discussed in chapter 4 regarding the estimation of elasticities will remain.

We believe these issues can be resolved by using the regional transport models. However, our experience has shown that this, too, is not without its problems. In particular, our enquiries revealed inconsistencies in the approach to mode-choice formulation between the regions, which would mean that although the general principles may be the same, the actual implementation would probably have to be transport model-specific.

The types of problem that we observed in Hamilton appear to be present to a greater or lesser extent in other regional models. In particular, while the models have been calibrated to achieve the expected response to PT fare changes in aggregate, they do not seem to have used the mathematical relationship between the logit model parameters and elasticities to ensure the models react to PT service and fare changes in a consistent manner.

Model development may thus require the approach to calibrating the mode-choice functions in the regional models to be reviewed. In some cases, new analysis may need to be undertaken. The need for this will be assessed on a case-by-case basis.

Three outcomes would be anticipated from this process:

- improved estimates of own- and cross-elasticities for use in the investment model, particularly estimates that would enable the bus–rail trade-off to be made with greater confidence
- optimum fare analysis consistent with regional models and the EEM – the investment model would then become a tool that allows partial analysis without requiring the full regional transport models
- improved performance and confidence in the regional models where changes to PT services or fares are contemplated.

Another advantage of using the regional models as a primary input is the increased ability to segregate the market. As well as segregation based on bus–rail competition, it should be possible to discriminate between CBD-orientated and suburban-focused services, where the 'second-best' and 'Mohring effect' warrants may be significantly different.

The other significant enhancement would be the incorporation of a service frequency optimisation into the model in a more specific manner.

There are several other significant tasks in expanding and calibrating the model:

- assessing the logical subregional network configurations for Auckland and Wellington (market segmentation)
- introducing the trade-off between bus and train
- expanding the model to simultaneously optimise both fares and service levels
- taking account of different fares and associated demand elasticities for different customer segments if this information is available in other regions.

Auckland and Wellington both contain network corridors that are distinguished by their geography, different mixes of PT modes (rail/bus), and disposable household incomes. Treating these corridors in the model as part of a city-wide network analysis would provide only generalised results of limited policy value. Also, in the context of adding rail, the issue of cross-elasticities would become more critical.

The alternative to calibrating the mode-choice functions in the regional models is to rely on existing estimates of elasticities and to make informed judgements on the likely range in the variation of elasticities between regional transport networks. This pragmatic approach would result in using the model to estimate a range of optimal subsidy levels for each region, based on an aggregation of subregional market segmentations.

Other than the finalising the approach to elasticity estimates, we do not see any significant data issues in expanding the model to other cities. More generally, the investment model contains a range of input measures, including patronage, passenger-kilometres travelled, occupancy and operating costs that are relevant to benchmarking both across and within regions, and to taking an ‘investing for outcomes’ approach. Thus the model itself could be developed and configured in a manner that enables benchmarking of such performance indicators. This would influence configuration of the Excel workbook and presentation of model outputs.

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Glossary

Average cost: Average costs are equal to the total cost of providing a service or good divided by the total quantity produced. In this model it is the total cost of providing passenger services divided by the passenger trips (average cost per trip) or divided by passenger-kilometres (average cost per passenger-kilometre). The unit of measure used in the model is cents per kilometre.

Busit card: For regular Hamilton bus users, the BUSIT card is a pre-paid travel card that can be used on all urban routes and also on the Cambridge, Huntly, Raglan, Taupo, Te Awamutu and Paeroa, and Morrinsville services.

Deadweight loss: This is a form of allocative inefficiency. It is the loss to society when the market price of a good differs from the social cost of its provision. Examples are the loss of benefit when people don't travel by bus because the price charged for PT is higher than the socially optimum price; or the congestion costs caused by car drivers who would not drive if they were faced with the true cost.

Economy of scale: Economies of scale are the cost advantages that enterprises obtain due to size, with cost per unit of output generally decreasing with increasing scale, as fixed costs are spread out over more units of output. Also see the Morhing effect below for these in relation to PT.

Elasticity: This is a measure of responsiveness of one variable relative to a change in another. In this model we are primarily concerned with the percentage change in demand for PT in respect to a change in its price; for example, through government providing an increase in subsidy, or from a change in frequency lowering the travel costs. We model the response to one cent change in price.

Externality: An externality is often referred to as 'spillover', and refers to situations where the 'external' costs or benefits of using a service or product are not included in market prices. For example, external benefits of PT services include congestion reduction from reduced private car use, which cannot be priced into lower fares by an operator unless the government provides a subsidy.

Home-based work trips: This refers to trip from home to work or from work to home.

Marginal cost: This is the change in total cost that arises when the quantity produced is changed – passengers and passenger-kilometres travelled in the model. This includes all additional costs required to produce the next unit, including capital costs (larger or additional buses when capacity constraints are met) and all operating costs (ie labour, fuel and maintenance, etc).

Mohring effect: The Mohring effect occurs where the frequency of a PT service (buses per hour) increases because of patronage demand and this shortens the waiting time for all passengers at bus stops. This implies increasing returns to scale, as average waiting times reduce for all patrons. Another way of thinking about this is that demand from new, additional passengers creates network spillovers that are not priced for existing users, who benefit from increased frequency.

The Mohring effect provides a rationale for PT subsidies on the grounds that subsidy is required for marginal cost pricing. The *average* cost of a passenger journey includes the average waiting time, while the *marginal* cost includes only the average waiting time less the decrease in total waiting time caused by the increase in frequency. Average cost thus exceeds marginal cost, and a subsidy that bridges the gap is said to improve allocative efficiency.

Operating costs: For a commercial PT enterprise, operating costs include fixed costs (which are same whether the operation is closed or running) and variable costs per kilometre travelled by a bus or train. See 'marginal cost' above for an expansion of what these costs include.

Spillover effects: See the definition of externalities and also the Morhing effect.

Social costs and benefits: 'Social cost' accounts for both privates costs (eg the costs of operating a private motorcar) and externalities or spillovers (eg congestion and safety costs of a private motor car). Social cost is then the sum of private costs and externality costs or benefits.

Two-part tariff: A two-part tariff is a price composed of two parts – a lump-sum fee and a per-use charge. Two-part tariffs are sometimes proposed as a means of cost recovery where the average cost exceeds the marginal cost. The per-use charge can then be set equal to the marginal cost, encouraging efficient use of the service or facility.

Commonly quoted examples of a two-part tariff are gym clubs that charge a membership fee plus a per-visit fee, and amusement parks that charge an entry fee plus a fee per ride. In both cases an average charge per use would result in fewer visits/rides, to the disadvantage of both the proprietor and the user (a deadweight loss).

It has been suggested that bus fares can be regarded as a two-part tariff – a user makes a municipal rates payment for the availability of the service plus a fare for each use.

Waikato Regional Transport Model (WRTM): This is a transportation model that was completed in February 2010. The model predicts the use of the road and PT network based on: the location of population, employment and other trip attractors; characteristics of the network such as current and new roads and services; and transport costs (fares, fuel prices, etc). It is used to predict the effect of changes in population and other factors over time, and to test different responses (new roads, new bus services, etc).

The geographic area covered by the model extends from the Bombay Hills in the north to Taupo in the south, and includes Rotorua and Tauranga to the east. While Rotorua, Tauranga and Taupo are included, the details within these areas are reasonably coarse, and the model provides the 'boundary conditions' to feed the existing models of these three urban areas. Trip distribution is undertaken using a standard gravity model, with the three-step model having distribution functions based on time. A four-step model of generalised travel cost enables the effects of fares, tolls and other travel demand management measures to be included, and to represent the differing values of time perceived for each mode of travel (ie PT, cycling and private vehicles).

Unit costs: Unit costs are the total cost of a defined unit of measure. The model uses unit costs per bus, per bus-kilometre, and per bus-hour to calculate the total operating cost of buses.