Measurement Valuation of Public Transport Reliability

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Abbreviations and acronyms

AML: Average Minutes' Lateness
BECA: Beca Carter Hollings & Ferner Ltd.
IVT: In-Vehicle Time
LUL: London Underground
PAT: Preferred Arrival Time
RP: Revealed Preference
SD: Standard Deviation
SP: Stated Preference

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Executive summary

Reliability relates to an uncertainty in the time taken to travel from the start to the end of a person's journey. For a public transport journey, reliability can affect users in one of two ways: as a delay when picking up the passenger and as a delay when the passenger is on the service. One or both of these sources of unreliability causes passengers to arrive at their destination at a different time than scheduled.

Reliability is important for operators and passengers alike. For operators, unreliable services cause difficulties in timetabling and resource planning. Also, unreliable services are typically more unevenly loaded, causing issues of passenger overloading and possible breaching of loading licences.

For passengers, unreliable services cause adjustments in an individual's desired trip-making behaviour to account for the possibility of a service not operating 'as normal'. In particular, variable departure times force the traveller to arrive earlier at the service, and create uncertainty and anxiety about whether the service has arrived. Variable arrival times cause travellers to arrive at their destination late and force them to take an earlier service. In-vehicle time variability causes the traveller to experience uncertainty and anxiety about how long they will have to spend in the service.

Reliability measures are typically used within performance regimes. Most of these regimes are based on the percentage of services arriving on time, where the notion of being on time and the penalty structure associated with not adhering to this differing between cities. For example, the UK rail industry tends to use the Public Performance Measure (PPM) within its incentive regime, with differing tolerance to late running depending on the distance of the total service (lower tolerance for shorter services that are also likely to be more frequent).

Valuations of reliability can be estimated using revealed and stated preference data. However, most valuations are undertaken using stated preference techniques, where a survey asks respondents about hypothetical situations. From these situations, values can be determined for changes in average delay and the variation in delay (which are both service characteristics), or by using more complex scheduling models that focus more on passenger travel information.

International evidence relating to public transport reliability suggests large variations in reliability valuation, indicating valuations to be highly context-specific. On average, one minute of average lateness is valued around four times more than in-vehicle time (IVT). In terms of varying service reliability, the evidence suggests one minute of standard deviation of lateness is worth one minute of IVT. Valuations for waiting passengers are generally higher than for passengers on the service. Little evidence suggests any consistent differences by mode, time of day or trip purpose.

A stated preference survey was designed and implemented as part of this project, which was carried out in 2007. The survey included two pilots which were used to adjust the number of showcards, variable levels and tolerances so as to minimise non-traders. Almost all user comments in the pilots and the survey were very positive, with some respondents stating how they enjoyed trying a new type of survey. The survey was delivered online using a pool of respondents through the SmileCity website. The final dataset yielded 750 useable surveys (and around 13 500 stated preference results). Results were segmented by geography (Auckland/Wellington), mode (rail/bus) and trip purpose (work, education and other).

The survey collected information about passengers' current arrival times at their stop/station. It was found that as service headway increased, the proportion of random arrivals at the stop/station reduced (from around 50% for headways less than 10 minutes, to 23% for headways of 60+ minutes). Furthermore, of the passengers who timed their arrival, around 87% arrived 5 minutes or more before the service's scheduled departure, indicating that a service running early by up to 5 minutes would cause problems for 13% of travellers, but would potentially be a benefit for the residual 87%. Finally, the average wait time per passenger by service headway was comparable to international studies.

Respondents were asked about their attitudes to reliability. Overall, 22% said arriving on time at their destination was very important, with trip purpose being the most significant differentiator; arriving on time was seen as more important for medical and education trips, and less important for shopping and social trips. Overall, 15% of passengers strongly agreed that their typical service usually picked them up on time, with rail being perceived as slightly better than bus. Fifteen percent also strongly agreed that their typical service was not usually delayed while they were on it.

Attitudes to unreliable services in general were also examined. In particular, Auckland bus users had a higher propensity to not like being late at their destination, delayed on pickup or delayed *en route* (Wellington rail users had the lowest). Reliability for education and medical trip purposes also appeared to be more important than for shopping and social trips.

The stated preference (SP) survey inferred valuations of two components of unreliable services, namely delay on pickup (SP1 – departure variability) and delay *en route* (SP2 – in-vehicle variability). From these two SPs, four initial models were estimated:

- a disaggregate model, where valuations for earliness, 5 minutes' lateness, and 10 minutes' lateness have been determined;
- a mean model, where an 'average minutes late' variable has been valued;
- a variance model, where the standard deviation of reliability has been valued; and
- a mean-variance model, combining the average minutes late and standard deviation valuations.

The disaggregate model indicated that valuations of earliness, being late by 5 minutes, and being late by 10 minutes were different on an equivalent per minute basis. For services that ran early, valuations on departure were highest (because of the possibility of missing the service), whilst valuations on the vehicle were lowest (because of the benefits of reduced travel times for some passengers). Valuations of 10 minutes' lateness were higher than 5 minutes' lateness, indicating that passengers become more agitated as delays increase. It should be noted, however, that the high valuation of early time on departure was some-what at odds with the proportion of passengers who might be affected by an early service. This finding requires more investigation.

A mean delay model was then estimated, using average minutes' lateness as a measure. This is the approach that is most widely adopted internationally to apply reliability impacts. Overall, it was found respondents place a higher value on average unexpected wait time (delay at departure) than average delay *en route*, with rail valuations lower than bus. Valuations were similar to those found in other international studies and recommended parameters in demand forecasting handbooks.

The variance delay model determined valuations of the standard deviation of wait and in-vehicle times. Interestingly, respondents placed a higher value on in-vehicle variability than departure variability, which was opposite to the average delay behaviour. Valuations were high by international valuations, although a large spread in these valuations makes comparison difficult.

A combined mean-variance delay model was fitted. However, this was found to generate negative valuations for standard deviation in some segments. Therefore, this formulation was not taken further.

From the departure SP, a value of time could be determined. The range in values of time (VoT) were around $8/hr, which is higher than the numbers currently used in the Economic Evaluation Manual (EEM) ($4.70/hr for commuting, $3.05 for other); however, these are 2002 prices and probably include a younger market. Also, the EEM assumes the same VoT for rail and bus users, but the SP survey found rail users consistently had a value of time almost twice that of bus users. Higher VoTs for rail users are generally found internationally.

The preferred approach, based on ease of use and comparability to international measures, was to use the mean delay model with average minutes' lateness and the valuations given in Table XS.1. Valuations are provided for delay on departure and delay in-vehicle. Wherever possible, the different sources of delay should be applied to each proportion of demand affected by such delay. This could be undertaken by looking at the major sources of time variation through a route's itinerary, and determining the proportion of users on the service and to be picked up by the service at each point. Valuations are also split by mode (rail and bus) and purpose (work, education and other). If demand data are available from any of these segments then using the segment-based valuations is desirable. Otherwise, using the total market (All) segment would be applicable.

In the simplest terms, assuming no difference in market segmentation, and having no distinction between departure and in-vehicle reliability would result in a valuation of one minute's average lateness at approximately 3 to 5 times IVT.

Table XS.1 Recommended valuations and parameters for reliability.

Model	Segment	Parameter	Valuation		
			Departure	IVT	Combined[b]
Mean	ALL	AML[a]	5.0	2.8	3.9
	Rail	AML	3.9	2.4	3.1
	Bus	AML	6.4	3.2	4.8
	Work	AML	5.5	2.8	4.1
	Education	AML	3.0	3.8	3.4
	Other	AML	5.4	2.0	3.7

Notes to Table XS1:

a AML = Average minutes' lateness.
b Combined value assumes a 50:50 split between departure and IVT delay *en route.*
c Services that are later than 10 minutes should be treated as being 10 minutes late.

This valuation is consistent with the average valuation obtained from the literature review, which also suggested an average value of around 4 times IVT for lateness and that departure variation is valued more highly than IVT variation.

These valuations could be used in evaluation guidelines, particularly in the Economic Evaluation Manual 2.

Abstract

Reliability in public transport is important for operators and passengers alike. Reliability can affect users in one of two ways: as a delay when picking up the passenger and as a delay when the passenger is on the service. Reliability measures are typically used within performance regimes to evaluate the quality of service of public transport providers.

This research, carried out in 2007, aims to find a method of measuring the value placed on public transport reliability in different contexts in New Zealand. As part of this project, a stated preference survey was designed and implemented to collect information about passengers' current public transport usage, their attitudes to reliability and how they valued reliability.

Using these stated preference surveys, four initial models were estimated: a disaggregate model, a mean model, a variance model and a mean-variance model. The preferred approach, based on ease of use and comparability to international measures, was the mean delay model.

A value of time was determined from the departure stated preference survey. Values of time ranged around $8/hour. The surveys also found that rail users consistently had a value of time almost twice that of bus users, which is consistent with international findings.

1 Introduction

1.1 This report

This report has been developed by Booz Allen Hamilton as part of the Land Transport New Zealand Research Programme 2005–2006, primarily to examine the valuation of public transport reliability and implications within the New Zealand planning context. The research was carried out in 2007.

The process has involved the development of this report, a survey conducted in conjunction with a market research company, and a peer review which examined the report and processes.

1.2 Scope and structure

The report provides an overview of the concept of reliability, particularly the impact that service reliability has on passengers and operators. Reliability measurement methods and monitoring processes are explored. An international review of reliability valuation methods is undertaken. Based on this review, a reliability valuation approach is applied to a New Zealand context. Finally, the implications of the approach for planning are outlined.

The report is structured as follows:

- Chapter 2: Overview of reliability,
- Chapter 3: Review of reliability measurement methods,
- Chapter 4: Review of approaches to reliability valuation,
- Chapter 5: Review of reliability valuation methods and findings,
- Chapter 6: Reliability state preference survey,
- Chapter 7: Survey results and implications,
- Chapter 8: Reliability stated preference valuations.

2 Overview of reliability

2.1 Definition of reliability

The term 'reliability' within a transport context relates to an uncertainty in the time taken to travel from the start to the end of a person's journey. This uncertainty means that a person must make some allowance in the timing of their journey to allow for this uncertainty so that they can still reach the end within a desirable time band. Within transport, different modes have different sources of reliability which relate to uncertainty within individual aspects of their journey.

In transport economics, generalised cost is used to represent the total user cost for a journey; this provides a useful framework to categorise reliability aspects. User costs when travelling by car are primarily comprised of the time taken, the operating cost of the vehicle and a parking cost. Variations of travel time occur particularly on heavily congested roads, where the deviations of other individuals' departure times or a one-off event (such as an accident or breakdown) can cause significant changes in delays. Variations in operating cost are less apparent to users, but could include unexpected maintenance on their vehicle. Variations in parking costs are usually ignored, but could involve extra time taken to find a park or an additional cost for having to park in a more expensive area than usual.

Public transport has similar sources of uncertainty, but the main difference from using a car is the reduced level of control users have over their own situation caused primarily by the reduced flexibility of public transport; car users can time their journey 'to the minute' whereas a public transport user needs to keep to an existing timetable. For a public transport user, the journey consists mainly of:

- travel time spent in the vehicle and access/egress to the vehicle), known as in-vehicle time (IVT);
- the time taken waiting for the service; and
- the fare paid.

In-vehicle travel time variations are usually caused by either infrastructure or vehicle failure. Waiting time variation is caused primarily by a previous in-vehicle time variation, but can also be caused by service cancellation. Waiting time variation is seen by a user as a delay to their departure from the stop/station.

For a public transport user, if a service is running early, he/she faces the real possibility that they may miss it given their arrival time at the stop/station. In this situation, a user would then have to wait for the next service, thus increasing their wait time substantially.

2.2 Components of public transport reliability

The purpose of this paper is to explore the notion of public transport reliability. Table 2. gives a summary of sources of reliability relating to public transport.

Table 2.1 Definitions of public transport 'reliability'.

Term	Definition	Standard measures
Punctuality • departure • arrival	Adherence to service schedule	Mean delay Percentage outside of 'comfort zone' (e.g. 1 min-early to 5 min late)
Cancellations* • at departure • during trip	Whether a scheduled train or bus actually arrives	Mean delay (which is a function of headway)
Variability around expected • departure time • travel time • arrival time	Spread around 'expected x time' Note: 'expected time' can be: • average time; or • targeted time (e.g. scheduled time)	Standard deviation
Waiting time variability	Spread around average waiting time	Standard deviation

* The UK rail industry uses 'reliability' to refer to the term described here as 'cancellations'.

Punctuality is defined in Table 2.1 as 'adherence to schedule'. This is a very common definition throughout the literature. As one would suspect, this term is only ever used in the context of public transport.

Cancellations are defined as whether a scheduled train or bus actually arrives. This definition is used primarily in the UK rail industry, but it is referred to here as simply 'reliability'.

Variability around expected time is probably the most common term used in the literature. It is usually measured using standard deviations.

However, as Bates et al. (2001) note, the interpretation of variability depends crucially on the meaning assigned to the term 'expected value'. For example, consider a bus that is always late relative to schedule, by *x* minutes:

- If 'expected value' is based on the bus schedule then the bus is exhibiting variability.
- If 'expected value' is based on the expectations of a passenger not familiar with the bus then the bus is exhibiting variability.
- But if 'expected value' is based on observed lateness over the past few months then the bus would be exhibiting no variability.

In general, throughout the literature, sources agree that variability should refer to the unpredictable component of variability, i.e. the component of variability that remains after predictable variations (e.g. longer trip times during peak hours) are removed.

The concepts of reliability can be further broken down into departure time, travel time and arrival time, as shown in Table 2.2.

Table 2.2 Components of 'reliability' in different contexts.

Components	Subcategories
Departure time	Punctuality Variability around expected departure time
Travel time	Variability around expected travel time
Arrival time	Punctuality Variability around expected arrival time

Note: departure time punctuality + travel time variability = arrival time punctuality

Most studies of reliability focus on either travel time variability or arrival time variability. Only a few studies direct attention to waiting time variability.

The relationship between travel time variability and arrival time variability is worth noting. If departure time is certain (as is presumed in a number of studies) then travel time variability is equivalent to arrival time variability. In such studies, a researcher can focus on either travel time variability or arrival time variability

2.3 Why reliability matters

Reliability is important for operators and passengers alike. For operators, unreliable services cause difficulties in timetabling and resource planning. Also, unreliable services are typically more unevenly loaded, causing issues of passenger overloading and possible breaching of loading licences.

For passengers, unreliable services cause adjustments in an individual's desired trip-making behaviour to account for the possibility of a service not operating 'as normal'.

- **Arrival time variability** causes the public transport user to arrive at their destination late and/or forces the traveller to take an earlier service. Arrival time variability can also cause the traveller to arrive at their destination too early, hence they have to wait around or make up time.
- **Departure time variability** has the following costs for public transport users (in addition to increasing arrival time variability):
  - *increased waiting times for the traveller*. Late services cause travellers to have to wait some time after arriving at their stop or station. Early services also increase waiting times because they force the traveller to wait for the next service, and/or they require the traveller to arrive earlier at the stop or station;
  - *increased concern and anxiety caused by fears of arriving late* at the destination;
  - *increased concern and anxiety caused purely by uncertainty* about when the next service will arrive; and/or

   – *increased likelihood of a late service* that, because of its lateness, picks up more people and hence forces additional passengers to ride standing and/or in crowded conditions[1].

- **In-vehicle-time (IVT) variability** has the following costs for public transport users (in addition to increasing arrival time variability):

   – increased concern and anxiety caused by fears of arriving late at the destination,
   – increased concern and anxiety caused by uncertainty about how long they will have to spend in the service, and
   – increased variability surrounding how long the passenger will have to spend standing and/or in crowded conditions.

The research focuses on passenger attitudes to service reliability and will investigate how the population of interest values the different components (listed above) of public transport reliability.

[1] The increased likelihood of standing or crowdedness may not be significant but is noted here because it may be included in valuations.

3 Review of reliability measurement methods

Reliability measurement methods are used throughout the world as a way for authorities to penalise passenger transport operators for poor performance. In general, the measurements used have a lot in common, the major differences being the tolerances that are applied and the subsequent penalty regimes.

Tables 3.1–3.3 provide a summary of some reliability measures that are used in practice by authorities and planners. Measures are typically used for two purposes:

- to aid in forecasting demand changes as a result of performance changes, and
- as a measure included in penalising/rewarding operators for bad/good performance.

In terms of demand forecasting, the UK rail industry typically uses Average Minutes' Lateness (AML) as a measure of reliability. Much of the literature on how passengers respond to changes in reliability is based around changes in the average delay that passengers experience, and this has been used as a recommended forecasting approach with appropriate weightings and levels of flexibility. For the London Underground, demand responses for forecasting are usually undertaken on a more disaggregate level where detailed information about individual services is available and service frequencies are high. As such, the London Underground adopts an individual passenger response for a given service depending on how long it is delayed.

Reliability measures are typically used within performance regimes. Most of these regimes are based on the percentage of services arriving on time, where the notion of being on time and the penalty structure associated with not adhering to this differing between cities. For example, the UK rail industry tends to use the Public Performance Measure (PPM) within its incentive regime, with differing tolerance to late running depending on the distance of the total service (lower tolerance for shorter services).

For bus services, tolerances are much lower, with a typical tolerance of late running of 5 minutes from timetable schedule. However, some cities distinguish between late running (typically 5 minutes) and extremely late running (later than 10 minutes). Services running early are not commonly tolerated, with many cities expecting services to run at least on time at timing points – although examples that allow for one minute's earliness exist.

Table 3.1 Measures of reliability used in practice in the UK.

End user	Measures currently used	Use
Passenger Demand Forecasting Handbook[2] Rail	AML • Calculated as the weighted average minutes' lateness. • Early arrivals are treated as being on time. • Cancellations treated as being equivalent to a late arrival of 1.5 times the service headway. • Delays advertised in advance should be treated as scheduled time for passengers aware of this at the start of the journey, and as delays for all other passengers – in the absence of hard data, the handbook recommends a proportion of 25% aware and 75% unaware.	Demand forecasting
Department for Transport UK (2007a) Rail punctuality and reliability	Public Performance Measure (PPM) • Percentage of trains running on time covering all scheduled services. • A train is on time if it arrives at its final destination within 10 minutes of the scheduled time (long distance), and within 5 minutes for other services.	Performance regime
Department for Transport UK (2006) Bus punctuality indicators	For infrequent services: • Percentage of buses departing within 1 min early or up to 5 mins late relative to the scheduled time. For infrequent services: • Excess waiting time.	
Transport for London (UK) Business Case Development Manual (Transport for London 2007)	Passenger weightings for equivalent in-vehicle time on London Underground (LUL) services that are 1 minute through to more than 9 minutes late,	Demand forecasting
Department for Transport UK (2007b) Bus priority: the way ahead	• The difference between timetabled and actual arrival times on low-frequency routes. • The variations in headways on high-frequency routes.	

[2] The Passenger Demand Forecasting Handbook is a publication from the UK Association of Train Operating Companies, which is available only to members of the Passenger Demand Forecasting Scheme. The data used in this table and elsewhere in the report are reproduced with the permission of this Scheme.

Table 3.2 Measures of reliability used in practice in Australia.

End user	Measures currently used	Use
Australian Transport Council (2006) National Guidelines for transport system management	• Actual average lateness (the guidelines recommend a weighting of 3). • Could apply to unexpected wait time (weighting of 6) and unexpected in-vehicle time (weighting of 1.5).	Demand forecasting
Translink, Southeast Queensland (Wallis 2005)	Percentage of buses arriving on time • A service early if earlier than 1 minute, and late if it is later than 5 minutes compared with the scheduled time. • Measured for the departure point and key connection points. • Only one early/late incident is recorded per trip.	Performance regime
Public Transport Division, Government of South Australia (Government of South Australia 2005)	• Percentage of buses operating early (before timetable) at any designated timing point. • Percentage of buses operating more than five minutes late at any designated timing point.	Performance regime
Perth (Wallis 2005)	• Percentage of buses operating early at any timing point. • Percentage of buses operating late more than five minutes at any timing point.	Performance regime
Department of Infrastructure Victoria (2007)	• Percentage of buses operating early (1 minute or more) at any designated timing point – target 0%. • Percentage of buses operating late (more than 5 minutes) at any designated timing point – target 5% over all routes and 10% on any one route.	Performance regime
Sydney (Wallis 2005)	• Percentage of timetabled services operating more than five minutes early or late.	Performance regime

Table 3.3 Measures of reliability used in practice in New Zealand.

End user	Measures currently used	Use
Auckland Regional Transport Authority (ARTA) (2006)	• Percentage of service trips departing early – maximum acceptable tolerance 0%. • Percentage of trips (per month) running between 5 and 10 minutes late – maximum acceptable tolerance 5%. • Percentage of trips (per month) running between 10 and 30 minutes late – maximum acceptable tolerance 0.25%.	Performance regime
Wellington (Wallis 2005)	• Any service that departs its terminal earlier than its scheduled departure time or more than 10 minutes late or half the headway (minimum frequency of service deemed to be 10 minutes), whichever is lesser, is deemed not to have operated.	Performance regime
Christchurch (Wallis 2005)	• Percentage of service trips that operate early – maximum acceptable tolerance 0%. • Percentage of services trips that operate more than 5 minutes late – maximum acceptable tolerance 1%.	Performance regime

From the measures shown in Tables 3.1–3.3, which are currently used in performance incentive regimes, typical relationships between demand and reliability can be determined. If information is available on how many services are early and late, then typical demand measures such as AML or standard deviations of travel time could be calculated from information already collected. It would therefore be desirable for a reliability forecasting methodology to use these two measures of reliability (AML and standard deviation), given that observed service information already exists.

4 Review of approaches to reliability valuation

4.1 Methodologies

Two main methodologies are used to determine people's valuations of transport costs: revealed preference (RP) and stated preference (SP) analysis. RP analysis examines the before and after situation of a given change in transport supply and can be used to determine people's response to this change. In other words, RP determines people's responses to changes in transport based on what they actually did. Whilst RP analysis is usually the preferred approach, it is rarely undertaken (particularly in a transport context) because:

- it is difficult to get consistent before and after data, therefore making it hard to undertake a comparison;
- many factors affect people's transport behaviour and it is unlikely that these factors will remain constant over the period of interest (for example, an improvement in reliability may be linked to the introduction of new rolling stock, with increased passenger numbers including the response to the new rolling stock as well as the reliability improvements. Separating these effects and interpreting the results is challenging);
- RP analysis requires situations where change has occurred and, once a situation is found, it may not be applicable to the transport market of interest – it cannot be used to examine hypothetical situations;
- RP analysis is generally based on patronage numbers with no ability to question individuals fully and therefore to understand the drivers and market segmentation of particular responses;
- RP data can include measurement error (or mis-specification) of the dependent variable. In a reliability example, RP data may use AML as a measure of reliability but for passengers, it might be the variation in reliability that is more important. Similarly, where the use of average lateness is appropriate, it may not be measured correctly or to a sufficient level of detail to discern passenger responses.

Most of the literature therefore focuses on SP approaches to reliability valuation. SP analysis differs significantly from RP analysis in that it asks respondents how they would behave given a series of alternatives (scenarios). Respondents are presented with a number of alternatives (usually two) that differ in the values of their transport costs, and are asked to choose which alternative they prefer. By varying the costs in an appropriate way, the alternative a respondent chooses can be used to determine valuations for the individual transport costs.

SP analysis overcomes all of the difficulties of RP analysis as listed above but has shortcomings of its own. In particular, some respondents do not actually behave as they do hypothetically. Some respondents may have their own agenda, and therefore either give unrealistic answers or the answers they think the survey is looking for. Respondents may not fully appreciate the impact of the hypothetical examples presented. For example, presenting a scenario where their fare is doubled may not invoke the same reaction as their fare actually being doubled and more money leaving their pocket. SP surveys usually ask respondents about a number of differing scenarios; therefore, surveys can become tiresome and fatigue biases can be an issue. Surveys need to be fairly simplistic, particularly when asking a respondent to decide between two options.

Given that most of the reliability literature focuses on SP analysis, and that an SP survey has been conducted as part of this project, the review of analysis methods focuses on SP rather than RP. In particular, it will discuss the representation and functional form of SP reliability studies.

4.2 Options for representing reliability in SP surveys

4.2.1 Existing options

The literature shows that reliability is generally represented in these forms:

- as a set of representative trips (maybe in a week or fortnight),
- as a maximum travel time delay,
- as a probability of delay, or
- as predetermined levels of earliness/lateness.

These are discussed in turn.

4.2.2 A set of representative trips

Many reliability studies associate each alternative presented to a respondent with a set of representative trips. The representative trips convey a sense of the distribution associated with that option, and can be used to present either a distribution of travel times or a distribution of departure/arrival times. As noted earlier, the two representations are mathematically related if departure time occurs at a definite, pre-determined time.

A set of representative **travel times** has the advantage that it is ‘realistic’ – it accords well with reality – and it conveys a lot of information about a distribution in an intuitive manner. However, for public transport users, departure and arrival times are also important, as passengers need to adhere to the schedule.

A set of representative **departure/arrival times** can be easier to comprehend, especially if represented in terms of minutes earlier or later. However, these surveys carry a risk of misinterpretation, as will be discussed later.

These trips are represented either by numbers or graphs (the most common approach is to represent travel times as numbers). The layout below (Figure 4.1) is a quintessential example of the sort of SP surveys used in Small et al. (1995), based on work undertaken by Black & Towriss (1993).

Sample stated preference question

Time: minutes	Time: minutes
12 13 14 16 20	5 7 9 12 18
Departure 15 minutes before your usual arrival time.	Departure 10 minutes before your usual arrival time.

Figure 4.1 SP survey layout as used by Small et al. (1995).

Black & Towriss also introduced a few notable variations to make the options clearer:

- A box was placed around the approximate mean of the distribution of times:
  e.g. 38 50 [60] 74 90
- A message was placed between the two sets of journey times:
  e.g. 'SAME AVERAGE TIME'
- A box was added (under the more variable option) to emphasise that it is the more variable option:
  e.g. [TRAVEL TIMES MORE VARIABLE]

A pilot survey by Black & Towriss (1993) indicated that arrivals are best represented as 'minutes earlier or later than planned'. The researchers presented respondents with reliability in the following forms:

- a tabular form – the number of arrivals falling into given categories of earliness and lateness,
- a textual list – the representation of arrivals in the form of minutes earlier or later than planned,
- a set of cards with exact arrival times, and
- a set of clocks – the clocks depicted arrival times and stated the likelihood of arriving at a particular time.

The rankings produced by the pilot survey were compared with the standard deviations to see which representation of reliability was most effective at producing the 'correct' rankings. The researchers found that the 'minutes early or late' representation was preferred, especially by respondents with little or no numerical background. Black & Towriss (1993) identified a problem with the 'minutes early or late' representation: respondents in the pilot survey who imagined their trip as not having a timing constraint were unable to comprehend the exercise. This prompted Black & Towriss to switch to journey times for the final survey.

The order in which the trips are represented might become problematic; Bates et al. (2001) posit that the order of a 'Benwell & Black' (1984) series of delays (e.g. 0, 0, 0, 0, 0, 5, 10, 25) may be misinterpreted. For example, people might assume a deteriorating service level. Or infrequent travellers might assume that they would not incur the delays. Therefore, Bates et al. (2001) proposed and implemented the 'clockface' design (shown in Figure 4.2), in which 'order' is removed.

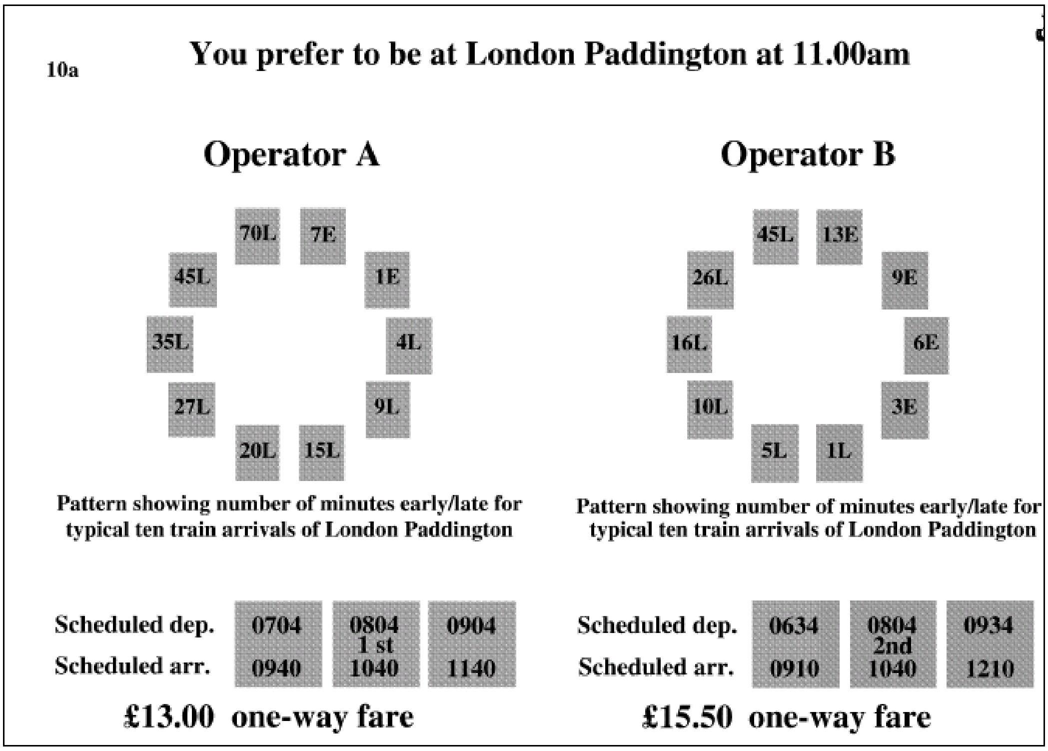

Figure 4.2 SP survey design used by Bates et al. (2001).

Cook et al (1999) referred to the Black & Towriss (1993) pilot survey discussed above and chose to use the 'minutes early or late' representation in their study of rail commuters.

However, Cook et al. encountered a problem with that representation: respondents appeared to gravitate towards zeroes. The researchers presented respondents with the following options:

- A: 1E 1E 1E 1L 1L 1L 5L 10L 10L 35L
- B: 1E 0 0 0 0 1L 5L 25L 25L 35L

Twenty-six percent of respondents preferred Option B, despite 90% saying that they would not consider a delay of one minute as being late at all.

Hollander (2005b) introduced a novel method of representing travel time for his SP survey of car, bus and rail commuters: departure and arrival times were represented by the relative locations of the bar, with the bar length giving journey time (as shown in Figure 4.3).

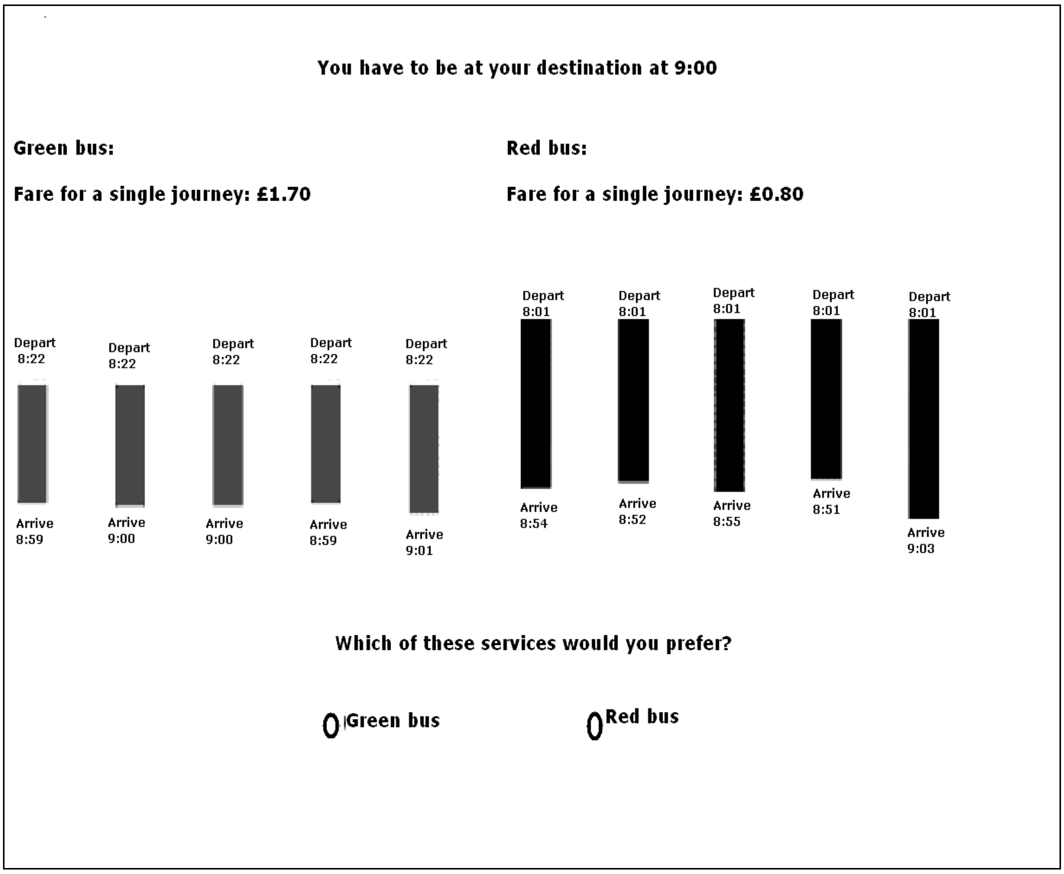

Figure 4.3 Representation of travel time used by Hollander (2005b) for SP surveys.

Tilahun & Levinson (2005) used histograms to represent travel time variability to respondents. An example of the histogram presentation is shown in Figure 4.4. The findings suggested a lack of comprehension owing to a lack of education: college-educated workers had a reliability ratio of 1.22 while non-college-educated workers had a reliability ratio of -0.14.

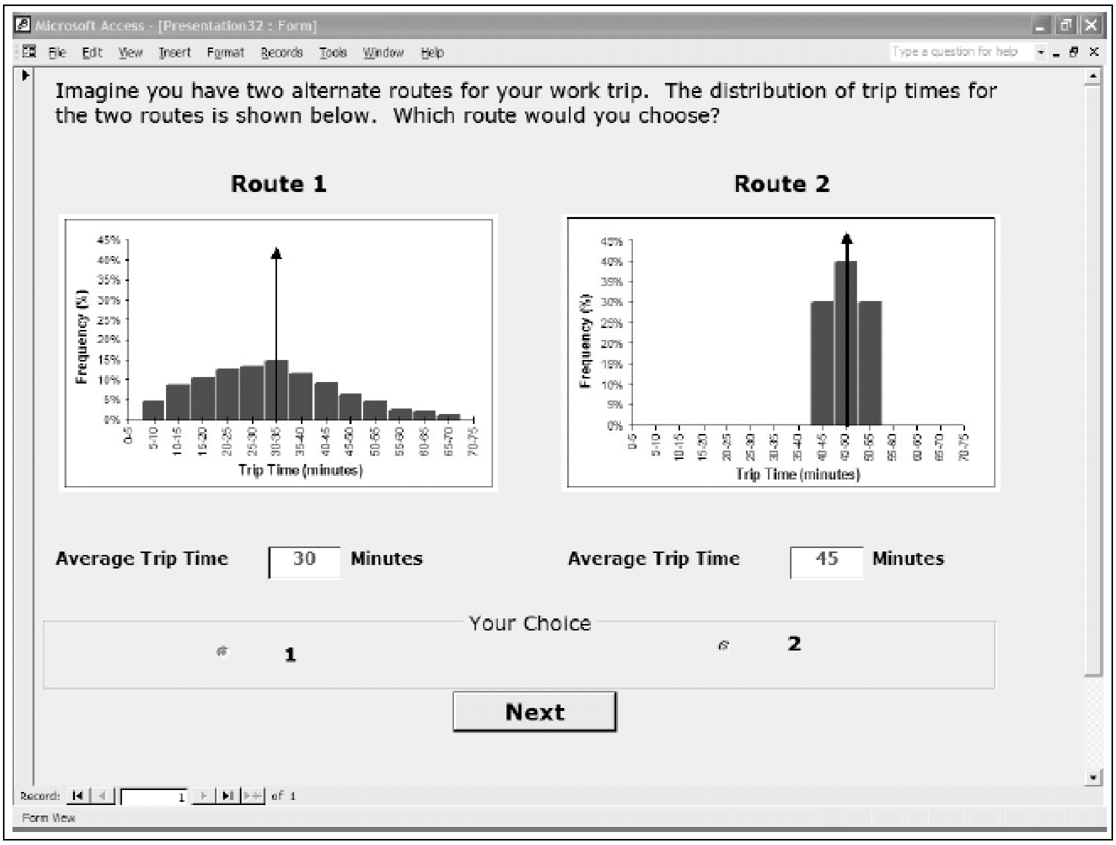

Figure 4.4 Screenshot of the online SP survey design used by Tilahun & Levinson (2005).

A number of reliability studies, particularly those relating to rail transport, focus solely on arrival times and the relationship between actual arrival time and scheduled (or preferred) arrival time.

Five representative trips were very common in recent research, perhaps because they possess the following advantages:

- Five representative trips can be easily associated with each day of the working week. Senna (1994) notes that respondents were asked to think of the five journeys as five commutes during their week.
- Five representative trips provide a broad spread without being excessively onerous. In their second pilot study, Black & Towriss (1993) assessed respondents' ability to understand five travel times versus ten travel times. They found that respondents were better able to differentiate with the five travel-time representation. Also, respondents found five travel times easier to understand than ten travel times.

4.2.3 Probability of delay

Another common approach is to represent reliability in terms of the probability of a delay of a certain magnitude. In the SP survey, the researcher varies the probability and/or the magnitude of the delay.

The existing research often presents only a few options, which are sometimes unrealistic. For example, Rietveld et al. (2001) presented only two options: 'no delays' or a 50% probability of a 15-minute delay.

MVA Consultancy Ltd. (2000) perhaps take a better approach:

- they refer to the most reliable option as 'never more than 5 minutes late,' rather that 'no delays' or perfectly reliability; and
- they present a range of options: 1 in 10 trains being 10, 15 and 20 minutes late, and 1 in 2 trains being 10 minutes late.

Beca Carter Hollings & Ferner Ltd (BECA) (2002) presented one level of 'complete reliability' and, in the other levels, delay was either a 1 in 10 chance of being late by 20% of total journey time, or a 1 in 10 chance of being late by 40% of total journey time. In their review of their findings, they note a potential problem with this type of representation: the probability representation assumed that the value associated with delay was linearly related to the length of the delay. For example, a 1 in 10 chance of a 20 minute delay is valued at twice the price of a 1 in 10 chance of a 10 minute delay. The researchers note that this may not reflect the actual thought processes of travellers.

Bates et al. (2001) note that this type of representation is often misinterpreted. For example, the '1 in 10 trains are 20 minutes late' formulation is often misinterpreted as meaning that the other nine trains are on time. Other potential problems with this type of representation (which are not usually discussed by researchers) include the following:

- The measures of reliability used are often too simplistic to capture reality; most scenarios have a 'perfect reliability' level.
- The researchers often vary either the magnitude of delay or the probability of delay, whereas travellers are probability concerned about both aspects of reliability.
- Interpreting and applying these results to real-world situations is difficult.

The probability of delay representation is used for estimating a variant on the 'variance delay model'. The probability of a particular delay is transformed into an expected mean delay (probability of delay *x* length of delay). The expected mean delay is then interpreted as a measure of variability, just as in standard variance-mean models.

4.2.4 Predetermined levels of earliness or lateness

Some studies presented respondents with options with different predetermined level of earliness or lateness (relative to preferred arrival time). The researchers then used the respondents' preference (either stated or revealed) to determine the value that respondents attach to early or late time.

Small (1982) conducted seminal work of this nature, but his research related to actual trips made by car commuters (revealed preference data). In terms of public transport, the key papers would be the Pells (1987) survey of both bus and car commuters, and the de Jong et al. (2003) survey of rail and car travellers.

4.3 SP survey design issues – levels and tolerances

4.3.1 Basic survey design

The SP survey presents a series of scenarios to a respondent, with each scenario giving a choice between two or more options where transport costs differ. Respondent choices are used to determine relative valuations. For a rich dataset of responses, the alternatives need to be framed in such a way that they are realistic but still provide adequate variation and extremes within each cost component. For this reason, the number and size of levels (values) used for each attribute is important.

4.3.2 Non-traders

The issue of 'non-traders' in SP surveys can be problematic. Non-traders are respondents whose choices tend to be dominated by one variable; for example, they may be highly cost-averse, meaning they will always choose the cheapest service no matter what other option is presented (such as a highly reliable service). Non-traders can also reflect unusual trip situations; a couple of respondents in particular in the survey conducted for this project did not pay any fare for their journeys using public transport (possibly because they had an employee pass). It is very difficult to encourage these respondents to trade if they do not incur the full cost of travel.

Respondents who do not trade can also reflect poor survey design:

- A survey which is too long (respondent fatigue) or complex can cause respondents to give unrealistic answers and choose based on one variable (such as cost).
- A survey which does not provide realistic scenarios consistent with respondents' current trip-making costs may cause a disassociation with the options presented and, as such, cause respondents to focus on one variable.
- A small level of variation in the options presented (small changes in cost or time), may not be enough to encourage respondents to trade based on other variable values.
- Having one type of service (such as the cheapest) always presented on the same side of the showcard (always service A for example) makes it easy for respondents who have little time to complete the survey to choose based on one variable without giving much thought.

Non-trading may reflect an individual's preference for one variable or (more often) it reflects issues with survey design. For that reason, a large amount of time was spent on the survey design to minimise the amount of non-traders. In fact, the first pilot resulted in approximately 50% of respondents not trading for one of the SP surveys. The number of levels for each variable and the associated tolerances were increased, resulting in a significant reduction (to around 12% of the total sample) in non-traders in the second pilot and the full survey (around 6% always chose the cheapest and 6% chose the most reliable). In particular, the impact of non-traders was minimised through:

- splitting the SP surveys of 16 showcards into two lots of 8, thus reducing any fatigue impacts on the individual;
- pivoting showcards around actual trip cost values, so as to produce realistic scenarios;
- swapping options on each showcard randomly so that the cheapest service was not always Service A; and
- using a 'Monte Carlo[3]' simulation using average values of time to minimise the number of non-traders, given a set of tolerances.

Non-traders have been excluded from the survey analysis.

4.3.3 Estimating the range of values

The range of values presented should be applicable to the respondent's situation – the more realistic the options, the easier it is for the respondent to give realistic answers. To ensure realistic scenarios, most researchers generate values that are pivoted off the respondent's reported travel characteristics (e.g. scheduled travel time + 20%). The medium level of the attribute typically represents the 'usual' amount reported by the respondent ('usual' travel time, fare, headway, etc). These 'usual' levels are then adjusted to produce high and low levels of the attribute. For example, Hollander (2005a) sets mean travel times randomly between 70% and 130% of the usual travel time.

Jackson & Jucker (1982) estimated the trade-off that people were willing to make between mean travel time and the variance of travel time. They designed their survey so that a wide range of trade-offs was available to respondents. Despite this, they still experienced non-trading. Jackson & Jucker used an iterative approach to estimate respondents' willingness to trade off between mean travel time and the variance of travel time. They presented respondents with two alternatives:

- Alternative A – a long time and no significant delays, or
- Alternative B – a short time and a relatively low amount of variability.

[3] A Monte Carlo method is a technique that involves numbers and probability to solve problems. The simulation calculates multiple scenarios of a model by repeatedly sampling values from the probability distributions for the uncertain variables and using those values within the model.

Gradually, the time differences between the two options and the levels of variability were increased until the respondent switched from alternative A to alternative B. The iterative approach has the advantage that it can produce willingness to trade off in each respondent. However, the iterative approach is less applicable for research where the focus is on trade-offs between multiple variables.

Hollander (2005a) chose an unorthodox method to generate travel times:

- The first travel time was chosen randomly subject to its lying no more than two standard deviations (SDs) away from the mean.
- The second travel time was within 1.5 SDs from the mean.
- The third travel time was within 1 SD from the mean.
- The fourth and fifth travel times were determined so as to ensure that the target mean travel times and target travel time variability was achieved.

However, generating realistic levels of the reliability attribute is more difficult. Three basic approaches are used:

- **Use of respondents' reports to infer the existing level of reliability.** For example, Bates et al. (2001) asked respondents about the proportion of trains that were:

  - more than 5 minutes early
  - on time or up to 5 minutes early,
  - up to 10 minutes late,
  - between 11 and 30 minutes late,
  - between 31 and 60 minutes late, or
  - more than 60 minutes late.

  and their responses were used to generate bar charts and 'clockfaces'.
- **Use of formulas to predict reliability.** For example, Small et al. (1995) predict the SD of travel time by assuming that SDs were larger for commuters whose travel time was longer. Hollander (2005a) adopts a similar approach: travel time variability is set randomly between 1 minute and 40% of the mean travel time.
- **Use of existing literature on levels of reliability.** For example, Black & Towriss (1993) imply that they use estimates of the coefficient of variation (between 0.1 and 0.3) to generate levels.

The distribution of representative trips should depend on the assumed underlying distribution of travel time. For example, Noland et al. (1998) and Small et al. (1995) assumed that travel times for car commuters were distributed log-normally. Therefore, they represented travel times as the 1^{st}, 3^{rd}, 5^{th}, 7^{th} and 9^{th} deciles in a log-normal distribution, for a given standard deviation.

5 Review of reliability valuation methods and findings

5.1 Measures

Three main measures are used for valuing reliability:

- value of delay minutes (average minutes' lateness),
- the reliability ratio (variance approach), and
- scheduling costs.

Each of these is discussed in turn.

5.2 Approaches for estimating the value of reliability

5.2.1 Categories

All of the research undertaken to date can be categorised into one of the three basic models described in Table 5.1.

Table 5.1 Models used in valuing public transport reliability.

Model type	Model equation	Example
Mean delay model	Utility = $T + \lambda\ E(DM)$ where : T = scheduled travel time $E(DM)$ = expected delay minutes after schedule	MVA Consultancy Ltd. (2000)
Variance delay model	Utility = $T + \lambda\ f(S)$ where : T = scheduled travel time $f(S)$ = SD or coefficient of variation of travel time	Black & Towriss (1993)
Scheduling model	Utility = $\alpha E(T) + \beta E(SDE) + \gamma E(SDL) + \theta P$ where: $E(T)$ = expected travel time $E(SDE)$ = expected time before Preferred Arrival Time (PAT) (SDL) = expected time after PAT P = probability of arriving after PAT	Hollander (2005a), based on Small (1982)

5.2.2 The mean delay approach

The mean delay approach incorporates either delays or expected delays into the estimated utility function. The approach focuses on delays relative to schedule and therefore is only applicable to public transport.

The value of delay minutes (or average minutes' lateness) is discovered by calculating the amount that people will pay to avoid a given probability of a delay of a given size. This willingness to pay is then corresponded to average minutes saved. For example, suppose commuters are willing to pay $0.50 to avoid a 1 in 10 probability of 10 minutes' delay. The average minutes saved would be (1/10) x 10 = 1. Therefore, each delay minute has a value of $0.50 (or $30/hour).

The value of delay minutes can vary, depending on the level of risk. For example, BECA (2002) found that delay minutes were valued at:

- $1.30/minute for a 1/5 probability of delay, and
- $1.06/minute for a 1/10 probability of delay.

Values of delay minutes are normally associated with models that represent mean delay using data given as the probability of delay.

5.2.3 The variance delay approach

The variance delay approach attempts to value variability in travel times explicitly by incorporating it into an estimated utility function. The main measures of variability used are standard deviations and coefficients of variation. The variance delay approach is commonly applied, perhaps because it is relatively easy to implement and it produces reliability ratios.

The reliability ratio is commonly associated with studies where respondents are presented with representative trips in a stated preference format. To calculate the reliability ratio, researchers estimate a utility function and then divide the coefficient on the standard deviation of travel time (generally) by the coefficient of travel time. The reliability ratio can be easily used to value improvements in transport reliability.

However, it is interesting to note that MVA Consultancy Ltd. (2000) used a probability of delay representation and were still able to estimate reliability ratios. But to do this, the researchers would have had to assume an underlying distribution for the data. In addition, the researchers were making the presumption that early arrivals have zero value (or cost) to travellers.

5.2.4 The scheduling cost approach

The scheduling cost approach directs attention away from actual variability and towards the costs of variability, i.e. the costs associated with being early or late.

The scheduling cost approach presents respondents with a Preferred Arrival Time (PAT) (e.g. a time when they want to be at their destination) and gives them a choice of alternatives. Each alternative has different implications for the respondent's arrival relative to their preferred arrival time. The scheduling cost approach uses their responses to infer the cost associated with being early or late to the destination.

The scheduling cost approach is often preferred in academic studies because it has strong theoretical grounds and perhaps because it focuses on the main reasons why travellers value reliability: they want to get to work on time without leaving home too early.

However, the scheduling cost approach only produces values of 'early time' and 'late time' *relative to preferred arrival times*. As Bates et al. (2001) note, obtaining a 'value of reliability' would require additional work: researchers would need to simulate the impact of changes in variability on people's arrival times and then calculate the cost of those changes in arrival times using their estimated values of 'early time' and 'late time'. Additional information on people's preferred arrival times would also be required in order to do this.

To calculate scheduling costs, the researcher presents respondents with alternate options with different schedules of representative travel tips. Each option will have different scheduling costs. For example, one option might get the commuter to work early by ten minutes on average; the other option might get the commuter to work late by five minutes on average.

Based on commuters' stated preferences, the researcher infers the likely value associated with:

- a minute of earliness (minutes before preferred arrival time), and
- a minute of lateness (minutes after arrival time).

The researcher can also incorporate non-linearities into the estimation method. It is common for researchers to add a 'penalty' based on the likelihood of being late by any amount of time. Other non-linearities can also be accommodated.
Values of mean delay have been estimated using scheduling models (Bates et al. 2001). However, detailed information about the distribution of passengers' preferred arrival times are required, and this can be problematic.

5.3 Estimating utility functions using Logit models

Most reliability studies estimate utility functions using Logit models. Estimating reliability ratios (variance delay model) and value of delay minutes (average minutes' lateness) is generally quite straightforward: both the change in reliability and the change in travel-time are entered into the utility functions, and the estimated reliability coefficient is divided by the estimated travel-time coefficient so a relative valuation can be obtained.

Estimating the scheduling costs involves a few (minor) additional steps: the researcher must create variables to represent scheduling costs (for example, expected minutes early, expected minutes late and a variable representing the proportion of trips that are late). Changes in the levels of those scheduling cost variables (compared with a distribution of preferred arrival times) are then incorporated into the utility functions.

5.4 Valuation findings

5.4.1 Valuations in the literature

Tables 5.2–5.5 summarise reliability valuations from the literature review, and are segmented by model type (variance/mean delay) and, where possible, by the source of delay (delay on pickup or delay in vehicle). Although evidence of scheduling model valuations appeared in the literature, almost all related to car-based modes, apart from the rail work undertaken by Bates et al. (2001). As such, schedule model valuations have not been included.

Table 5.2 Reliabilty valuation evidence from New Zealand.

Reference	Market/context	Model/source	Valuations (mins of IVT*)	Comments
Booz Allen Hamilton (2002)	SP/study review	Variance/combined	0.8 minutes IVT per 1.0 minute change in standard deviation of journey time	Based on UK findings
BECA (2002)	SP	Mean/combined	0.74 (based on 1 out of 10 trips being late) for a 1.0 minute change in AML	No significant difference between commuter and other trip purposes
Booz Allen Hamilton (2000)	Study review	Mean/wait	5.0 for a 1.0 minute change in unexpected wait time	
Steer Davies & Gleave (NZ) Ltd. (1991)	SP	Mean/combined	1.75 for a 1.0 minute change in AML	

* IVT = In-Vehicle Time

Table 5.3 Reliability valuation evidence from Australia.

Reference	Market/ context	Model/source	Valuations (mins of IVT)	Comments
NSW				
Douglas (2005)	Rail SP	Mean/combined	All: 2.9 for a 1.0 minute change in AML Peak: 2.3 Off-peak: 3.5	Valuation of 1 minute's lateness (based on preferences involving 10%/20% of trains being 5/10 minutes late) Value reduces with trip length
Hensher & Prioni (2002)	Bus SP	Mean/combined	1.82 for a 1.0 minute change in AML	Survey of 3800 respondents from 25 bus operators in New South Wales
Booz Allen Hamilton 2001	Bus/ferry SP	Mean/combined	Ferry peak 1.7 for a 1.0 minute change in AML Ferry off-peak: 2.2 Bus peak: 7.8 Bus off-peak: 6.2	Lower valuation for ferry and higher valuation for bus - owing to waiting conditions and also the fact that ferry passengers can see service a long way off which reduces the uncertainty associated with reliability
Douglas (1996)	Bus SP	Mean/combined	9.7 for a 1.0 minute change in AML	
Victoria				
Booz Allen Hamilton (2006)	Rail SP	Mean/combined	**Suburban – short distance** Work: 3.3 for a 1.0 minute change in average minutes lateness Education: 2.3 Other: 3.0 Population: 2.9 **Suburban – long distance** Work:1.5 Education: 2.1 Other: 1.3 Population: 1.6 **Long distance** Work:1.8 Edu: 1.8 Other: 1.9 Population: 1.9	
Bell (2004)	Rail SP	Mean/combined	Trains always within 5 minutes of timetabled time: 2.2 minutes No more than 1 peak cancellation per week: 1.2 minutes	Contingency valuation

Table 5.4 Reliability valuation evidence from the UK.

Reference	Market/ context	Model/ source	Valuations (mins of IVT)	Comments
Passenger Demand Forecasting Handbook	UK Rail Manual	Mean/ combined	**Airport journeys:** Full fare & season: 6.5 for a 1.0 minute change in AML Restricted: 6.5 **Long distance high speed:** Full fare & season: 6.1 Restricted: 4.2 **All other:** Full fare & season: 2.5 Restricted: 2.5 **Overall: 3.0**	Treats early arrivals as being 'on time' A cancelled train is equivalent to a late arrival of 1.5 times the service interval Delays advertised in advance (such as engineering works) should be treated as scheduled journey time for people who are aware, and the same as other delays for unaware - recommended split 25% aware, 75% unaware Suggestion of 6 month lag between level of reliability change and revenue impact
Transport for London (2007)	London Underground Manual	Mean/IVT	On-train delay weights: 1st minute: 1.0 2nd minute: 1.0 3rd minute: 1.0 4th minute: 1.2 5th minute: 1.6 6th minute: 2.0 7th minute: 2.4 8th minute: 2.8 9th minute and beyond: 3.0	Average weight during each minute LUL
Hollander (2005a)	York, UK SP	Variance/ combined	Bus: 0.10 per 1.0 minute change in SD of journey time Rail: 0.16	Rail only sample of 20
Black & Towriss (1993)	SP	Variance/ combined	Bus: 0.51 22 per 1.0 minute change in SD of door-to-door journey time Rail: 0.63	Survey was based around door-to-door travel times rather than IVTs or wait times
Bates et al. (1997)	Review of Network South End survey data	Variance/ combined	Commuters: 1.04 to 1.22 per 1.0 minute change in SD of journey time Leisure: approx 0.66	
Benwell & Black (1985)	Intercity Rail SP	Mean/ combined	3.0 minute change in AML	

Table 5.5 Reliability valuation evidence from other countries.

Reference	Market / context	Model / source	Valuations (mins of IVT)	Comments
De Jong et al. (2004)	France - Bus study review	Variance/IVT Variance/ Wait	0.24 per 1.0 minute change in SD of IVT 0.48 per 1.0 minute change in SD of wait time	Stated preference of 309 bus users in France by MVA Consultancy Ltd. (2000)
Blomquist & Jansson (1995)	Study review	Mean/ combined	12 for a 1.0 minute change in AML	
Kouwenhoven et al. (2006)	Paris SP	Mean/ combined	Delay between 5 and 15 mins: First 3 services (out of 20): 5.27 for a 1 minute change in AML Next 3 services: 4.76 More than 7: 3.45 (commuting/ education) 1.90 (other) Delay more than 15 mins First 3 services (out of 20): 7.62 More than 4: 6.15	Suburban rail users
Geerts & Haemers (2004)	Brussels - Tram SP	Mean/ combined	Approx. 4 for a 1.0 minute change in AML	Tram users
Rietveld et al. (2001)	SP	Mean/ combined	2.4 for a 1.0 minute change in AML	Based on 781 public transport users in the Netherlands
MVA Consultancy Ltd. (2000)	Rail	Mean/ combined Variance/ wait Variance/IVT	5.25-13.75 for a 1.0 minute change in AML 0.48 per 1.0 minute change in SD of wait time 0.24 per 1.0 minute change in SD of IVT	
Rohr & Polak (1998)	Bus SP	Variance/ wait Variance/IVT	1.3 per 1.0 minute change in standard deviation of wait time 1.6 per 1.0 minute change in standard deviation of IVT	
Polak & Hazelton (1997)	Bus	Variance/ wait Variance/IVT	**Bus wait time SD:** By journey purpose: Work: 2.5 per 1.0 minute reduction in SD of wait time Shopping: 1.0 Other: 1.9 * By time period: Peak: 3.0 Off-peak: 1.2 **Bus in-vehicle time SD:** By journey purpose: Work: 2.0 per 1.0 minute change in SD of IVT Shopping: 0.8 Other: 2.3 * By time period: Peak: 1.8 Off-peak: 1.2	Suggests similar valuation to scheduled wait time * not significant
Algers et al. (1995)	Sweden - rail SP	Mean/ combined	1.5 for a 1.0 minute change in AML	Long distance trains
MVA Consultancy Ltd.(2000)	Rail	Mean/ combined Variance/ combined	Mean delay: Commuters: 1.25 for a 1.0 minute change in AML Leisure: 2.5 Reliability Ratio: Commuters: 2.8 per 1.0 minute change in SD of journey time Leisure: 1.3	A one-in-ten chance of delay by one minute

5.4.2 Mean delay valuations

Evidence for mean delay valuations is more extensive than variance delay, and has, in some cases, been segmented by mode and trip purpose. Sources range from individual local studies, using mostly SP approaches, through to guidelines and handbooks with recommended approaches/parameters.

Most valuations are not explicit about the source of the delay (whether it be delay on passenger pickup or delay while in the vehicle), and tend to represent delay as the overall impact if a service is late/early. The evidence that does exist suggests passengers value delay while waiting higher than delay when on the vehicle. Booz Allen Hamilton (2000) recommends a fivefold weighting for unexpected wait time, whilst the Transport for London Business Case Development Manual (Transport for London 2007) recommends weightings ranging from 1 to 3 times that of in-vehicle delay.

Overall, the average of the studies listed above suggests that an average minute's delay is worth four minutes of IVT, with a higher valuation for passengers picked up later and a lower valuation for passengers already on the vehicle. A large range has been noted across sources, with valuations as high as 13.75. No consistent relative valuations of peak v. off-peak, bus v. rail, or trip purpose have been made, which suggests that reliability valuations, when segmented, are very context-specific. It should also be noted that people who value reliability highly are likely to use choose modes that are more reliable.

5.4.3 Variance delay valuations

Whilst less evidence is available for variance of delay valuations, the studies that exist tend to provide more insight into the relative importance of pickup v. IVT variations. Overall, an average reliability ratio of around 1 is seen in the studies, meaning a one minute change in the variation (standard deviation) of delay is valued the same as one minute of IVT. The evidence also suggests variation of wait times is valued around 20% higher than variation of IVT. As with the mean delay valuations, the range of valuations is large, up to 2.8 times IVT and as low as 0.1 times IVT, with little evidence of consistence differences between modes and trip purposes.

5.4.4 Valuation summary

Examination of reliability attribute valuations suggests large variations, indicating the valuations to be highly context-specific. On average, one minute of average lateness is valued at around 4 times IVT. In terms of variability of service reliability, the evidence suggests one minute of standard deviation of lateness is worth one minute of IVT. Valuations for waiting passengers are generally higher than for passengers on the service. Little evidence suggests any consistent differences by mode, time of day or trip purpose.

6 Reliability SP survey

6.1 Possible approaches

As discussed in Chapter 4, in general, two methods for determining passengers' valuation of reliability exist: revealed preference and stated preference approaches. The lack of consistent patronage data when reliability improvements occurred meant that revealed preference methods could not be used in this study. As such, a stated preference survey was undertaken to determine passengers' preferences for different levels of reliability and other related issues.

This chapter outlines the development of the survey, particularly the thought processes that contributed to the final design. The survey process is discussed, including pilot surveys and findings.

6.2 Why does reliability matter?

Chapter 2 outlines some of the issues that public transport users face when using an unreliable service. In particular, public transport users are concerned about lateness on arrival at their destination, which can be caused by unreliability both at pickup and during the trip. A cost is also associated with early services as passengers get distressed – they do not know if they have missed the service or if, having missed their preferred service, they are required to wait for the next. For passengers that are on the service, however, early running could be viewed as a benefit because of the reduced journey times. In general, passengers are irritated by a service that does not follow its schedule.

As such, any developed survey needs to explore late and early running services for bus and train modes. Ideally, it should explore the effect of delay in waiting for services (unexpected wait time) and delay *en route*.

6.3 Parameter valuation

A review of reliability methodology frameworks in Chapter 5 identified three main measures used for valuing reliability:

- the value of delay minutes (AML),
- the reliability ratio (variance delay approach), and
- the scheduling model.

A scheduling model (variability relative to a preferred arrival time) was not chosen as the preferred valuation methodology, primarily because a distribution of preferred arrival times in many cases needs to be assumed – and, as such, limits the usefulness of the approach.

The structure of a delay model SP survey (variability relative to a schedule) can be used to examine both a reliability ratio and a valuation of delay minutes, as the contained variables are applicable to both forms. Furthermore, a delay approach has other benefits:

- it can be used focus on non-linearities in the value of lateness;
- is is easier to implement, as passenger impacts can be determined from service statistics without the need for passengers' preferred arrival times; and
- it is an easier concept for respondents to understand.

Another advantage of the delay model is that standard deviation around average lateness may be important. For example, passengers might be happy with a service that is consistently late as they can change their trip behaviour accordingly (e.g. always arriving at the service five minutes later than the scheduled time). As a further illustration, both distributions below have the same mean delay (disregarding non-linearities) but the first distribution might be preferred because it has the smaller standard deviation:

2	2	2	2	2	→	mean delay = 2,	SD =0
0	0	0	0	10	→	mean delay = 2,	SD = 4.5

Therefore, to the extent possible, the SP exercises were designed so that any combination of mean delays or standard deviations could be explored. The research could fit a model with mean delays only, standard deviation only or a combination of both.

6.4 Presentation of reliability

As mentioned previously, unreliable services hinder passengers in the following ways:

- pickup variability (unexpected wait time),
- IVT variability, and
- arrival variability.

Early on in developing the survey's methodology, we examined two distinct models (see Table 6.1). The first (Model 1) looked at varying one aspect of reliability at a time, with three variants (a, b, c) based on this list. The second (Model 2) looked at varying two aspects of reliability simultaneously: departure and in-vehicle times.

Table 6.1 Potential presentation of variability in SP exercises.

Model	Source of variability	Variability attributes presented	Other information	Pros/cons	Status
1a	• Arrival times vary	Distribution of arrival time difference to schedule	The distribution of late arrival times would not be explicitly attributed to either departure variability or travel time variability	**Pros:** • presentation relatively simple **Cons:** • presentation would not identify the cause of arrival time variability	Model excluded as capturing the same valuation as 1b/1c (because of the linear relationship)
1b	• Departure times vary • Travel time fixed	Distribution of departure time difference to schedule	The respondent would be told that the service will travel for a fixed period of time (e.g. 20 mins). This would imply that arrival times will be delayed by the same amount of time.	**Pros:** • presentation is relatively simple • contribution of departure time variability isolated **Cons:** • presentation contrived • contribution of travel time variability ignored	Model included as SP1
1c	• Departure times fixed • Travel times vary	Distribution of in-vehicle delay compared with schedule	The respondent would be told that the service would pick them up on time.	**Pros:** • presentation is relatively simple • contribution of travel time variability isolated **Cons:** • presentation contrived • contribution of departure time variability ignored	Model included as SP2
2	• Departure times vary • Travel times vary	• Distribution of departure times • Distribution of arrival times*		**Pros:** • presentation gives more realistic scenarios • interactions between departure and travel time variability can be explored **Cons:** • presentation is complex and onerous for respondents	Model excluded as highly complex.

*In Model 2, the distribution of departure times and a distribution of travel times were combined to create the distribution of arrival times.

Model 2 (varying departure and in-vehicle reliability simultaneously) was excluded early in the process because of the complexity of the survey design. Varying both would require complex trade-offs by the respondents, and might result in confusion and unrealistic trading between services. It was decided that the simpler approach of examining one aspect of reliability at a time was more desirable. Model 1a was then excluded as arrival time variation is a result of either delay at pickup or delay *en route* (arrival time = departure time + travel time), and these would be captured by Models 1b and 1c.

It was decided to take Models 1b and 1c forward as part of the survey process. These would form two SP surveys that each respondent would be asked to complete. The first related to departure time reliability; the second, IVT reliability.

We decided to present reliability in terms of the number of services (out of 10) 5 minutes early, the number that were 5 minutes late and the number that were 10 minutes late. The level of reliability (numbers presented) was varied between scenarios, and was fixed for all respondents.

The SP survey was designed to provide valuations for earliness, being 5 minutes late and being 10 minutes late. Our initial hypothesis was:

- Early departure time would be valued highly because of the risk that some passengers would miss a service.
- Reduced ('early') IVT is likely to have a lower valuation, as some passengers may see the reduction in travel time as a bonus.
- Five minutes' lateness should have a higher valuation than IVT but also have a lower valuation than ten minutes' lateness or ten minutes' earliness.

6.5 SP survey design

The questionnaire design is extremely important, particularly in SP surveys where respondents are usually asked about complex hypothetical situations. The information needs to be relayed to respondents in a clear and concise manner so that the decision making process is as simple as possible.

An SP showcard gives a respondent the choice between two scenarios with differing levels of reliability and travel characteristics. Generally, the respondent trades off a more reliable, more expensive and shorter scheduled time service against a less reliable/cheaper/longer service. How the respondent trades gives an indication of the value they place on reliability, cost and travel time.

To encourage respondents to trade, the showcards presented need to have sufficient variation, while still providing realistic options. Variation can be controlled by the number of levels presented for each variable and by the tolerance around a central value. The central value (for scheduled travel time and fare) is based on the respondents' current trip-making characteristics so as to provide realistic alternatives. The number of levels is based on the number of showcards that are to be presented and the number of variables included. The more showcards presented, the richer the dataset; however, the longer the survey, the higher the chances of fatigue.

The project team decided to use a 16 showcard design for each of the two SPs (32 cards in total). Both SPs were then split in half, with each respondent being asked to respond to 8 cards from each SP (a total of 16 cards per respondent), as it was felt that 32 cards would be too onerous for an individual.

The design for the departure time variability survey would include five variables:

- scheduled trip time (at 4 levels),
- trip fare (at 4 levels),
- the number of trips about 5 minutes early on departure (at 3 levels),
- the number of trips about 5 minutes late on departure (at 3 levels), and
- the number of trips about 10 minutes late on departure (at 3 levels),

The in-vehicle time variability survey would include 4 variables:

- trip fare (at 4 levels)
- the number of trips about 5 minutes early whilst on service (at 3 levels),
- the number of trips about 5 minutes late whilst on service (at 3 levels), and
- the number of trips about 10 minutes late whilst on service (at 3 levels).

Scheduled travel time (not included in the IVT SP survey) and fare paid were both included in the SP survey as well as the reliability variable. The inclusion of fare (in addition to minutes of IVT) was recommended because it enables the estimation of a value of time (which is a useful 'check' on the validity of the survey), it disguises the trade-offs from the respondent to the SP survey, and prevented 'over-rationalisation'.

Scheduled travel time was excluded from the in-vehicle survey as it was felt that including in-vehicle time then varying in-vehicle time would confuse respondents.

The inclusion of headway (as an attribute) was avoided for two reasons:

- frequency can overwhelm the other attributes and reduce the accuracy of estimates of the other attributes; and
- hypothetical changes in frequency can confuse the respondent. For example, a service that is halved in frequency will mean that the respondent has a 50% chance of catching the bus that they currently catch – communicating this to respondents would be very difficult.

Respondents were asked to assume that services ran as frequently as they currently do. Although headway was not included as an attribute, the headway of the respondent's current service was recorded. The headway of the respondent's current service could then be used as an explanatory variable if further analysis was required.

The levels on the showcard were presented in such a way that the experiment was orthogonal. The in-vehicle time SP included the same variables and number of levels, but trip time was excluded as it was felt that including this (at varying levels) would cause confusion if trip time was changed for reliability reasons.

Differing approaches have been used to represent reliability in SP surveys with varying degrees of success (see Chapters 4.2 and 4.3). The following representation mechanisms were considered:

- the clockface design,
- the bar-chart design,
- the pie-chart design, and
- text descriptions.

The standard method used in the literature is a set of representative trips using either a clockface design or bar-chart design. In the end, the combination of a bar-chart (but using pictures of vehicles) and text descriptions were used to outline the scenarios presented in the showcards (see

Introduction

You will now be asked about 8 scenarios and for each scenario you will be asked to choose between two services, either A or B.

Firstly we are going to show you an example scenario... Pretend that your current train service for your usual **work** trip is to be replaced by either Service A or Service B. Both services run with your current level of frequency (a service every 20 minutes minutes).

However, Service A and Service B have different fares, travel times, and certainty of being picked up on-time – an example of this is shown below:

When we say that 1 in ten will be five minutes early, we mean that over a period of time, this will be your average experience. You will not be able to predict when the early arrival will occur, but you will find that if you always arrive at the scheduled time, you will miss the service on 10 percent of occasions and have to wait for the next service.

When we say that 2 in ten will be five minutes late, we mean that over a period of time, this will be your average experience. You will not be able to predict when the late arrival will occur, but you will find that if you always arrive at the scheduled time, you will have to wait an extra 5 minutes for the service to arrive on 20 percent of occasions. This may cause you to arrive late at your destination, and inconvenience you.

Which service would you prefer?

Service A	Service B
Certainty of Pick-up Times: On average, for every ten times you make this trip:	**Certainty of Pick-up Times:** On average, for every ten times you make this trip:
- **One** will pick-up about **5 minutes early**.	
- **Nine** will pick-up **on-time**.	- **Seven** will pick-up **on-time**.
	- **Two** will pick-up about **5 minutes late**.
	- **One** will pick-up about **10 minutes late**.
Time in train: 32 minutes	**Time in train: 37 minutes**
Fare: $6.00	**Fare: $5.20**
Prefer A	**Prefer B**

You can assume that if a train is late (early) picking you up then it will be late (early) arriving at your destination.

Service A is sometimes early: You could risk missing the service, or you would have to get to your stop early (every day).

Service B is unpredictable and often late: You might have to wait at the stop/station for some time. Alternatively, to ensure you get to your destination on time, you might have to catch an earlier service.

Figure 6.1), as this would give the clearest explanation and would appeal to visual and non-visual respondents alike. The pie-chart option was disregarded as it was felt some respondents would be unable to understand or fully appreciate proportional representations.

Introduction

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When we say that 2 in ten will be five minutes late, we mean that over a period of time, this will be your average experience. You will not be able to predict when the late arrival will occur, but you will find that if you always arrive at the scheduled time, you will have to wait an extra 5 minutes for the service to arrive on 20 percent of occasions. This may cause you to arrive late at your destination, and inconvenience you.

Which service would you prefer?

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Certainty of Pick-up Times: On average, for every ten times you make this trip:	Certainty of Pick-up Times: On average, for every ten times you make this trip:
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- **Nine** will pick-up **on-time.**	- **Seven** will pick-up **on-time.**
	- **Two** will pick-up about **5 minutes late.**
	- **One** will pick-up about **10 minutes late.**
Time in train: 32 minutes	Time in train: 37 minutes
Fare: $6.00	Fare: $5.20
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You can assume that if a train is late (early) picking you up then it will be late (early) arriving at your destination.

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Figure 6.1 Screenshot of a departure time variability showcard.

Respondents were presented with ten trips, each represented by an icon, with a different number of services within these trips displaying certain reliability traits. Ten trips were chosen, as this would represent two working weeks' worth of trips; five trips did not give enough scope to vary reliability levels.

Table 6.2 outlines the final design of the showcards and the values at each level. The values were determined by simulating a sample of 100 respondents with random values of time around an average value of $10/hour, and simulating the proportion that would trade under differing tolerances for each level. A balance was reached whereby the number of non-traders were minimised, while retaining the credibility of the options presented.

Table 6.2 Final SP survey design.

SP	Attribute	Service	Levels (relative to central value)			
			1	2	3	4
Departure time variability	Trip time	A	115%	110%	105%	100%
		B	85%	90%	95%	100%
	Fare	A	68%	76%	84%	92%
		B	132%	124%	116%	108%
	Number of trips (out of 10) that are about 5 minutes early	A	0	0	1	Only at 3 levels
		B	0	0	0	Only at 3 levels
	Number of that are about 5 minutes late	A	2	2	2	Only at 3 levels
		B	0	1	2	Only at 3 levels
	Number of trips that are about 10 minutes late	A	2	2	2	Only at 3 levels
		B	0	1	2	Only at 3 levels
IVT variability	Fare	A	88%	91%	94%	97%
		B	112%	109%	106%	103%
	Number of trips (out of 10) that are about 5 minutes early	A	0	0	0	Only at 3 levels
		B	0	1	2	Only at 3 levels
	Number of that are about 5 minutes late	A	2	2	2	Only at 3 levels
		B	0	1	2	Only at 3 levels
	Number of trips that are about 10 minutes late	A	2	2	2	Only at 3 levels
		B	0	1	2	Only at 3 levels

6.6 Survey delivery

6.6.1 Recruitment and delivery

A survey specification was provided to the market research company. The target population was defined as:

'All bus users in Auckland and Wellington, and all train users in Wellington.'

The survey was conducted online using SmileCity, and was customisable to a user's response (particularly their current trip-making behaviour). SmileCity has an online membership pool of around 130 000 users, who earn rewards by completing online surveys.

6.6.2 Sample size and selection

It was decided that quotas were required so that reasonable results could be estimated when the market was segmented (See Table 6.3). The segments decided on were geography (Auckland/Wellington), mode (bus/train) and trip purpose (work/education/other). The pilot showed that education trip purposes would provide the biggest recruitment challenge, so the quotas for these segments were set lower. Also, a priority selection (education, work then other) was initiated whereby if a respondent had used public transport for several purposes, then the segments that would be hardest to obtain would be sampled first. This meant that the sample obtained as part of this study is not a random sample.

Respondents were only selected if they lived in Auckland or Wellington, and if they had made a return trip on public transport in the last month. Very occasional users of public transport were not included in the sample, as they would be unlikely to provide realistic insights into reliability.

Table 6.3 Final SP survey quotas for our survey.

Mode	Location	Purpose	Quota target
Bus	Auckland	Work	50
		Education	30
		Other	50
Bus	Wellington	Work	50
		Education	30
		Other	50
Train	Wellington	Work	50
		Education	30
		Other	50
Total			**390**
	Bus		260
	Train		130
		Work	150
		Education	90
		Other	150

6.6.3 Design

The online survey had four distinct phases and is given in Appendix A:

- Phase 1: current usage questions,
- Phase 2: SP 1 - departure time variability,
- Phase 3: SP 2 – IVT variability,
- Phase 4: demographic.

The answers to current usage and demographic questions provided input to the SP surveys and gave the basis for possible market segmentation, as well as criteria for data expansion.

6.6.4 Pilot survey

Two pilot surveys were undertaken. These were used to evaluate respondent comprehension (particularly given that the survey was self-conducted), and whether the data produced enough variation to analyse. The first pilot was unsuccessful owing to insufficient tolerances and variations in the scenarios provided, and resulted in a high proportion of non-trading respondents. However, little evidence suggested difficulties in comprehension and fatigue. As such, the results from the first pilot could not be used in the full survey. The second pilot provided a more acceptable level of non-traders and the results of this pilot were pooled with the full survey.

7 Survey results and implications

This chapter summarises some of the key findings from the survey conducted as part of this project. The survey collected a significant amount of information about public transport passengers' trip-making behaviour, with a particular focus on reliability as an issue. As such, it produced a rich dataset of around 750 useable surveys (and around 13 500 stated preference results). Further interrogation of the dataset could be undertaken at a later stage to examine other trip-making behaviour not covered in this analysis.

7.1 Market segments

Analysis of passengers' attitudes to reliability have been undertaken using market segments defined by geography (Auckland/Wellington), mode used (bus/rail) and trip purpose (work/education/other). Other possible segmentation data were collected such as time (of day) of travel, trip length (in minutes), trip frequency (per week) and service frequency, which could also be used to segment the data. However, including trip purpose served as a good proxy for time of day, and weighting the stated preference survey by trip frequency reduced the need for further segmentation. Table 7.1 provides a summary of the size of each segment.

Table 7.1 Segment sizes in the SP survey.

Mode	Location	Purpose	Observations	Proportion
Bus	Auckland	Education	33	4%
		Medical	7	1%
		Shopping	52	7%
		Social	47	6%
		Work	82	11%
Bus	Wellington	Education	41	5%
		Medical	6	1%
		Shopping	70	9%
		Social	46	6%
		Work	104	14%
Rail	Wellington	Education	24	3%
		Medical	4	1%
		Shopping	42	6%
		Social	81	11%
		Work	112	15%
Total			**751**	**100%**

For the analysis of the SP survey medical, shopping and social trip purposes were classed as 'other' (shopping and social purposes could be estimated separately). Survey quotas were set by geography, mode and purpose, with education trips by rail in Wellington being the only quota not to be reached (24 observations out of a quota of 30).

7.2 Passenger trip timing

In the survey, respondents were asked approximately how early they arrived at the stop/station before the service was scheduled to depart, with answers provided as numerical values. Respondents were also able to tick a box if they arrived randomly.

This information is particularly useful when examining the impact of early running services on passengers. Table 7.2 shows the average passenger wait time and the proportion of random arrivals under varying levels of service. Between headways of 5 and 15 minutes, passengers tend to arrive at half the headway on average, with a high proportion of random arrivals at 5 and 10 minutes. At frequencies lower than 15 minutes, passengers tend to time their journeys more to the schedule, as reflected by the lower proportion of random arrivals and average wait times (as a proportion of headway).

A 'theoretical' average wait time (based on a calibrated function using UK-based wait time literature) provides a good comparison with the survey average wait times, particularly at lower and higher frequencies. This comparison is useful as it shows that the arrival behaviour (to the stop/station) of the New Zealand passengers in this survey is not too different from international experience.

Table 7.2 Passenger trip timing by service frequency.

Reported headway (mins)	Proportion of random arrivals	Mean reported wait time[a] (mins)	Overall mean wait time[b] (mins)	Theoretical average wait time[c] (mins)	Overall mean wait time proportion of headway
5 (n=18)	83%	3.3	2.6	2.4	53%
10 (n=72)	49%	4.9	5.0	4.0	50%
15 (n=146)	29%	6.2	6.6	5.5	44%
20 (n=121)	21%	7.6	8.1	6.8	41%
30 (n=271)	20%	7.2	8.7	9.2	29%
45 (n=21)	24%	8.8	12.1	12.5	27%
60+ (n=83)	22%	10.5	16.5	18.1	23%
Average (n=732)	27%	7.3	8.7	8.5	31%

Notes to Table 7.2:

a This excludes random arrivals.

b Random arrivals are assumed to wait half the headway.

c This is the theoretical average, calculated using function 0.72*hdwy^0.75 (based primarily on the Passenger Demand Forecasting Handbook).

Table 7.3 provides a cross-tabulation of reported wait time by reported service headway. The most significant waiting time is 5–9 minutes, with a significant proportion of respondents saying they arrive 5 minutes before the scheduled service departure.

Interestingly, only 69 out of the 537 (13%) respondents (who didn't arrive randomly) timed their arrival to the stop/station within 5 minutes of scheduled service departure. This means that a service that arrived, say, 5 minutes earlier than scheduled departure could still pick up 87% of passengers that timed their journey to the schedule.

Given the low proportion of 'just-in-time' arrivals, the tendency seemed to be that passengers would build contingency into their trip timing to reduce the chance of missing an early service. Also, valuations of early service time in the SP survey could be lower than expected as only a small proportion would miss a service if it ran five minutes early; for the others, an early arrival could be seen as a benefit (reduced wait times).

Table 7.3 Number of observations by passenger trip timing and service frequency, excluding random arrivals.

Reported headway (mins)	Reported wait time (mins)				
	0–4	5-9	10-14	15+	Total
5	2	1	–	–	3
10	11	21	5	–	37
15	14	62	25	3	104
20	14	42	29	10	95
30	23	115	59	20	217
45	1	5	8	2	16
60+	4	20	20	7	65
Total	69	266	146	42	537

7.3 Current perceptions and attitudes to reliability

7.3.1 Method

A series of questions were asked relating to passengers' current perceptions and attitudes to reliability. The questions included were framed around:

- how important it is for them to arrive at their destination by a specific time,
- their current perceptions about their typical services level of reliability, and
- Statements on attitudes to delayed arriving, delay at pickup and delay *en route*

Responses to each of these are discussed in turn. In general, passengers were asked for attitudinal responses that ranged from 'not at all important' to 'very important', or from 'strongly disagree' to 'strongly agree'. Market segments were split by trip direction to determine whether the trip to the destination (e.g. work) was more important in terms of reliability than the reverse trip (returning home).

7.3.2 Importance of arriving on time

Table 7.4 shows the proportion of respondents (by segment and direction) placing different levels of importance on arriving at a specific time. Overall, 22% of respondents thought that arriving at a specific time was very important, with little distinction by direction. Similarly, little difference appeared when respondents were segmented by mode.

However, the differences are more marked when segmented by trip purpose. In particular, arriving at a specified time was seen as very important for medical (41%) and education (39%) trip purposes, with the trip to the medical centre (inward) having a higher importance than the trip home (outward). Arriving at a specified time is less important for shopping (11%) and social (17%) trip purposes, with the trip home after shopping being more important (possibly because passengers are carrying goods), and the outward trip being more important for social (possibly because of a need to be punctual when meeting people or appointments). Work trips fitted into the middle, with 24% rating arriving at a specific time as very important, with little difference by direction.

Table 7.4 Answers to the question 'How important is it to arrive at your destination by a specific time?'

Segment	Direction	Not at all important	Quite important	Very important
Auckland – bus	Both	19%	60%	21%
Wellington – bus	Both	18%	58%	24%
Wellington – rail	Both	18%	61%	21%
Education	Inward	8%	53%	39%
	Outward	8%	54%	38%
	Both	8%	53%	39%
Medical	Inward	0%	50%	50%
	Outward	0%	64%	36%
	Both	0%	59%	41%
Shopping	Inward	28%	63%	9%
	Outward	25%	61%	13%
	Both	27%	62%	11%
Social	Inward	30%	51%	19%
	Outward	30%	54%	16%
	Both	30%	53%	17%
Work	Inward	11%	64%	25%
	Outward	13%	65%	22%
	Both	12%	64%	24%
Total	**Inward**	**18%**	**59%**	**23%**
	Outward	**19%**	**60%**	**21%**
	Both	**19%**	**60%**	**22%**

Where respondents had answered 'very important', they were then asked to provide a reason. These reasons have been allocated to broad categories, with the results provided in Table 7.5. The most significant reasons for arriving at a stated time include the meeting of appointments, and work reasons.

Table 7.5 Reasons why it is `very important' to arrive at a destination at specific time.

Reason	Proportion
Appointments, schedule or time management	5.3%
Work reasons (other)	4.5%
School, lectures, other classes	2.8%
Work reasons (starting time obligations stated)	2.7%
Misinterpretation (did not interpret the question correctly)	2.3%
Personal dislike of lateness	2.3%
Connection to other transport	1.2%
Other	0.7%
Dropping child at school	0.1%
Total	**22%**

7.3.3 Perceptions of current service reliability

Respondents were asked about the reliability of their typical public transport service. The distinction was made between services picking them up on time, and services not being delayed whilst *en route*.

Table 7.6 shows little difference in the perception of service pickup reliability between modes and locations.

Table 7.6 Answers to 'My typical service usually picks me up on time.'

Segment	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Auckland – bus	9%	15%	26%	38%	13%
Wellington – bus	7%	15%	28%	36%	15%
Wellington – rail	6%	14%	25%	37%	18%
Total	**7%**	**15%**	**26%**	**36%**	**15%**

Table 7.7 also shows little difference in the perception of on-vehicle reliability between modes and locations.

Table 7.7 Answers to 'My typical service is not usually delayed while I am on it."

Segment	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Auckland – bus	7%	19%	26%	32%	16%
Wellington – bus	4%	13%	31%	36%	15%
Wellington – rail	5%	15%	29%	38%	14%
Total	**5%**	**15%**	**29%**	**36%**	**15%**

7.3.4 Attitudes to unreliable services

Respondents were asked to state their level of agreement with statements relating to their dislike of arriving late, uncertainty about pickup time (departure time variability), and uncertainty about being delayed while on the service (in-vehicle time variability).

Table 7.8 shows little difference between modes and geography. However, Auckland bus users, in particular, do not like services that cause them to be late to their particular destination, while Wellington rail users are more relaxed. Education and medical trip purposes have the highest dislike of lateness at the destination, with shopping and social the lowest – this is consistent with the findings in 7.3.2. Clear directional biases were also shown by trip purpose, with a greater dislike of lateness on the inward trips to work, and the outward trips from shopping.

Table 7.8 Answers to 'I dislike services that cause me to be late to my destination.'

Segment	Direction	Don't agree	Slightly agree	Agree	Strongly agree
Auckland – bus	Both	5%	18%	28%	50%
Wellington – bus	Both	6%	15%	35%	45%
Wellington – rail	Both	4%	16%	41%	39%
Education	Inward	3%	8%	29%	59%
	Outward	5%	10%	23%	62%
	Both	4%	9%	27%	60%
Medical	Inward	0%	33%	17%	50%
	Outward	0%	9%	36%	55%
	Both	0%	18%	29%	53%
Shopping	Inward	10%	21%	37%	32%
	Outward	7%	19%	33%	41%
	Both	9%	20%	35%	37%
Social	Inward	7%	17%	37%	39%
	Outward	4%	24%	34%	37%
	Both	6%	21%	36%	38%
Work	Inward	3%	13%	31%	52%
	Outward	1%	13%	44%	41%
	Both	2%	13%	37%	47%
Total	**Inward**	**5%**	**15%**	**33%**	**46%**
	Outward	**4%**	**17%**	**37%**	**43%**
	Both	**5%**	**16%**	**35%**	**44%**

In terms of departure time variability (Table 7.9), the same modal variations are seen as for arriving at the destination late, with departure variability disliked more on Auckland buses and less so on Wellington rail. Educational and medical trip purposes also have a higher agreement of dislike for departure time variability. However, the proportion of shopping and social trips disliking unreliable pickup times is higher than the proportion of those who disliked arriving at the destination late, indicating that passengers do not like waiting for an unreliable service no matter what the trip purpose.

Table 7.9 Answers to 'I dislike unreliable services because I become uncertain about when the next service will pick me up.' (departure time variability)

Segment	Direction	Don't agree	Slightly agree	Agree	Strongly agree
Auckland – bus	Both	5%	8%	30%	56%
Wellington – bus	Both	6%	10%	36%	48%
Wellington – rail	Both	5%	13%	41%	41%
Education	Inward	5%	7%	34%	54%
	Outward	8%	3%	36%	54%
	Both	6%	5%	35%	54%
Medical	Inward	0%	0%	33%	67%
	Outward	0%	9%	36%	55%
	Both	0%	6%	35%	59%
Shopping	Inward	7%	17%	36%	40%
	Outward	7%	13%	30%	49%
	Both	7%	15%	33%	45%
Social	Inward	5%	10%	37%	49%
	Outward	3%	13%	34%	49%
	Both	4%	11%	36%	49%
Work	Inward	6%	11%	35%	48%
	Outward	4%	8%	43%	45%
	Both	5%	10%	39%	47%
Total	**Inward**	**6%**	**11%**	**35%**	**48%**
	Outward	**5%**	**10%**	**37%**	**48%**
	Both	**5%**	**11%**	**36%**	**48%**

For in-vehicle time unreliability (Table 7.10), the same modal variations are seen. Interestingly, medical trip purposes strongly dislike delay *en route*, but this is based on a small sample.

Table 7.10 Answers to 'I dislike unreliable services because I become uncertain about when the service I am on will arrive at my destination.' (IVT time variability)

Segment	Direction	Don't agree	Slightly agree	Agree	Strongly agree
Auckland – bus	Both	5%	15%	29%	51%
Wellington – bus	Both	6%	15%	36%	44%
Wellington – rail	Both	4%	14%	41%	40%
Education	Inward	7%	10%	34%	49%
	Outward	10%	8%	36%	46%
	Both	8%	9%	35%	48%
Medical	Inward	0%	0%	17%	83%
	Outward	0%	18%	18%	64%
	Both	0%	12%	18%	71%
Shopping	Inward	10%	15%	37%	38%
	Outward	5%	20%	28%	47%
	Both	7%	18%	32%	43%
Social	Inward	4%	13%	37%	46%
	Outward	4%	16%	39%	41%
	Both	4%	14%	38%	44%
Work	Inward	4%	11%	36%	48%
	Outward	2%	19%	39%	40%
	Both	3%	15%	38%	44%
Total	**Inward**	**6%**	**12%**	**36%**	**46%**
	Outward	**4%**	**17%**	**35%**	**43%**
	Both	**5%**	**15%**	**36%**	**45%**

In summary, little difference appears between respondents' attitudes to reliability by mode or by geography, but some differences appear between trip purposes. In particular, respondents dislike unreliable services for education and medical trips purposes more than for shopping or social purposes. The direction of the trip can also be a determining factor, with respondents disliking arriving late to work or arriving late from shopping.

8 Reliability stated preference valuations

8.1 Model overview

8.1.1 General

A number of reliability model formulations have been examined as part of the valuation process using the NLOGIT statistical package. Note that the data could be segmented many ways that could provide differences in valuations. Furthermore, the models that have been concentrated on are based on the most common models determined from the literature review. Because of budget and time constraints, only a limited number of models could be examined; however, other models could also be proposed.

It should be noted that values of time are represented in $/hour (with a typical New Zealand value being $6–10/hour) and reliability valuations are in equivalent uncrowded in-vehicle minutes. Because IVT was not included in the in-vehicle reliability survey (SP2), it is not possible to determine a value of time. It has been assumed that the value of time is the same as obtained from the departure reliability survey (SP1), given that the survey covers the same respondents. The in-vehicle time survey provides a reliability valuation in monetary terms ($) by dividing the reliability coefficient by the fare coefficient. By using the value of time ($/hr) from the departure time survey, the valuation can be converted into an equivalent time unit.

For all reliability valuations, graphs showing the error bounds of each parameter have been produced. The error bounds have been calculated using two standard errors on both the numerator (reliability coefficient) and denominator (time coefficient).

For all models and all SPs, between segments, a significant amount overlap occurred between parameter valuations.

8.1.2 Departure time variability model

8.1.2.1 Variables

The departure time variability stated preference survey collected respondents' preferences for particular services given changes in the following variables:

- scheduled trip time (at four levels),
- trip fare (at four levels),
- number of trips about 5 minutes early on departure (at 3 levels),
- number of trips about 5 minutes late on departure (at 3 levels), and
- number of trips about 10 minutes late on departure (at 3 levels).

Using the three reliability variables, two other variables have been calculated for use in model estimation: average minutes' lateness and standard deviation of lateness as explained below.

Four models have been examined.

8.1.2.2 Model 1

This is a disaggregate model which allows valuations for departing 5 minutes early, 5 minutes late and 10 minutes late to be determined:

$$Utility = \alpha T + \beta F + \mu^D\ Early + \lambda^D\ Late5 + \gamma^D\ Late10 + \text{constant} \qquad \text{[Equation 1]}$$

Where: *T* = scheduled travel time
F = average fare
Early, Late5, Late10 = number (out of 10) of services early, 5 minutes late, and 10 minutes late
α, β, μ, λ, γ = coefficients

The coefficients on the variables *Early, Late5* and *Late10* can be interpreted as the impact of the number (*N*) out of ten services with the specified earliness/lateness. Since we require valuations in the context of a **single** journey, it is appropriate to multiply the estimated coefficients by ten (this effectively converts the variables '*Early'* etc. to probabilities. For the '*Late'* variables, the expected lateness for each service would be the proportion of services out of ten (i.e. the probability) multiplied by the delay. For example, if 3 out of 10 services were 5 minutes late, the expected lateness for the '5 minutes' category would be 3/10 x 5=1.5 minutes. We can thus convert the coefficients to a 'per minute' effect by first multiplying by 10 and then dividing by the specified number of minutes' lateness. In addition, since we have a coefficient on the IVT variable, we can calculate the ratio of this 'per minute' effect to the IVT coefficient, thus measuring the impact of the specified level of lateness in IVT terms.

While the same calculations can be made for the early departures, the interpretation here is less straightforward because of the interaction with the possibility of missing the desired service, which depends on the time of a passenger's arrival at the station/stop prior to the scheduled departure. In addition, if the service is missed because the service is running early, the consequences will depend on the service frequency, as discussed above.

8.1.2.3 Model 2

This is a mean model, which allows a valuation for the mean unexpected waiting time.

$$Utility = \alpha T + \beta F + \chi AML + \text{constant} \qquad \text{[Equation 2]}$$

Where: *T* = scheduled travel time
F = average fare
AML = mean unexpected waiting time (average minutes' lateness)
α, β, χ = coefficients

The mean waiting time (over and above the allowed-for time between arrival time at the stop and the scheduled departure) is calculated based on the variables *Early, Late5* and *Late10*, by taking, as before, the probabilities of services falling within each early/late band (5 or 10 minutes), and multiplying by the impact on waiting. While this is straightforward in the case of 'late' variables, for the early cases, the calculation takes explicit account of the possibility of missing the service (as discussed above).

For a service that is 5 minutes early (compared with scheduled arrival time), then the waiting time will be 5 minutes less for passengers who arrive more than 5 minutes before the service. For passengers who arrive within 5 minutes of the scheduled service, they will miss the preferred service (which is running early) and have an unexpected wait time of the service headway minus the 5 minutes it is running early (assuming the next service exhibits the same behaviour). For a service that is late by 5 (or 10) minutes on departure, the additional wait time will be 5 (or 10) minutes. The AML is then calculated by taking the weighted average (based on the number of services out of 10) unexpected wait times for services that are early, 5 minutes late or 10 minutes late.

The implications for AML are:

- Early pickup: if time (*Y)* between arrival at stop and scheduled departure ≥5, then waiting time = $Y - 5$.
- If time (*Y)* between arrival at stop and scheduled departure <5, then the traveller must wait for the next service, with headway *H*, so that waiting time = $Y + H - 5$ (assuming the next service is also 5 minutes early).
- Late pickup: waiting time = + 5 (or 10).

This measure of AML differs slightly from that used in the in-vehicle time variability survey in its treatment of early services.

As with Model 1, the coefficient can be divided by the IVT coefficient to give the impact of additional waiting time (positive or negative) in IVT terms.

8.1.2.4 Model 3

This is a variance model, which allows a valuation of the standard deviation departure time relative to schedule.

$$\text{Utility} = \alpha T + \beta F + \phi SD + \text{constant} \qquad \text{[Equation 3]}$$

Where: T = scheduled travel time (not included in in-vehicle time model)
F = average fare
SD = standard deviation calculated relative to schedule as

$$\sqrt{(0.1*[(-5^2)*EARLY+(5^2)*LATE5+(10^2)*LATE10]}$$

α, β, ϕ = coefficients

The standard deviation of lateness is calculated by determining the square root of the variance between the expected (or scheduled) time and the actual times.

8.1.2.5 Model 4

This is a mean-variance model, which allows the valuations of both the mean unexpected waiting time and the standard deviation.

$$\text{Utility} = \alpha T + \beta F + \chi AML + \phi SD + \text{constant} \qquad \text{[Equation 4]}$$

The variables have been calculated as per the mean and variance models.

8.1.3 IVT variability model

8.1.3.1 Variables

The stated preference survey on IVT variability collected respondents' preferences for particular services given changes in the following variables:

- trip fare (at 4 levels),
- number of trips about 5 minutes early whilst on service (at 3 levels),
- number of trips about 5 minutes late whilst on service (at 3 levels),
- number of trips about 10 minutes late whilst on service (at 3 levels).

As discussed previously, scheduled IVT was excluded from this SP to avoid confusion with the reliability variables.

Once again, four models have been examined.

8.1.3.2 Model 1

This is a disaggregate model which allows valuations for being delayed by 5 minutes or 10 minutes, or running quicker by 5 minutes while on the service:

$$\text{Utility} = \beta F + \mu^I Early + \lambda^I Late5 + \gamma^I Late10 + \text{constant} \qquad \text{[Equation 5]}$$

Where: F = average fare
$Early, Late5, Late10$ = number (out of 10) of services early, 5 minutes late, and 10 minutes late
$\beta, \mu, \lambda, \gamma$ = coefficients

The coefficients on the variables can be interpreted in the same way as for the SP1 models. However, the coefficient of early time has a different meaning than in SP1, in that a 5 minute saving in journey time will usually be seen as a benefit, and is less complex than a service arriving 5 minutes earlier and some passengers having to wait longer as a result.

8.1.3.3 Model 2

This is a mean model, allowing a valuation for mean unexpected IVT.

$$Utility = \beta F + \chi AML + constant \quad \text{[Equation 6]}$$

Where: F = average fare
AML = mean unexpected IVT (average minutes' lateness)
α, β, χ = coefficients

The mean unexpected in-vehicle time is calculated based on the variables *Early, Late5* and *Late10* by taking, as before, the probabilities of services falling within each early/late band (-5, 5 or 10 minutes) and multiplying by the impact on waiting.

This measure of AML differs slightly from that used in the departure time variability survey in its treatment of early services.

8.1.3.4 Model 3

This is a variance model which allows a valuation of the standard deviation of IVT relative to schedule.

$$Utility = \beta F + \phi SD + constant \quad \text{[Equation 7]}$$

Where: F = average fare
SD = standard deviation calculated relative to schedule as

$$\sqrt{(0.1*[(-5^2)*EARLY+(5^2)*LATE5+(10^2)*LATE10)])}$$

α, β, ϕ = coefficients

The standard deviation of lateness is calculated by determining the square root of the variance between the expected (or scheduled) time and the actual times.

8.1.3.5 Model 4

This is a mean-variance model which allows the valuations of both the mean unexpected in-vehicle time and the standard deviation.

$$Utility = \beta F + \chi AML + \phi SD + constant \quad \text{[Equation 8]}$$

The variables have been calculated as per the mean and variance models.

8.1.4 Weighting data

Initial models were examined using both unweighted and weighted data. Weighting was undertaken using the trip frequency question ('How often do you typically make a trip such as this?'), with the following weights applied:

- 5 or more times a week: 5,
- 2–4 times a week: 3,
- once a week: 1,
- once a month: 0.25.

It was found that, in general, weighting by trip frequency reduced the valuations of reliability, reduced the implied value of time and reduced the residual model constant (the results are shown in Appendix B). The impact of weighting was also similar across both stated preference surveys.

Table 8.1 Effect of weighting on disaggregate model valuations.

Parameter	Value of time ($/hr)	Value of constant ($)	IVT valuations		
			Early	Late5	Late10
Departure time variability					
Unweighted	$10.20	$1.14	13.5	4.7	6.0
Weighted	$8.56	$0.61	10.6	3.0	6.2
In-vehicle time variability					
Unweighted	NA	$0.10	2.8	4.0	4.7
Weighted	NA	$0.05	1.3	3.5	4.5

Weighted results have been produced as part of this study, as this gave the better estimate of impacts on numbers of trips (rather than number of people affected). All analysis from here on uses weighted data.

Observations could also be weighted based on the demographic information that was collected as part of the survey. In particular, the online recruitment pool used by SmileCity tends to over-represent the 15–24 year age group and under-represent the proportion of those aged 55+ years compared with census information. Data could be corrected for these demographic biases, but detailed information about ages and incomes of public transport users would be required.

8.1.5 The constant

Models can be estimated with and without a constant term. The constant term represents an additional value and explains the residual preference for one option over another once the explanatory variables are excluded. The departure time variability SP gave an overall constant of around $0.60 per trip, while the IVT variability SPs have a constant very close to zero (around $0.05). Defining what the constant represents is difficult; in this study, the positive constant could represent an overall preference for the cheaper (and hence less reliable) service. However, as the constant is higher in the first SP and close to zero in the second, this suggests that the constant may be an artefact of the SP design. In particular, the first SP was more complex, as it included more variables and resulted in more non-traders.

The impact of excluding the constant is shown in Table 8.2. The table shows that, in general, excluding the constant reduced the reliability valuations of the departure variability SP, increased the reliability valuations of the in-vehicle variability SP and decreased the implied value of time.

Table 8.2 Effect of eliminating the constant on disaggregate model valuations.

Parameter	Value of time ($/hr)	Value of constant ($)	IVT valuations		
			Early	Late5	Late10
Departure time variability					
No constant	$6.86	NA	10.8	0.8	5.8
Constant	$8.56	$0.61	10.6	3.0	6.2
In-vehicle time variability					
No constant	NA	NA	1.5	4.5	5.5
Constant	NA	$0.05	1.3	3.5	4.5

Valuations have been undertaken including the constant in the model formulation.

8.2 Departure variability model

8.2.1 Summary

The four models presented in Chapter 8.1 have been estimated for the departure variability stated preference survey. The results of these estimations are summarised in Table 8.3 below for the total sample, with more details provided in Appendix B by segment.

The disaggregate model provides the best fit overall as indicated by the lowest log-likelihood measure, but little distinguishes the four models. All model coefficients are of the right sign, and only two coefficients are not significantly different from zero (the constant in the variance model and the standard deviation in the mean-variance model).

Values of time range between $7.82 and $8.56, indicating the estimated models are fairly consistent. A typical range of $6 to $10 is applicable in a New Zealand context.

Values of reliability are also fairly consistent across the four models. The disaggregate model indicates a higher value for earliness (10.6 times IVT) than being late by 5 minutes (3 times IVT) or 10 minutes (6.2 times IVT). The high valuation of earliness is an interesting result and somewhat at odds with the proportion of passengers affected by services running early, as indicated in Chapter 7.2. This finding requires more investigation.

The mean model gives a value of AML of 5 times IVT, which fits within the range of the disaggregate model. The variance model gives a reliability ratio of around 3, whilst the mean-variance model explains most of the reliability valuation through the AML parameter. However, the mean-variance model has a high correlation between AML and SD (0.80).

Table 8.3 Departure variability model summary.

Model	Parameter								
	Constant	IVT	Fare	Early	Late5	Late10	AML	SD	Log-likelihood
Disaggregate:							NA	NA	
Coefficient	-0.399	-0.093	-0.651	-0.439	-0.142	-0.572			-2530
P(Z>z)	0.000	0.000	0.000	0.000	0.005	0.00			
Value[a]	$0.61	$8.56	–	10.6	3.0	6.2			
Mean:				NA	NA	NA		NA	
Coefficient	-0.308	-0.092	-0.651				-0.463		-2556
P(Z>z)	0.000	0.000	0.000				0.00		
Value[a]	$0.47	$8.51	–				5.0		
Variance:				NA	NA	NA	NA		
Coefficient	-0.044	-0.087	-0.670					-0.273	-2556
P(Z>z)	0.563[b]	0.000	0.000					0.000	
Value[a]	$0.07	$7.82	–					3.1	
Mean-variance:				NA	NA	NA			
Coefficient	-0.273	-0.92	-0.655				-0.388	-0.049	-2549
P(Z>z)	0.006	0.000	0.000				0.000	0.462[b]	
Value[a]	$0.42	$8.39	–				4.2		

Notes to Table 8.3:

a Valuation for constant is in $; for IVT, it is $/hr; and for reliability attributes, it is the equivalent of IVT.

b Not significant to 5%

Each of the models has been estimated to the various market segments. These are discussed in turn. The full set of statistics is provided in Appendix B.

8.2.2 Disaggregate model

This model provides IVT-equivalent valuations for services that are 5 minutes early, 5 minutes late and 10 minutes late (based on a 1/10 change in each) in picking up a passenger from a stop/station.

The average values of time are $8.56 for weighted data, with the values for rail ($12.38) being significantly higher than for a bus ($6.20), and higher for work trips ($8.96) than for education ($7.53) and other purposes ($8.12). Services being early have the highest overall valuation per minute (10.6 times IVT minutes): Auckland bus passengers in general have the highest valuation of earliness (12.6), and ‘other trip purposes’ have the lowest (7.8). Services running 5 minutes late have the lowest overall valuation per minute (3.0): Auckland bus (4.4) and other (5.4) purposes have the highest valuation. Services running 10 minutes late have an overall per minute valuation between running early and 5 minutes’ lateness (6.2): Wellington rail has a lower valuation (4.5); bus, a higher valuation (8.0).

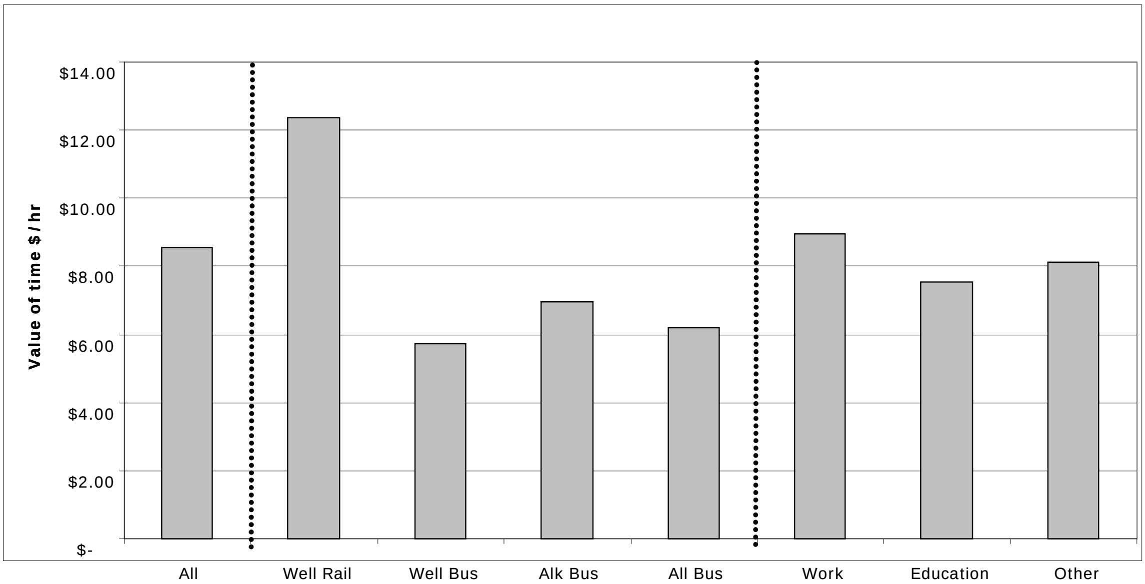

Figure 8.1 Values of time for departure time variability SP – disaggregate model.

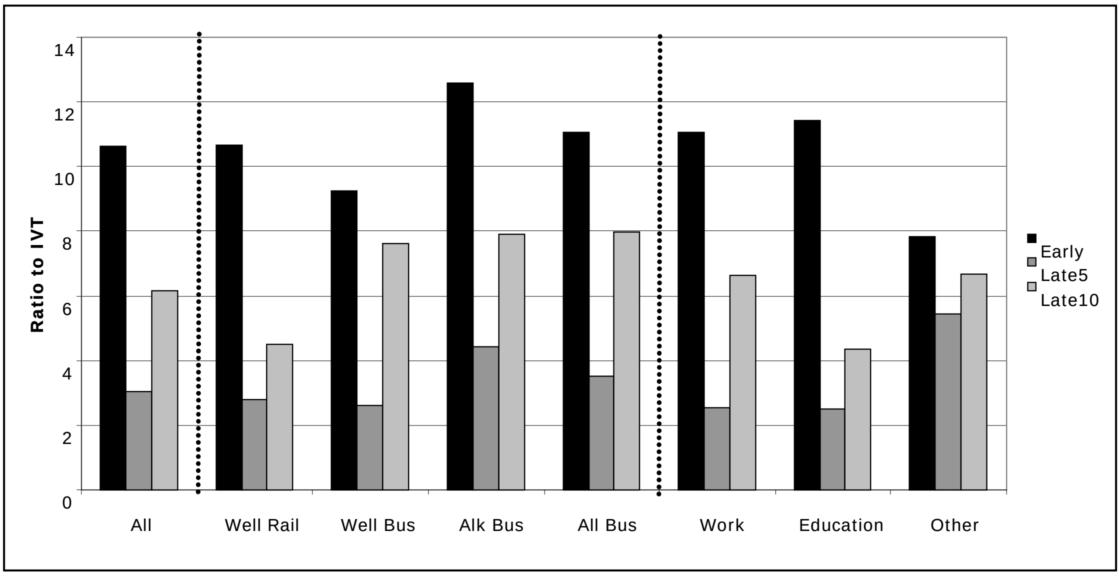

Figure 8.2 Segmented reliability valuations for departure time variability SP – disaggregate model.

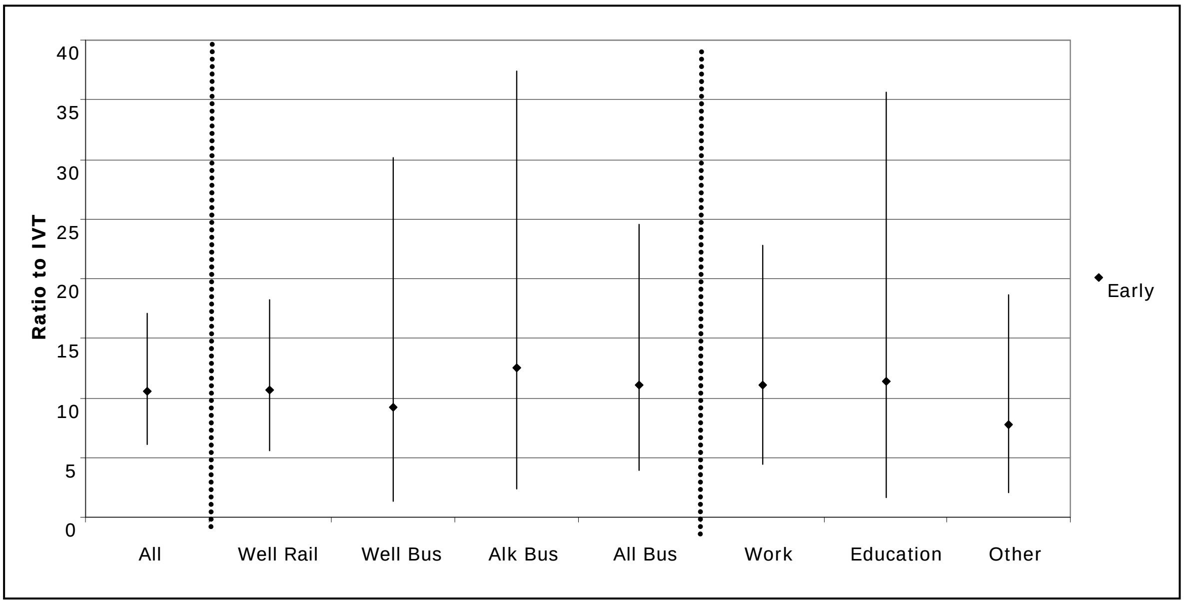

Figure 8.3 Error bounds (early) for departure time variability SP – disaggregate model.

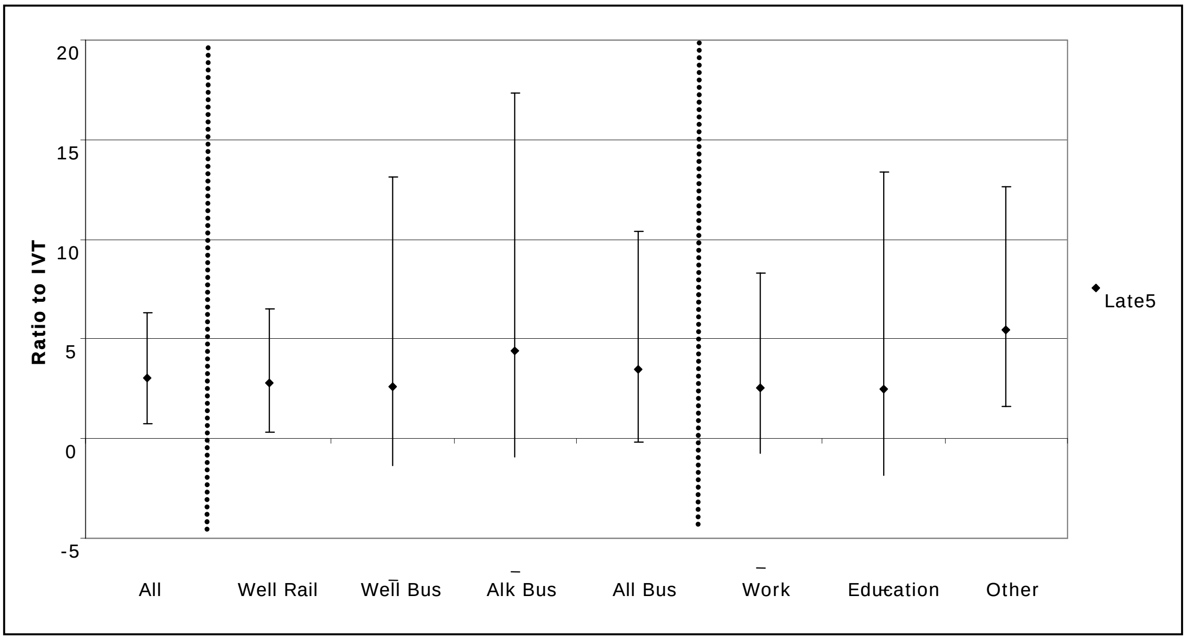

Figure 8.4 Error bounds (five minutes late) for departure time variability SP – disaggregate model.

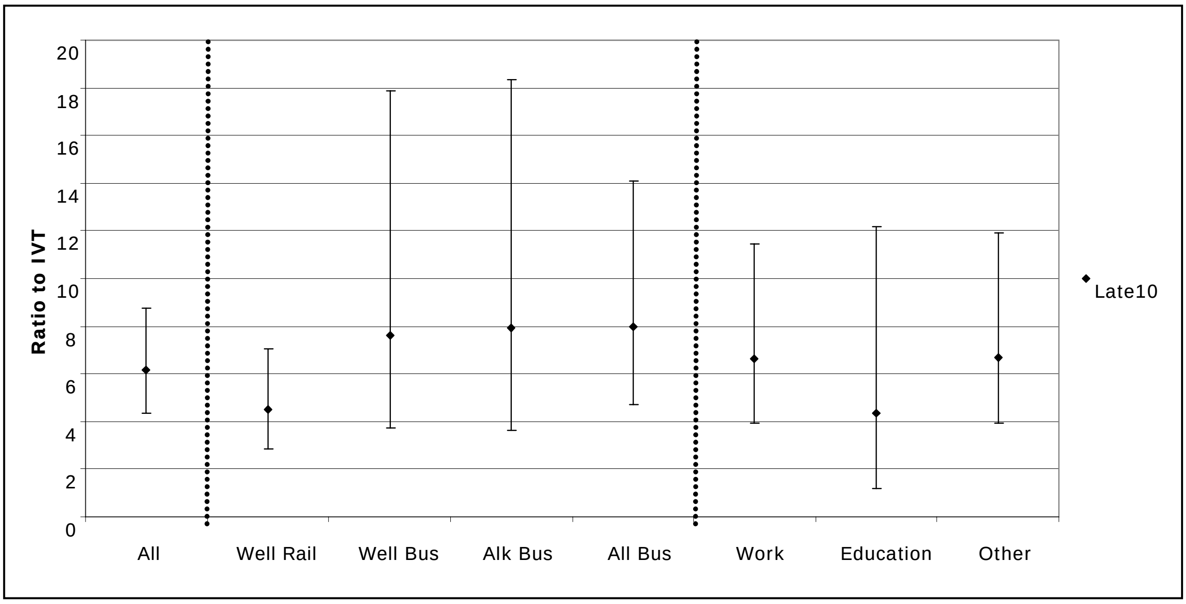

Figure 8.5 Error bounds (10 minutes late) for departure time variability SP – disaggregate model.

8.2.3 Mean delay model

This model provides IVT-equivalent valuation of the average delay on picking up a passenger from a stop/station (unexpected wait time).

The average value of time is $8.51 for weighted data, with the valuation for rail ($12.51) being significantly higher than for bus ($6.06), and higher for work trips ($8.95) than for education ($7.51) and other purposes ($8.00). Overall, average lateness on pickup is valued at 5 times IVT, with Wellington rail (3.9) and education trip purpose (3.0) providing the lowest, and bus/work/other providing the highest (5.4–6.5).

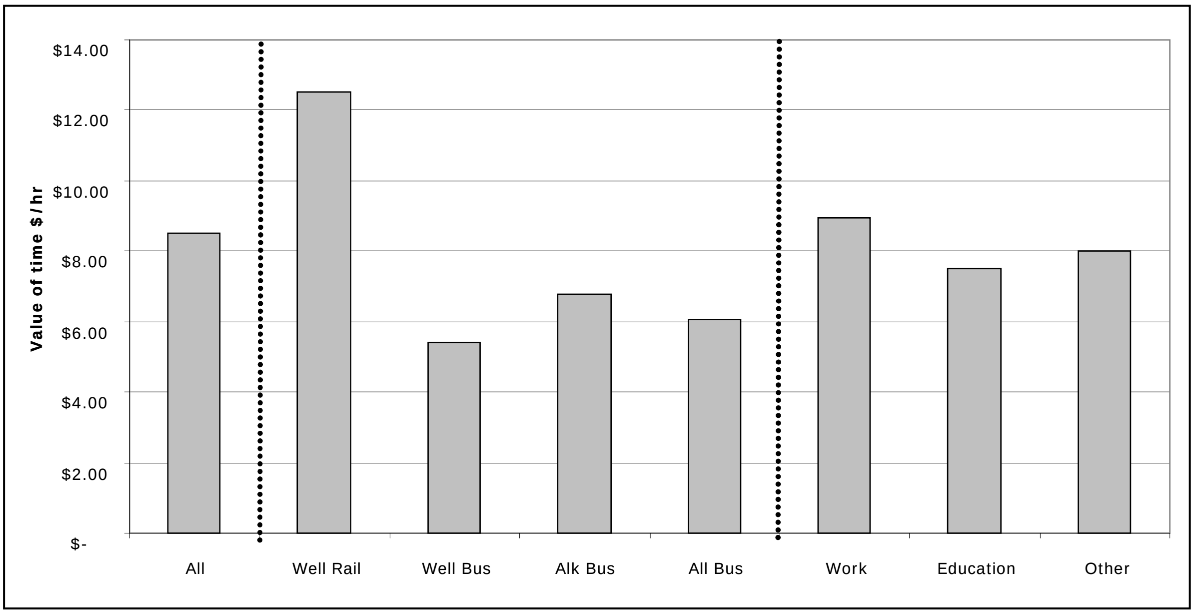

Figure 8.6 Values of time for departure time variability SP – mean model.

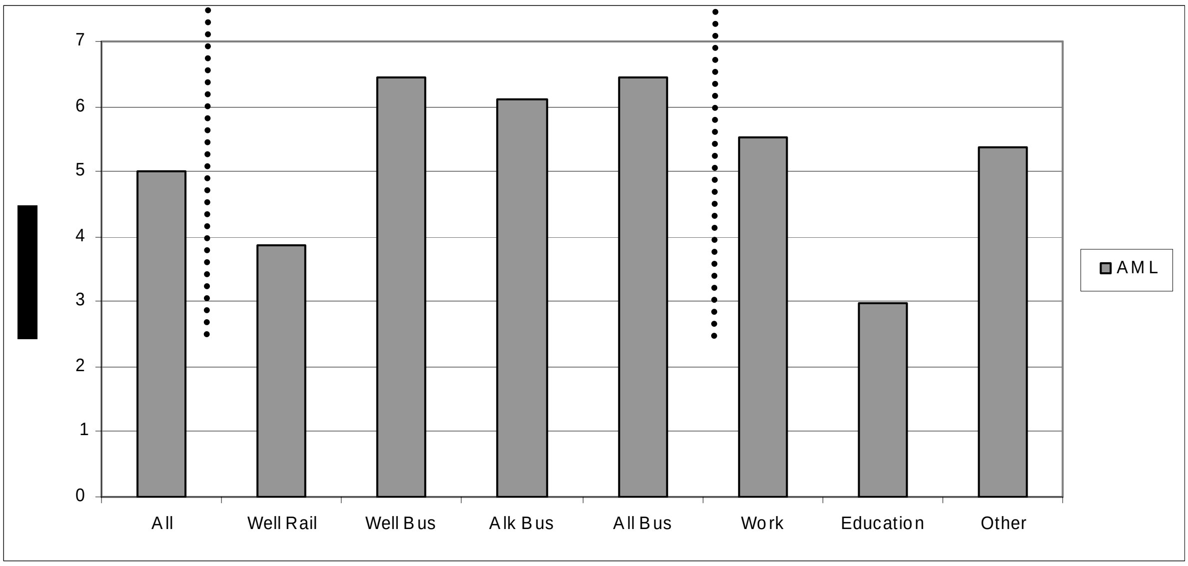

Figure 8.7 Segment reliability valuations for departure time variability SP – mean model.

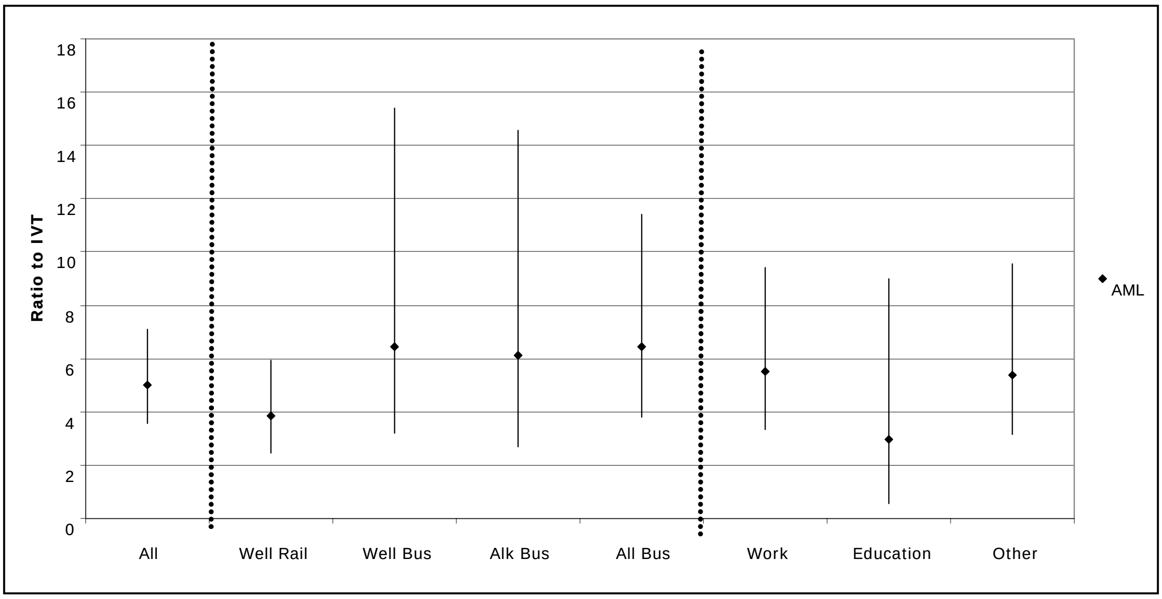

Figure 8.8 Error bounds for departure time variability SP – mean model.

8.2.4 Variance model

This model provides an IVT-equivalent valuation of the standard deviation of delay on picking up a passenger from a stop/station.

The average value of time is $7.82 for weighted data, with the valuation for rail ($11.55) being significantly higher than for bus ($5.56), and higher for work trips ($8.14) than for education ($7.17) and other purposes ($7.39). Overall, the standard deviation of lateness (i.e. the reliability ratio) on pickup is valued at 3 times IVT, with Wellington rail (2.6) and education trip purposes (1.8) providing the lowest, and bus/work/other providing the highest (3.2–3.8).

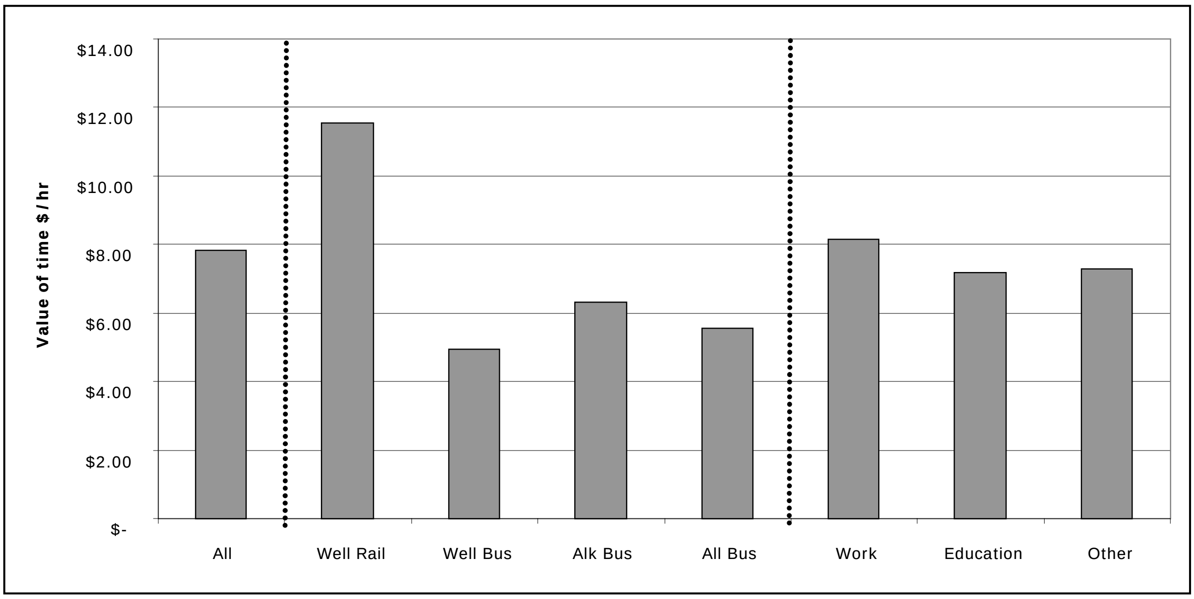

Figure 8.9 Values of time for departure time variability SP – variance model.

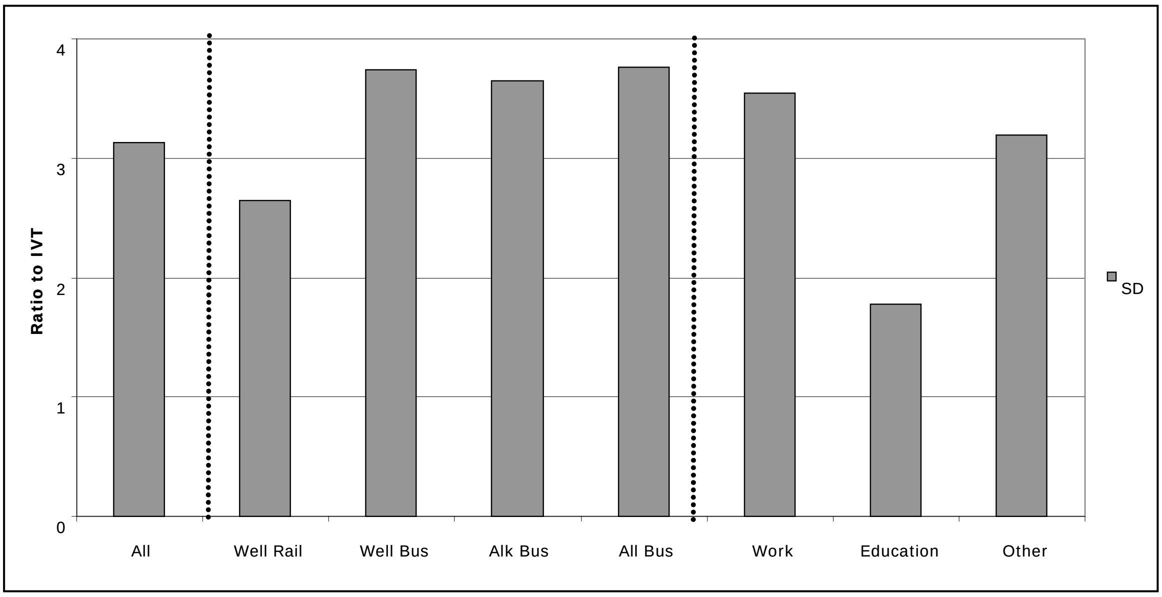

Figure 8.10 Segment reliability valuations for departure time variability SP – variance model.

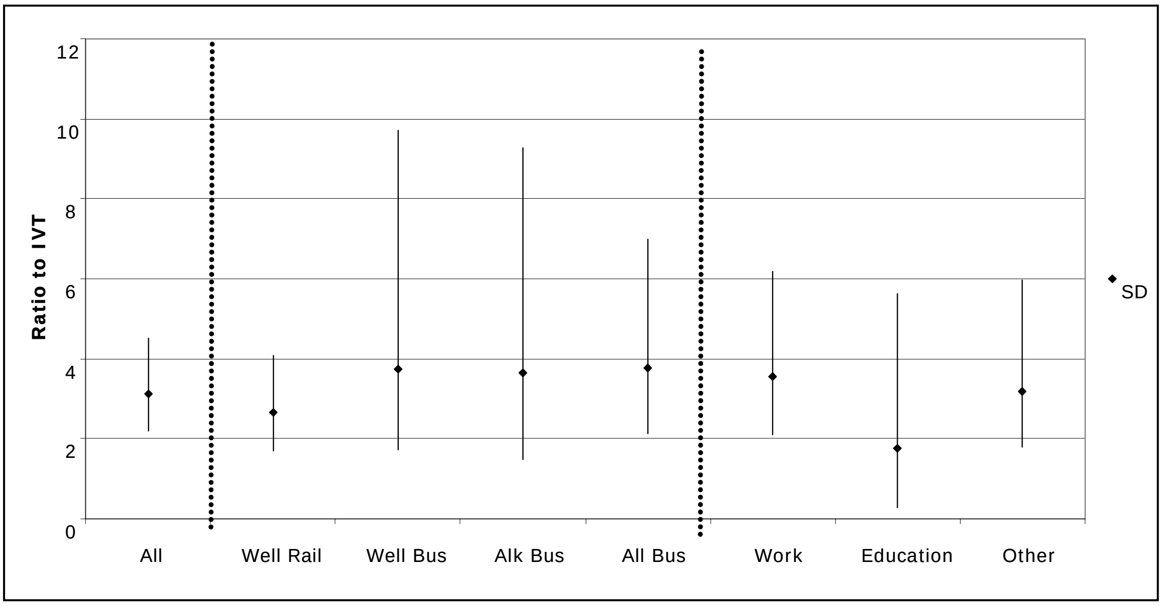

Figure 8.11 Error bounds for departure time variability SP – variance model.

8.2.5 Mean-variance model

This model provides IVT-equivalent valuations of the combined impact of average delay and standard deviation of delay on picking up a passenger from a stop/station.

The average value of time according to this model is $8.39 for weighted data, with the valuation for rail ($11.59)being significantly higher than for bus ($6.25), and higher for work trips ($8.67) than for education ($7.53) and other purposes ($8.25). Overall, average lateness on pickup is valued at 4.2 times IVT, and standard deviation of lateness on pickup is valued at 0.5 times IVT. However, within segments, some valuations for standard deviation have the wrong sign, meaning that the combined model does not produce adequate results.

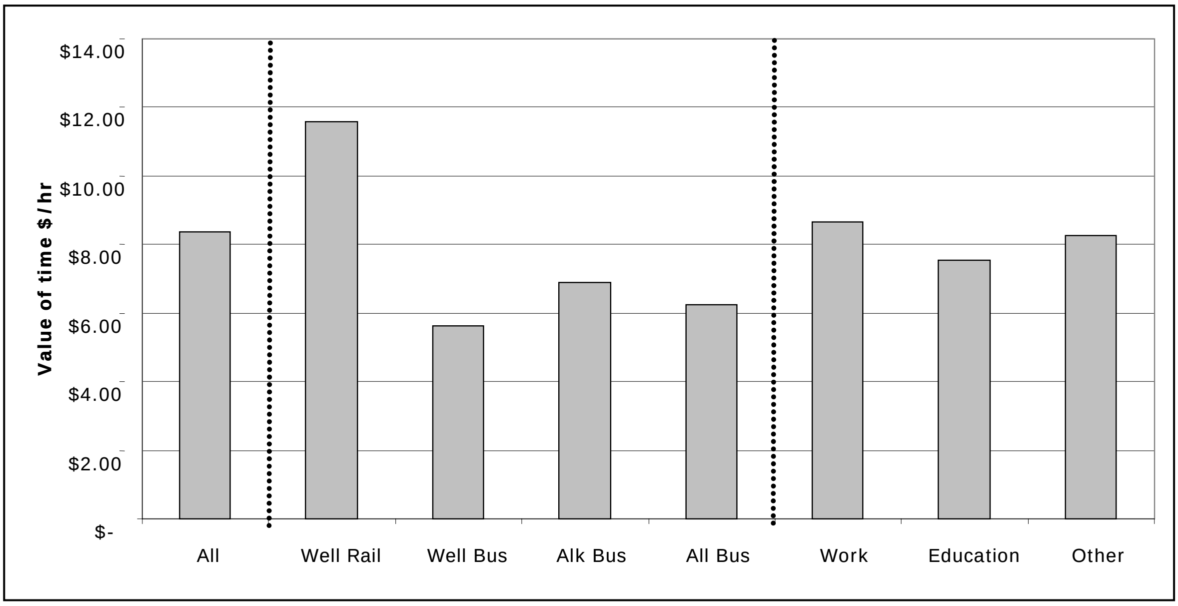

Figure 8.12 Values of time for departure time variability SP – mean-variance model.

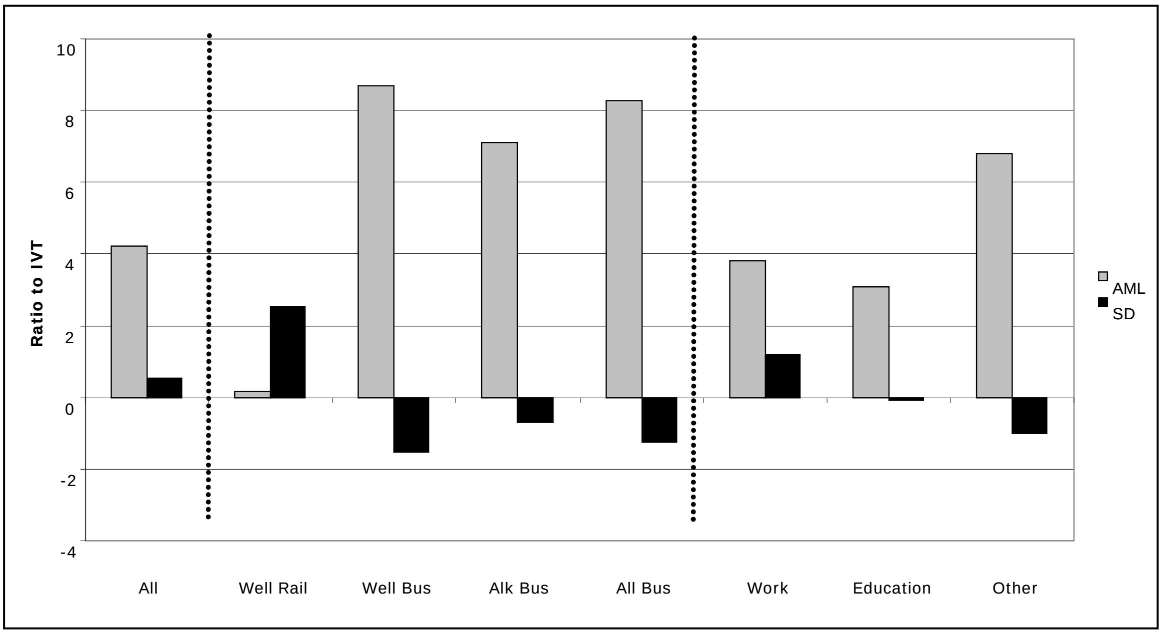

Figure 8.13 Segmented reliability valuations for departure time variability SP – mean-variance model.

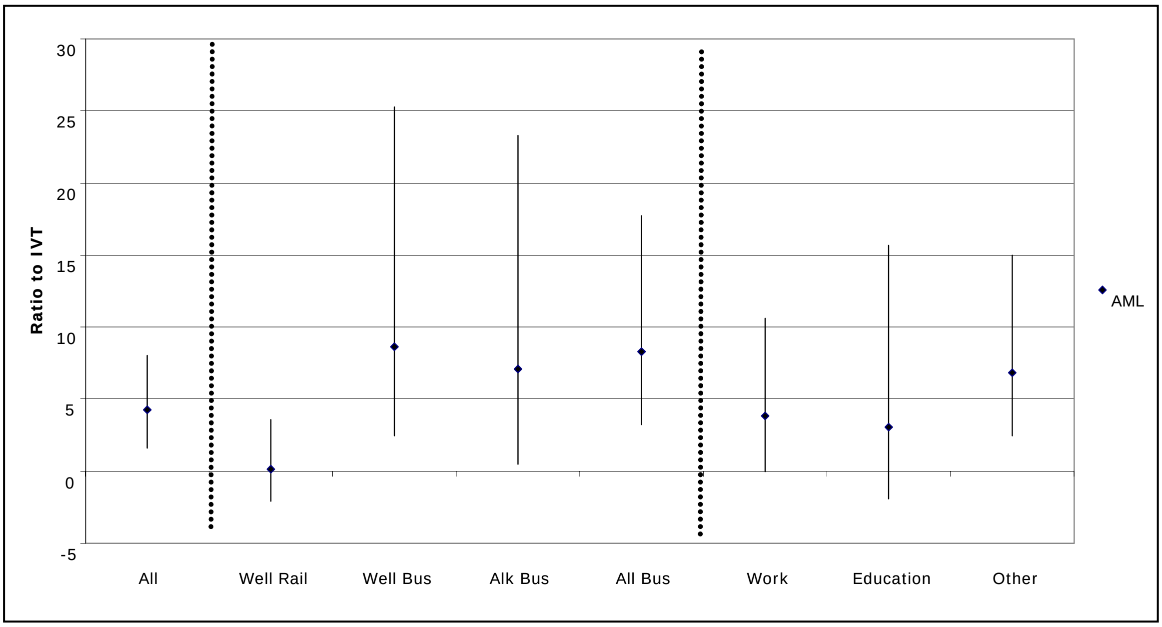

Figure 8.14 Error bounds (AML) for departure time variability SP – mean-variance model.

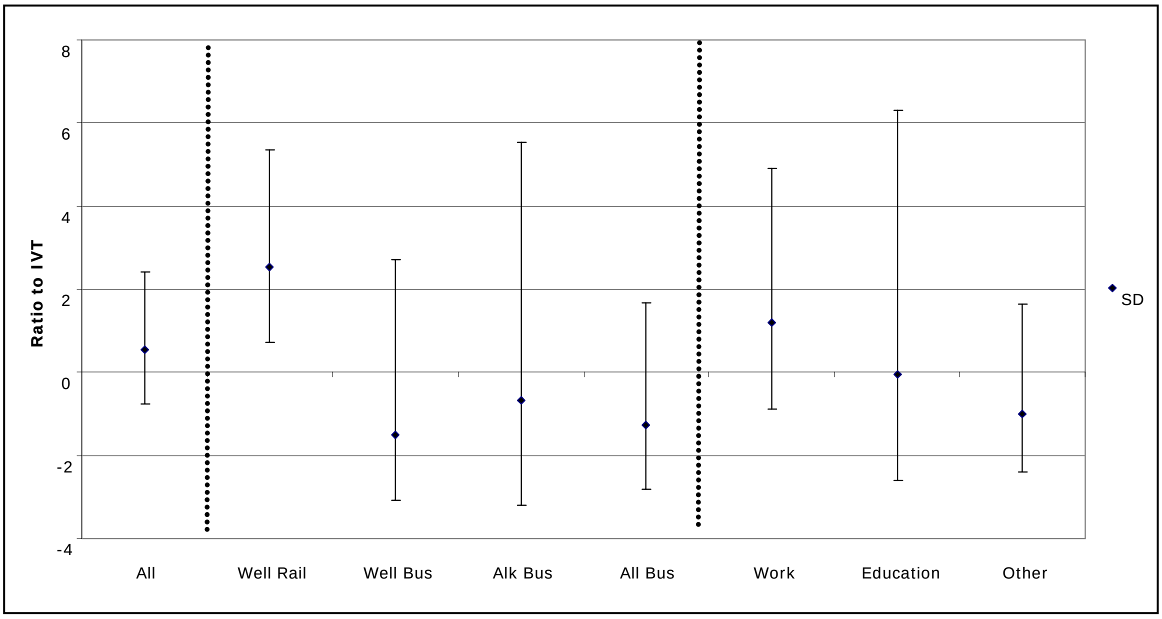

Figure 8.15 Error bounds (SD) for departure time variability SP – mean-variance model.

8.3 In-vehicle variability model

8.3.1 Summary

The four models presented in Chapter 8.1 have also been estimated for the in-vehicle variability stated preference survey. Results of these estimations are summarised in Table 8.4 for the total sample, with more details provided in Appendix B by segment.

The disaggregate model again provides the best fit overall, as indicated by the lowest log-likelihood measure. All model coefficients are of the right sign, and only two constants are not significantly different from zero.

Values of reliability are again fairly consistent across all four models. The disaggregate model indicates a lower value for earliness (1.3 times IVT) than for being late by 5 minutes (3.5 times IVT) or by 10 minutes (3.5 times IVT). The mean model gives a value of AML of 2.8 times IVT, which fits within the range of the disaggregate model. The variance model gives a reliability ratio of around 5, while the mean-variance model splits reliability valuation between the AML and standard deviation parameters. The mean-variance model has a high correlation between AML and SD (0.85).

Table 8.4 In-vehicle variability model summary.

Model	Parameter							
	Constant	Fare	Early	Late5	Late10	AML	SD	Log-likelihood
Disaggregate: Coefficient P(Z>z) Value[a]	-0.051 0.154[b] $0.05	-1.120 0.000	-0.103 0.016 1.3	-0.282 0.000 3.5	-0.719 0.000 4.5	NA	NA	-2544
Mean: Coefficient P(Z>z) Value[a]	0.012 0.735[b] $0.01	-1.220 0.000 –	NA	NA	NA	-0.477 0.000 2.8	NA	--2583
Variance: Coefficient P(Z>z) Value[a]	-0.132 0.000 $0.19	-0.702 0.000 –	NA	NA	NA	NA	-0.483 0.000 5.3	-2592
Mean-variance: Coefficient P(Z>z) Value[a]	-0.105 0.003 $0.12	-0.888 0.000 –	NA	NA	NA	-0.158 0.000 1.3	-0.347 0.000 2.8	-2583

Notes to Table 8.4:

a Valuation for constant is in $; for IVT, it is $/hr; and for reliability attributes, it is the equivalent of IVT.

b Not significant to 5%

Each of the models has been estimated for the various market segments. These are discussed in turn. The full set of statistics is provided in Appendix B.

8.3.2 Disaggregate model

This model provides IVT-equivalent valuations for services that are 5 minutes early, 5 minutes late and 10 minutes late (based on a 1/10 change in each) while a passenger is on the vehicle.

Services running early have the lowest overall valuation (1.3 times IVT minutes), with Wellington bus passengers (2.5) and education trip purposes having the highest (2.7), and Wellington rail (0.3) and work (0.8) having the lowest valuation. Services running 5 minutes late have an overall valuation between earliness and 10 minutes' lateness (3.5), with the education purpose (5.7) having the highest, and Wellington rail (2.7) and other purpose (2.8) the lowest. Services running 10 minutes late have the highest overall valuation (4.5), with Wellington rail (3.9) and other purpose (3.4) having the lowest valuation, and Wellington bus the highest (6.2)

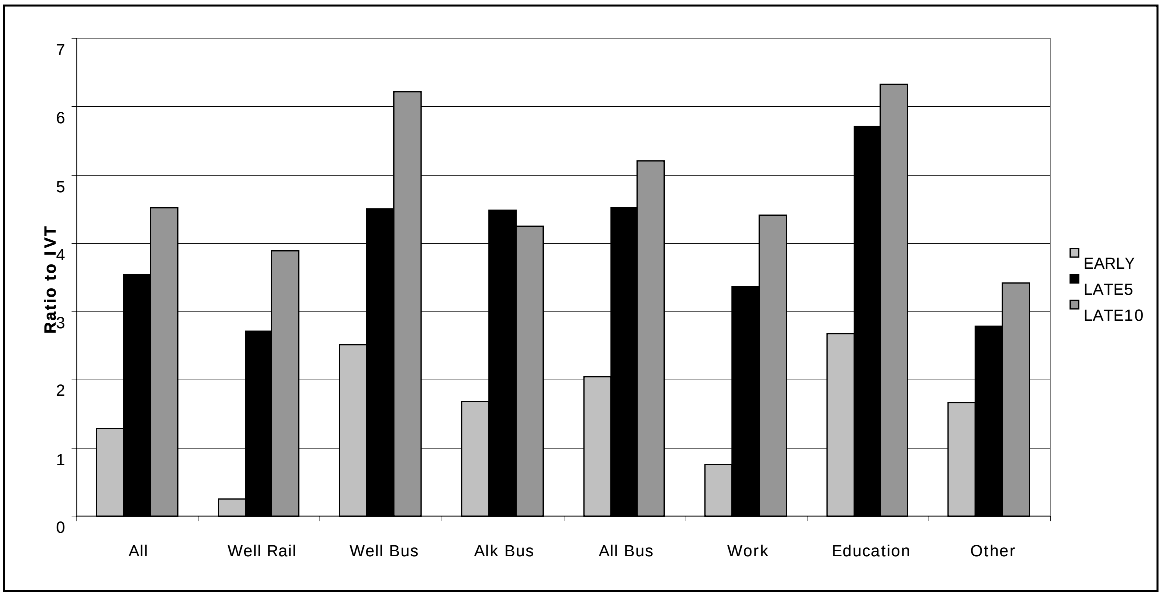

Figure 8.16 Segment reliability valuations for IVT variability SP – disaggregate model.

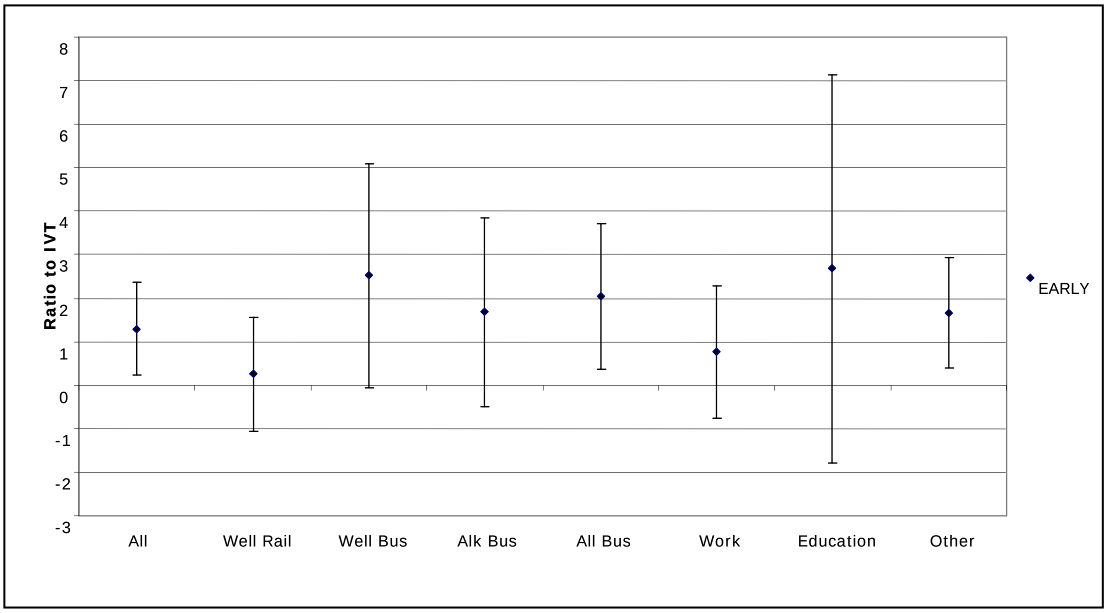

Figure 8.17 Error bounds (early) for IVT variability SP – disaggregate model.

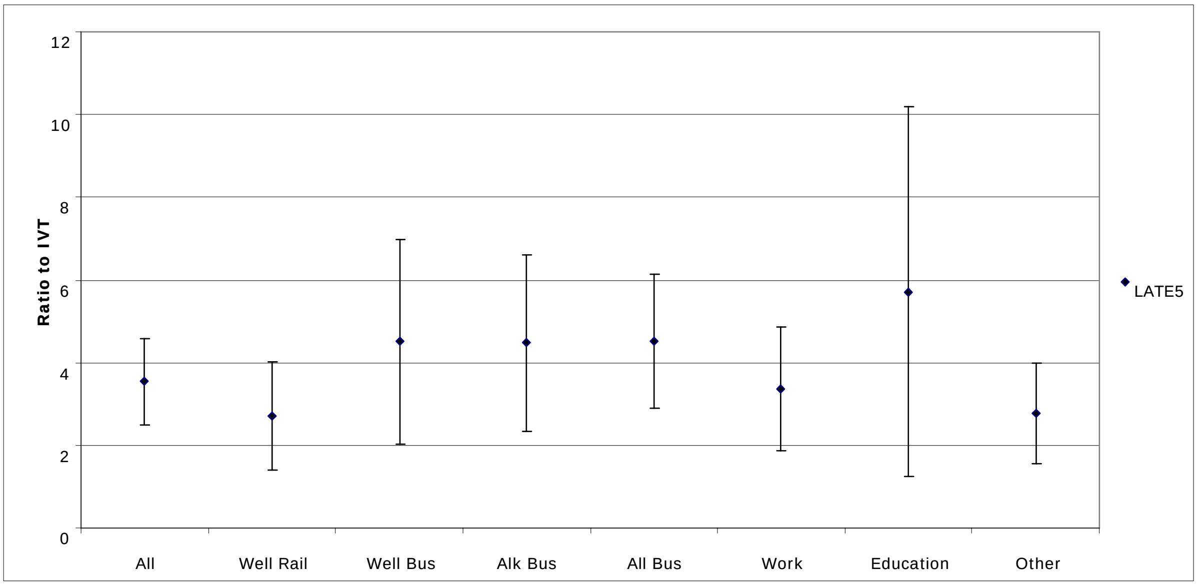

Figure 8.18 Error bounds (5 minutes late) for IVT variability SP – disaggregate model.

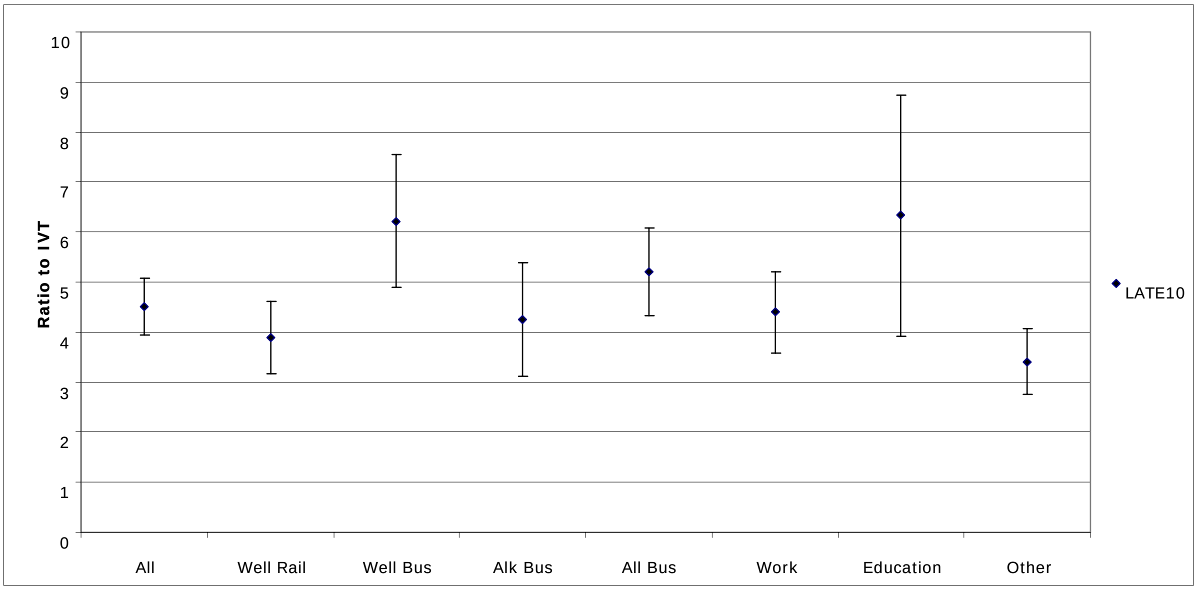

Figure 8.19 Error bounds (10 minutes late) for IVT variability SP – disaggregate model.

8.3.3 Mean delay model

This model provides an IVT-equivalent valuation of the average delay while a passenger is on the vehicle (unexpected in-vehicle time).

Overall, average lateness in-vehicle is valued at 2.8 times IVT, with Wellington rail (2.4) and other trip purpose (2.0) providing the lowest, and Wellington bus (3.6) and education purposes (3.8) providing the highest valuation.

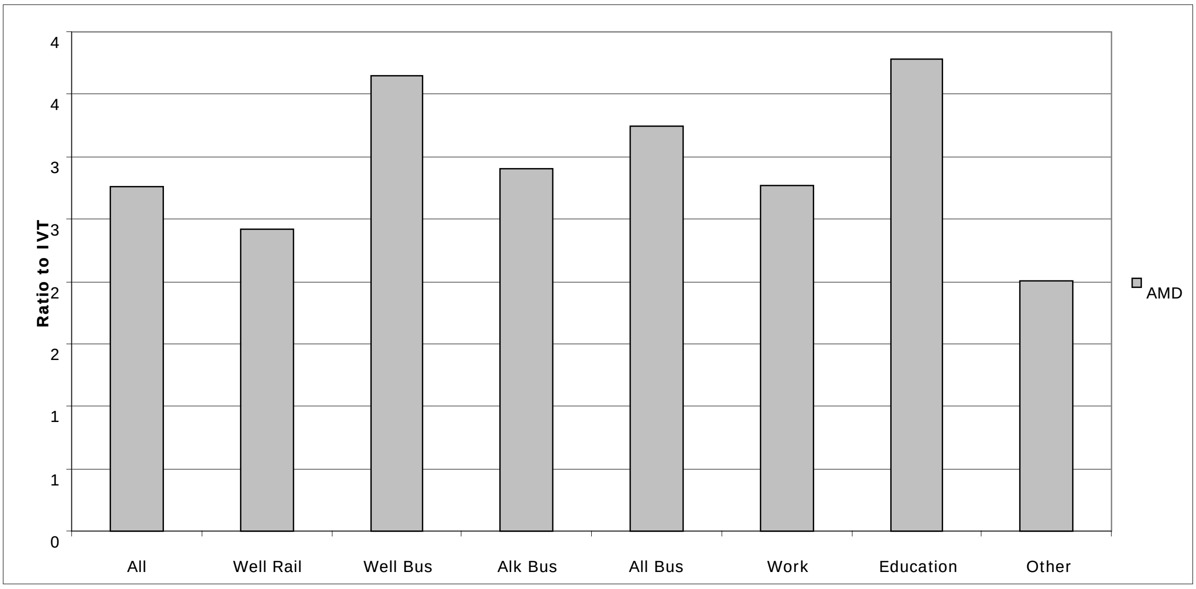

Figure 8.20 Segment reliability valuations for IVT variability SP – mean model.

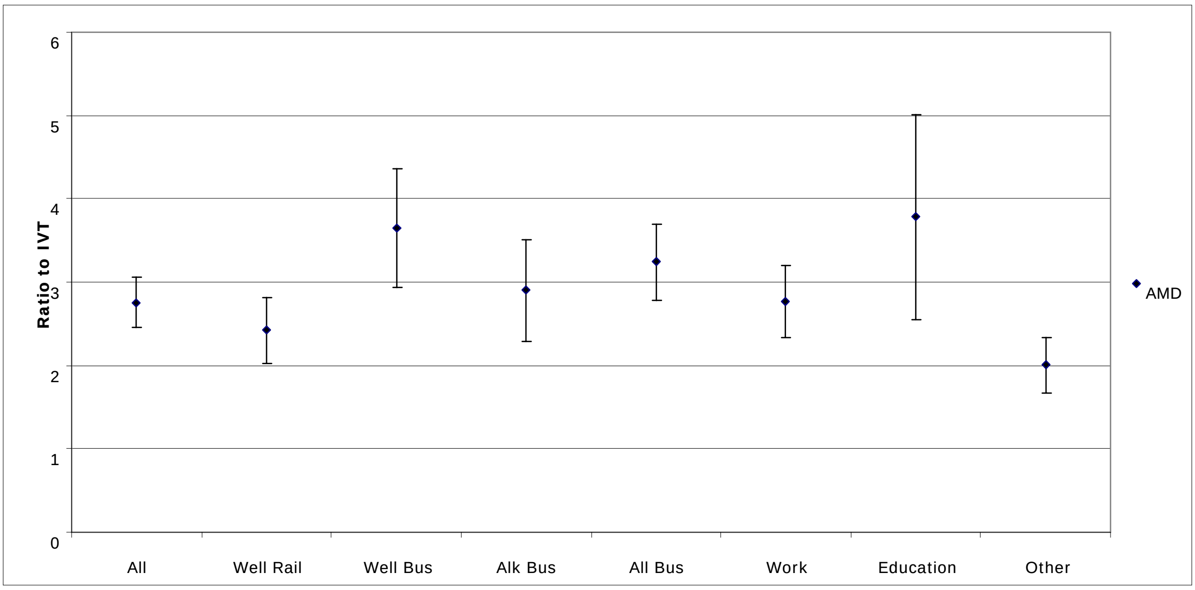

Figure 8.21 Error bounds for IVT variability SP – mean model.

8.3.4 Variance model

This model provides an IVT-equivalent valuation of the standard deviation of delay experienced while a passenger is on the vehicle.

Overall, the standard deviation of lateness in-vehicle is valued at 5.3 times IVT, with Auckland bus (4.4) and other trip purpose (3,2) providing the lowest, and Wellington bus (6.7) and education purposes (6.6) providing the highest valuation.

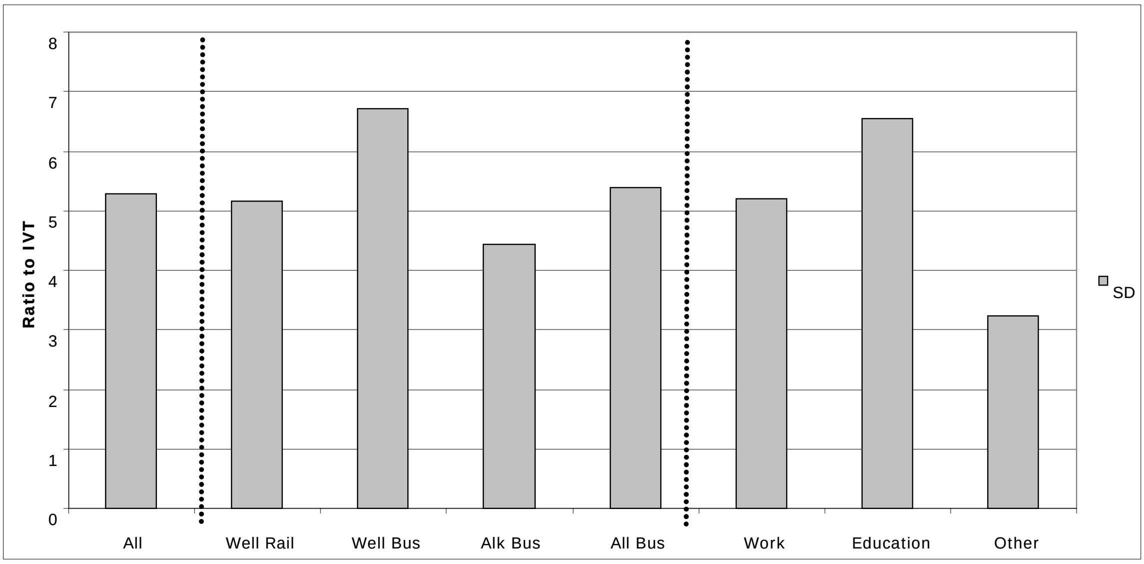

Figure 8.22 Segment reliability valuations for IVT variability SP – variance model.

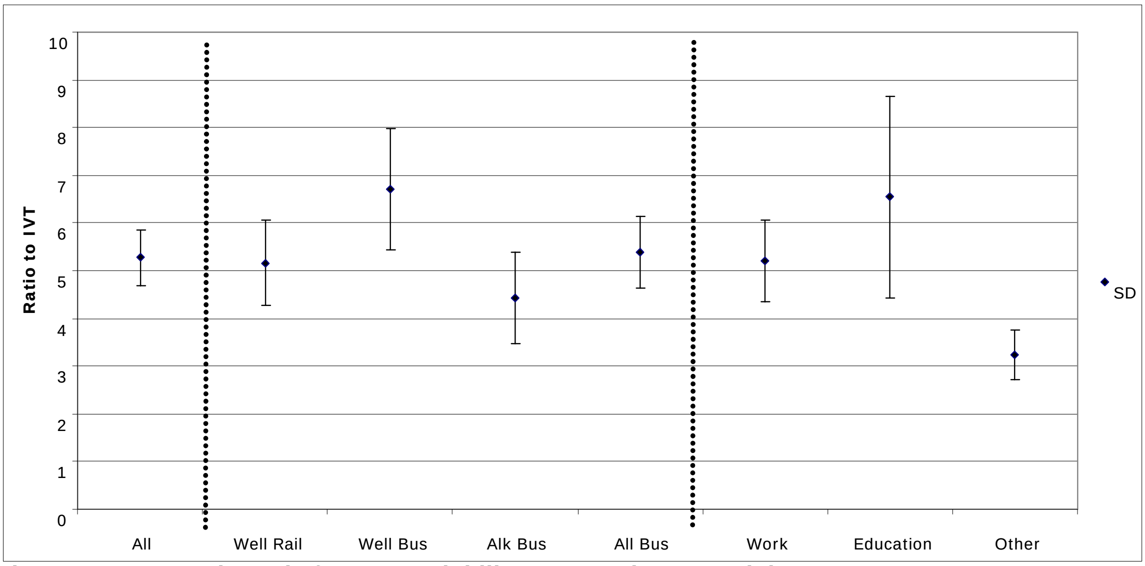

Figure 8.23 Error bounds for IVT variability SP – variance model.

8.3.5 Mean-variance model

This particular model provides an IVT-equivalent valuation of the combined impact of average delay and standard deviation of delay while a passenger is on the vehicle.

Overall, average lateness on pickup is valued at 1.3 times IVT, and standard deviation of lateness on pickup is valued at 2.8 times IVT. The relativities of the two parameters differ by segment. Wellington rail and work purpose have the average lateness as more important than the variation in lateness, and the converse for the others.

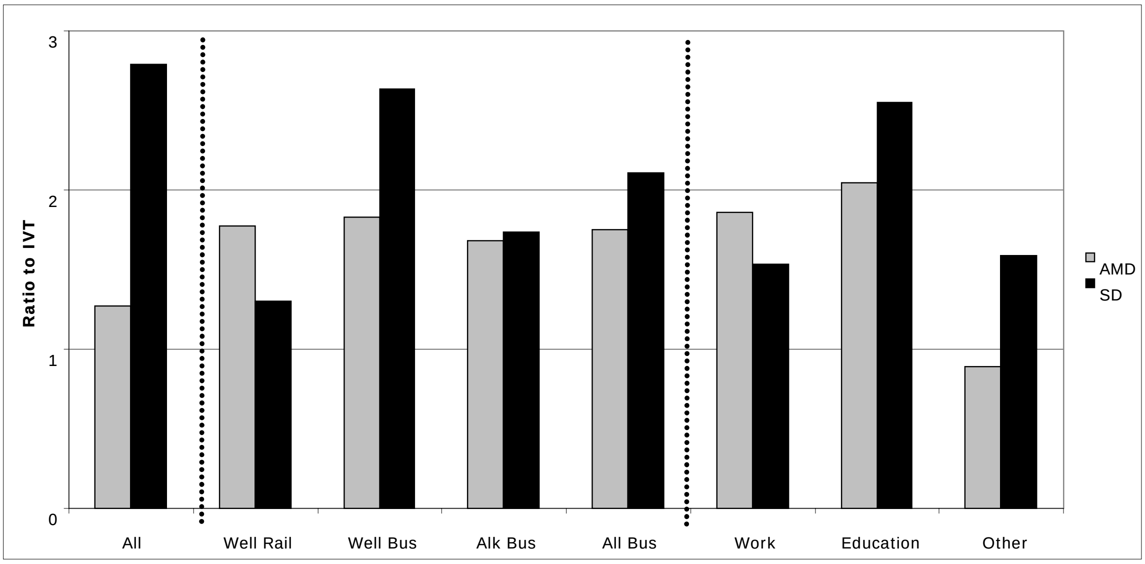

Figure 8.24 Segment reliability valuations for IVT variability SP – mean-variance model.

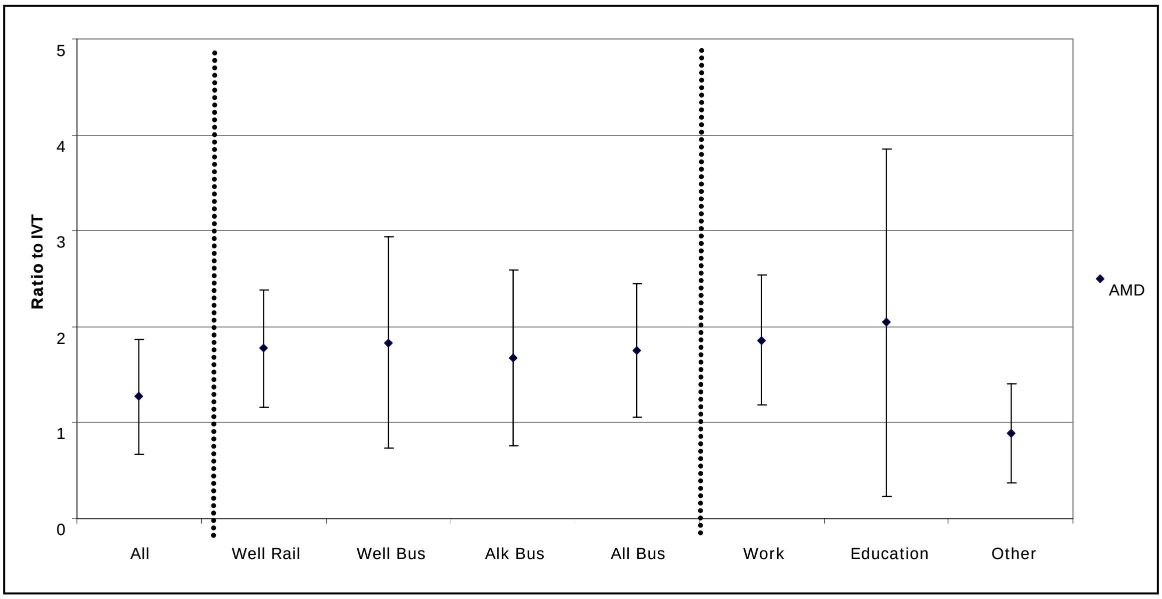

Figure 8.25 Error bounds (AML) for IVT variability SP – mean-variance model.

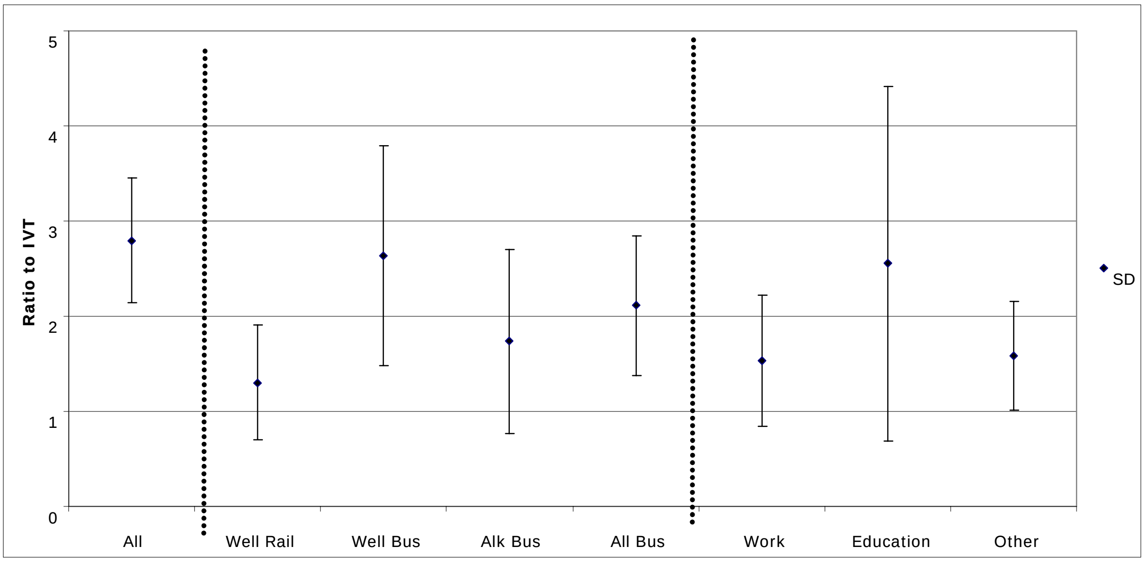

Figure 8.26 Error bounds (SD) for IVT variability SP – mean-variance model.

8.4 Comparison of departure and in-vehicle variability models

8.4.1 Purpose

This section compares the results from the departure and in-vehicle variability models. In particular, it discusses differences in reliability valuations by segment. Each of the four models will be discussed in turn and evaluated.

8.4.2 Disaggregate model

Overall, passengers place a high valuation on services running early on pickup (because of the chance of missing the service), and place a much lower valuation when the passenger experiences early running in the vehicle (a consistent theme throughout all segments). It should be noted, however, that the high early departure valuation is somewhat at odds with the findings in Chapter 7.2. This requires further investigation

In general, a passenger experiencing 5 minutes' lateness on pickup values this as similar to 5 minutes' delay on the vehicle, although differences by mode (Wellington bus) and trip purpose (education and other) were noted.

Once the delay gets to 10 minutes, passengers value pickup higher than in-vehicle time (except for education).

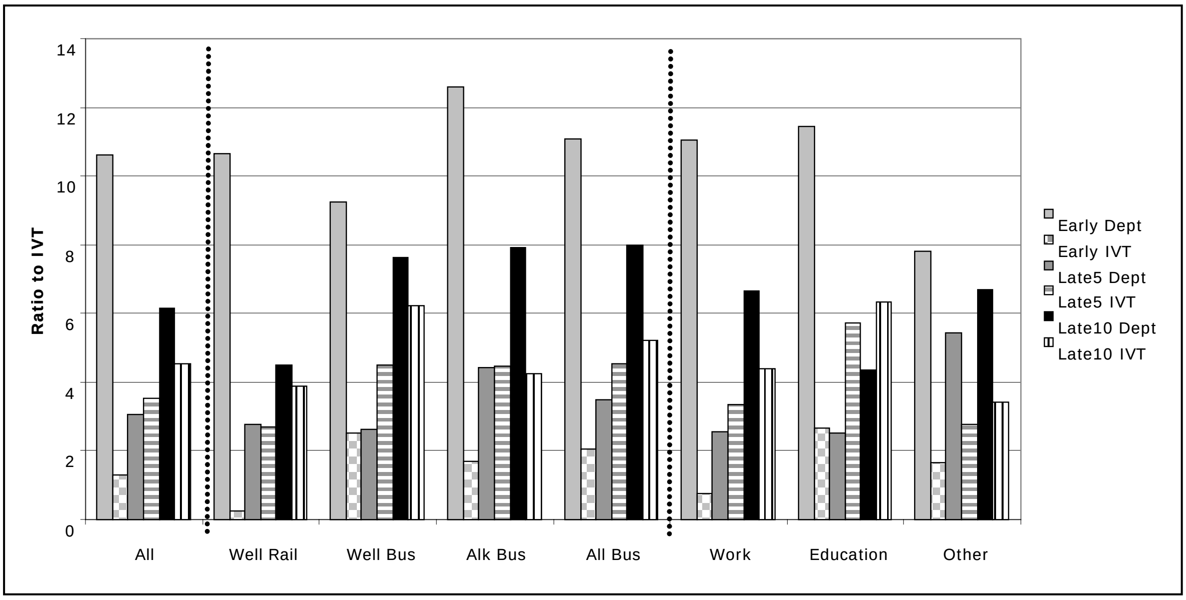

Figure 8.27 Comparison of segment reliability valuations– disaggregate model.

The disaggregate model indicates that the valuations of unreliable services are not linear, with early services on pickup providing the highest valuation (because of the possibility of missing the service), but services running early while a passenger is in the vehicle (early IVT) providing the lowest (because a quicker journey time is a benefit for some passengers). Being delayed by five minutes on pickup has a similar valuation to being delayed by five minutes while on the service; possibly because both scenarios provide the same late arrival time at the destination. However, being delayed 10 minutes on pickup has a higher valuation than the same delay on the service, possibly owing to increased anxiety over when the next service will arrive.

Assuming a 50:50 split between passengers who are delayed on pickup and those who are delayed in-vehicle, the total passenger impact caused by a late service at a stop/station would be around 6 times IVT for services 5 minutes early, 3.3 times IVT for services 5 minutes late, and 5.3 times IVT for services 10 minutes late.

8.4.3 Mean delay model

Overall, passengers place a higher valuation on unexpected wait time than unexpected in-vehicle time. Rail valuations are lower than bus, with the ratio between unexpected wait time and IVT valuations remaining fairly constant between modes. For work and other trips, a higher relative valuation is placed on unexpected in-vehicle time; for education trips, a higher valuation is given for delay in the vehicle, which could be caused by a lower valuation of wait time in general (education users have a higher propensity to listen to music before the service arrives).

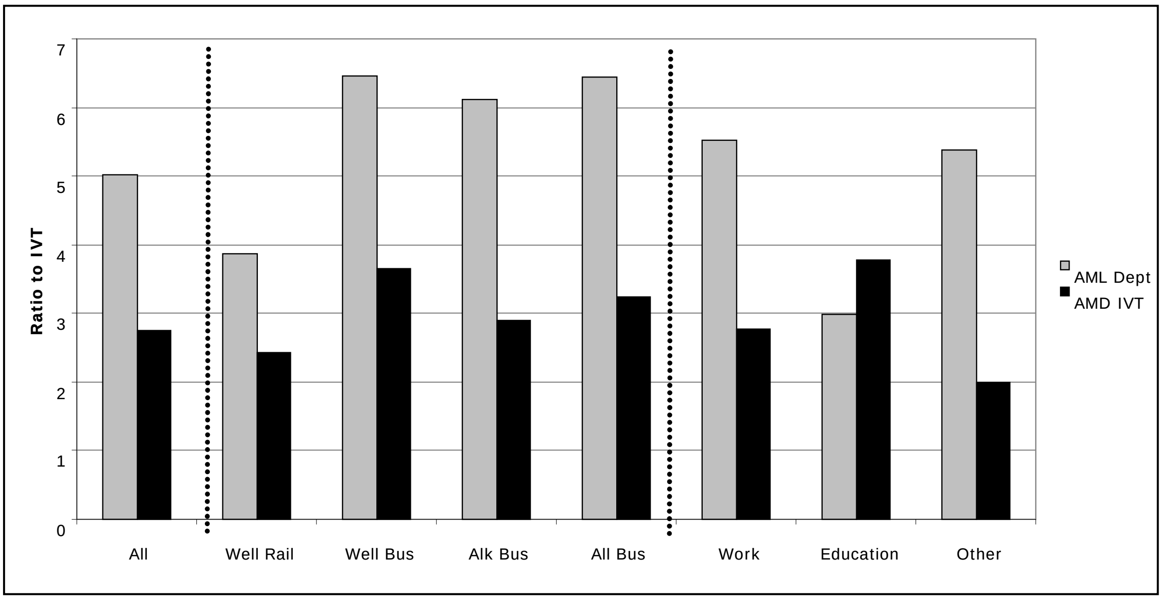

Figure 8.28 Comparison of segment reliability valuations – mean model.

The mean model indicates that valuations of unreliable services in terms of average delay are fairly consistent across all market segments. Overall, unexpected wait time is valued around five times IVT. Given that normal wait time is valued around two times IVT, the unexpected aspect increases this by a factor of 2.5. This finding is fairly consistent with other valuations of unexpected wait time. Unexpected in-vehicle time has a lower valuation that is around 2.8 times IVT (or around 60% of unexpected wait time).

Assuming a 50:50 split between passengers who are delayed on pickup and those who are delayed in the vehicle, the total passenger impact caused by a service being late at a stop/station would be around 4 times IVT.

8.4.4 Variance model

Overall, passengers place a higher valuation on variation of in-vehicle time than variation of wait time (the opposite to the non-linear and mean models). The higher valuation is consistent across all segments; the education purpose shows a larger difference in values, whereas ‘other purpose’ indicates valuations that are the same. Relative valuations by mode show a larger difference for Wellington bus and rail, compared with Auckland buses.

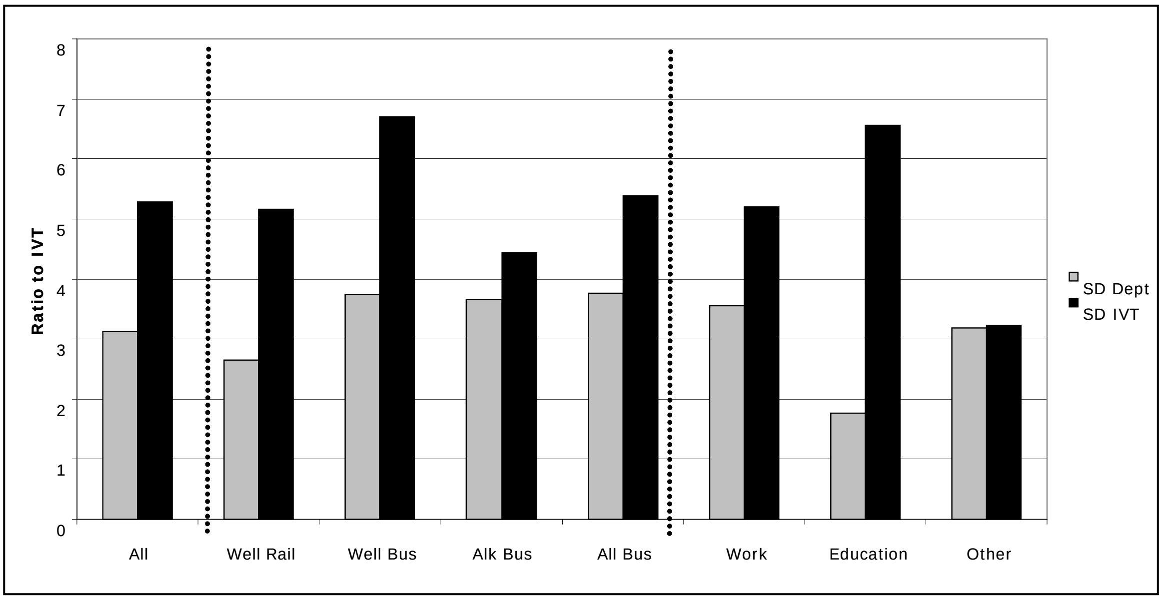

Figure 8.29 Comparison of segment reliability valuations – variance model.

The variance model indicates that valuations of unreliable services in terms of standard deviation of delay are fairly consistent across all market segments. Overall, standard deviation of wait time is valued around three times IVT; this is fairly consistent across the market segment. Standard deviation of in-vehicle time has a higher valuation of around five times IVT. International literature gives a wide variety of valuations for variance of reliability, and these valuations are certainly at the higher end.

Assuming a 50:50 split between passengers who experienced variability on pickup and in-vehicle, the total passenger impact caused by a late service at a stop/station would be around four times IVT.

8.4.5 Mean-variance model

Overall, passengers place a higher valuation on average delay on departure and variation of delay while in the vehicle than on variation of wait time and average delay in the vehicle. However, because of the negative valuations for some segments, this model does not apply well by mode or trip purpose.

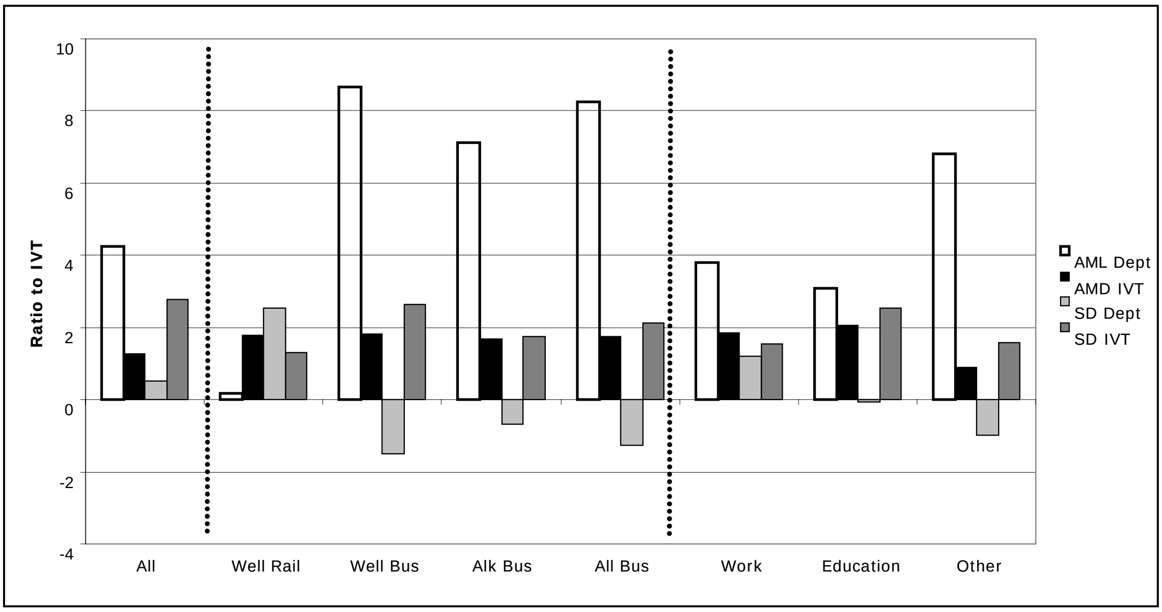

Figure 8.30 Comparison of segment reliability valuations – mean-variance model.

The mean-variance model indicates valuations of unreliable services in terms of average delay and standard deviation of delay. Overall, average delay is more important when passengers are waiting for a service, and variation of delay is more important when a passenger is on the service. International literature does not provide valuations for these models. Also, because the model was given the wrong parameter valuations for some segments, this is not the best model to use for predictive purposes.

Assuming a 50:50 split between passengers who experienced variability on pickup and those who experienced variability in-vehicle, the total passenger impact caused by a late service at a stop/station would be around 2.8 times IVT for average delay and 1.7 times IVT for standard deviation of delay.

However, because the mean-variance model does not provide a consistent set of parameters that are significantly different from zero or have the correct sign, **this model has not been recommended for adoption**.

8.5 Implications for planning – recommended valuations

8.5.1 Summary

A summary of the valuations from the SP is provided in Table 8.5. This study was able to separate departure and in-vehicle reliability; in the real world, however, the impact on an individual service will be a combination of the two sources of delay. A service that is running five minutes late will result in the passengers still to be picked up being late on departure, and the passengers already on the service being delayed in-vehicle by five minutes. By knowing where the delay occurs on the route, the proportion of passengers affected by both delays can be determined, and so a weighted average impact can be calculated. Without this information, you could roughly assume a 50:50 split between the two effects (the combined column).

Depending on the information that is available to practitioners, any of the models and parameters listed in Table 8.5 could be used. However, it should be recognised that applying the different models to the same dataset (albeit with different indicators) will produce different demand impacts (see examples 1–3 in Chapter 9). In particular, a scenario that currently has some early or very late running services will show a bigger uplift when using the disaggregate or variance approach. Where levels of reliability are lower, the difference between the three approaches is smaller.

Table 8.5 Reliability parameter summary.

Segment	Model	Disaggregate			Mean			Variance		
	Parameter	Departure	IVT	Combined[a]	Departure	IVT	Combined[a]	Departure	IVT	Combined[a]
All	Early	10.6[c]	1.3	6.0	–	–	–	–	–	–
	5 mins late	3.0	3.5	3.3	–	–	–	–	–	–
	10 mins late[b]	6.2	4.5	5.3	–	–	–	–	–	–
	AML	–	–	–	5.0	2.8	3.9	–	–	–
	SD	–	–	–	–	–	–	3.1	5.3	4.2
Rail	Early	10.6	0.3	5.5	–	–	–	–	–	–
	5 mins late	2.8	2.7	2.7	–	–	–	–	–	–
	10 mins late	4.5	3.9	4.2	–	–	–	–	–	–
	AML	–	–	–	3.9	2.4	3.1	–	–	
	SD	–	–	–	–	–	–	2.6	5.2	3.9
Bus	Early	11.1	2.0	6.6	–	–	–	–	–	–
	5 mins late	3.5	4.5	4.0						
	10 mins late	8.0	5.2	6.6	–	–	–	–	–	–
	AML	–	–	–	6.4	3.2	4.8			
	SD	–	–	–	–	–	–	3.8	5.4	4.6
Work	Early	11.1	0.8	5.9	–	–	–	–	–	–
	5 mins late	2.5	3.4	3.0	–	–	–	–	–	–
	10 mins late	6.6	4.4	5.5	–	–	–	–	–	–
	AML	–	–	–	5.5	2.8	4.1	–	–	–
	SD	–	–	–	–	–	–	3.5	5.2	4.4
Education	Early	11.4	2.7	7.1	–	–	–	–	–	–
	5 mins late	2.5	5.7	4.1	–	–	–	–	–	–
	10 mins late	4.3	6.3	5.3	–	–	–	–	–	–
	AML	–	–	–	3.0	3.8	3.4			
	SD	–	–	–	–	–	–	1.8	6.6	4.2
Other	Early	7.8	1.7	4.7	–	–	–	–	–	–
	5 mins late	5.4	2.8	4.1	–	-	-	-	-	–
	10 mins late	6.7	3.4	5.1	–	–	–	–	–	–
	AML	–	–	–	5.4	2.0	3.7	–	–	–
	SD	–	–	–	–	–	–	3.2	3.2	3.2

Notes to Table 8.5:

a The combined value assumes a 50:50 split between departure and IVT delay *en route.*
b Services that are later than 10 minutes should be treated as being 10 minutes late.
c Valuations are in equivalent in-vehicle minutes.

8.5.2 Recommended valuations

Given these three possible approaches, we think it worthwhile to recommend a **preferred approach** based on ease of use and comparability to international measures. As such, we recommend the mean delay approach as the best to use, given that:

- calculating the mean delay across a number of services is easy for practitioners;
- the mean delay is a measure that is used more widely overseas;
- while the disaggregate approach includes valuations for a service being 5 minutes early, 5 minutes late and 10 minutes late, the high valuation for early departure time needs more investigation; and
- the variance model approach valuations are highly influenced by the distribution of reliability options that were presented to the individual. Also, the international evidence provides a wide range of variance valuations, with the valuations obtained here being at the high end – as such, we have less confidence in these.

The recommended valuations are given in Table 8.6. Valuations are provided for the two sources of delay: delay on departure and delay in-vehicle. Where possible, the different sources of delay should be applied to each proportion of demand affected by such delay. This could be undertaken by looking at the major sources of time variations through a routes itinerary, and determining the proportion of users already on the service and those waiting to be picked up by the service at each point. Valuations are also split by mode (rail and bus) and purpose (work, education and other). If demand data are available by any of these segments, then using the segment-based valuations is desirable. Otherwise, using the total market (ALL) segment would be applicable.

In the simplest terms, if we assume that no difference exists in market segmentation, and make no distinction between departure and in-vehicle reliability, this would result in a valuation of one minute's average lateness at 3–5 times IVT.

Table 8.6 Reliability parameter recommendations.

Model	**Segment**	**Parameter**	**Valuation**		
			Departure	**IVT**	**Combined[a]**
Mean	ALL	AML[b]	5.0	2.8	3.9
	Rail	AML	3.9	2.4	3.1
	Bus	AML	6.4	3.2	4.8
	Work	AML	5.5	2.8	4.1
	Education	AML	3.0	3.8	3.4
	Other	AML	5.4	2.0	3.7

Notes to Table 8.6:

a The combined value assumes a 50:50 split between departure and IVT delay *en route.*

b Services that are later than 10 minutes should be treated as being 10 minutes late.

This valuation is consistent with the average valuation obtained from the literature review, which also suggested an average value of around 4 times IVT, with departure variation being valued more highly than IVT variation.

These valuations could be used in evaluation guidelines, particularly in the Economic Evaluation Manual 2 (Land Transport New Zealand 2005).

9 Application

9.1 Journey time in all examples

Three examples of applying these reliability valuations are provided below. In these examples, the passenger's trip is composed of 30 minutes IVT (scheduled), a $3.00 fare (converted to 22.5 minutes assuming a value of time of $8/hr), 16 minutes of wait time (8 minutes of actual wait time weighted by 2), and 10 minutes of access time (5 minutes of actual access time weighted by 2). The total generalised time for the trip (excluding reliability) is the sum of these components (78.5 minutes).

'Before' and 'after' reliability valuations are added, and a generalised journey time elasticity (-1.25) is applied to determine the change in demand resulting from the change in reliability. Reliability valuations are included for the disaggregate, mean and variance models to compare the effect of each. Effects on departure, in-vehicle and the combined time (assuming a 50:50 split) are also included using the 'all' market parameters.

9.2 Example 1: a service that occasionally runs early

In this example, 10% of services currently arrive 5 minutes early, 60% arrive on time, 20% arrive 5 minutes late and 10% arrive 10 minutes late. Improvements to the service eliminate earliness and running 10 minutes late, increase on-time running to 80% and have 20% of services running 5 minutes late. Table 9.1 shows the calculated before and after effects.

Table 9.1 Before and after calculations for Example 1.

Factors	Models	Departure		IVT		Combined
		Before	After	Before	After	
Reliability Measures (min)	AML	2.5	1.0	1.5	1.0	
	SD	4.2	2.2	4.2	2.2	
Reliability costs including weighting (min)	Disaggregate[a]	14.5	3.0	8.7	3.5	
	Mean[b]	12.5	5.0	4.1	2.8	
	Variance[c]	13.1	7.0	22.1	11.8	
Total costs (min) [d]	Disaggregate	93.0	81.5	87.2	82.0	
	Mean	91.0	83.5	82.6	81.3	
	Variance	91.6	85.5	100.6	90.3	
Demand impact	Disaggregate[e]		17.9%		7.9%	12.9%
	Mean		11.4%		2.1%	6.8%
	Variance		9.0%		14.4%	11.7%

Notes to Table 9.1:

a Calculated by multiplying the proportion of services running 5 minutes early, 5 minutes late and 10 minutes late by the relative weightings.
b Calculated by multiplying the AML by the mean per minute valuation.
c Calculated by multiplying the SD by the variance per minute valuation.
d Adding the reliability costs to the other trip costs = 30 minutes IVT + 22.5 minutes fare + 16 minutes wait time + 10 minutes access time = 78.5 minutes.
e Uses an elasticity of -1.25 applied to the change in total costs between 'before' and 'after'.

The three reliability approaches provide quite different results under this extreme example. In particular, the non-linear approach provides the highest uplift in demand overall, with a significant contribution from improvements in departure reliability. A disaggregate approach is expected to give higher impact results, particularly when services run early or 10 minutes late, which have a higher weighting. The mean delay model is the most conservative, mostly because services that run early have a positive impact on IVT that will in turn offset any AML improvement; however, any scenario that does not have any services running early will close the gap between the mean approach and the others. The variance model has a larger effect on in-vehicle reliability, driven by the higher valuation.

9.3 Example 2: a service that does not run early.

In this example, currently, no services run early, 60% arrive on time, 30% arrive 5 minutes late and 10% arrive 10 minutes late. Improvements to the service will eliminate running late by 10 minutes, increase on-time running to 80% and have 20% running 5 minutes late. Table 9.2 shows the calculated before and after effects.

Table 9.2 Before and after calculations for Example 2.

Factors	Model	Departure		IVT		Combined
		Before	After	Before	After	
Reliability measures (min)	AML	2.5	1.0	2.5	1.0	
	SD	4.2	2.2	4.2	2.2	
Reliability costs including weighting (min)	Disaggregate[a]	10.7	3.0	9.8	3.5	
	Mean[b]	12.5	5.0	6.9	2.8	
	Variance[c]	13.1	7.0	22.1	11.8	
Total costs (min)[d]	Disaggregate	89.2	81.6	88.3	82.0	
	Mean	91.0	83.5	85.4	81.3	
	Variance	91.6	85.5	100.6	90.3	
Demand impact	Disaggregate[e]		11.9%		9.7%	10.8%
	Mean		11.4%		6.4%	8.9%
	Variance		9.0%		14.4%	11.7%

Notes to Table 9.2:

a Calculated by multiplying the proportion of services running 5 minutes early, 5 minutes late and 10 minutes late by the relative weightings.
b Calculated by multiplying the AML by the mean per minute valuation.
c Calculated by multiplying the SD by the variance per minute valuation.
d Adding the reliability costs to the other trip costs = 30 minutes IVT + 22.5 minutes fare + 16 minutes wait time + 10 minutes access time = 78.5 minutes.
e Uses an elasticity of -1.25 applied to the change in total costs between 'before' and 'after'.

As expected, not having services running early reduces the difference in uplifts for the three approaches. In particular, the disaggregate departure uplift is reduced (because of the high weighting placed on an early departure time) and the in-vehicle time uplift is increased (because of the low valuation of earliness for IVT). The mean approach in-vehicle contribution is increased by the low valuation of earliness compared with lateness.

The variance model impacts do not change, as the SD measure is the same as for Example 1.

9.4 Example 3: a small reliability improvement

In this example, currently no services run early, 80% arrive on time and 20% run 5 minutes late. Improvements to the service increase the on-time running to 90% and reduce services late by 5 minutes to 10%. The calculated before and after effects are shown in Table 9.3.

Table 9.3 Before and after calculations for Example 3.

Factors	Model	Departure		IVT		Combined
		Before	After	Before	After	
Reliability Measures (min)	AML	1.0	0.5	1.0	0.5	
	SD	2.2	1.6	2.2	1.6	
Reliability costs including weighting (min)	Disaggregate[a]	3.0	1.5	3.5	1.8	
	Mean[b]	5.0	2.5	2.8	1.4	
	Variance[c]	7.0	4.9	11.8	8.3	
Total costs (min)[d]	Disaggregate	81.6	80.0	82.0	80.3	
	Mean	83.5	81.0	81.3	79.9	
	Variance	85.5	83.5	90.3	86.9	
Demand impact	Disaggregate[e]		2.4%		2.8%	2.6%
	Mean		3.9%		2.2%	3.0%
	Variance		3.1%		5.0%	4.0%

Notes to Table 9.3:

a Calculated by multiplying the proportion of services running 5 minutes early, 5 minutes late and 10 minutes late by the relative weightings.
b Calculated by multiplying the AML by the mean per minute valuation.
c Calculated by multiplying the SD by the variance per minute valuation.
d Adding the reliability costs to the other trip costs = 30 minutes IVT + 22.5 minutes fare + 16 minutes wait time + 10 minutes access time = 78.5 minutes.
e Uses an elasticity of -1.25 applied to the change in total costs between 'before' and 'after'.

Under a smaller (and more realistic) change, the three models provide similar uplift effects, caused by the removal of extreme reliability changes in this example (no services are early or 10 minutes late).

9.5 Application within an Emme/2 modelling process

These three examples can be applied within an Emme/2 public transport model process by using a combination of node and in-vehicle time adjustments. Any implemented approach can be determined by the reliability information available. The recommended approach is to use the mean model approach, where demand is based on average reliability. An Emme/2 assignment process includes information on passengers waiting for and travelling on services. As such, departure and in-vehicle variability could be represented separately.

Assuming each service (or mode) has its own AML measure (from existing service information) then reliability should be included in the transit assignment process. If the AML is an average across the system (does not differ by mode), then reliability could be included through a simple additional matrix calculation of the type shown in Examples 1–3.

This could also be included in the assignment by taking an AML measure, and multiplying it by the average of the departure and in-vehicle weights; subsequently, this could be included as an additional boarding penalty in the assignment.

If, however, more detailed reliability information is available (such as the distribution of reliability down a service, or differences by mode or service) then this measure can be included in a transit line segment attribute. The segment would represent the change in reliability between stations or stops on the network. Within the transit assignment, the departure variability could be included by an additional boarding penalty based on the sum of the segment values up to the point of boarding. This would then be multiplied by the appropriate departure variability weighting to provide an additional penalty for reliability. The in-vehicle reliability impact could be represented by including the AML segment values in the transit time functions, again with the appropriate weights.

10 Further work

We see the dataset that has been created as part of this study as a valuable resource for further examination of reliability. In particular, the market could be segmented many ways to provide further insight. Possible segmentations could be:

- by time of day,
- by service frequency,
- by trip length (IVT could be used as a proxy), or
- by inbound v. outbound valuations.

This study has also grouped shopping and social trips together in the 'other' group. We have a sufficient amount of observations in these trip purposes to separate them in the analysis if desired.

Collecting actual reliability service data and subsequently linking them with the valuations would be a useful exercise to give a more accurate overall picture of the reliability impacts.

Applying this methodology within specific transport models such as Wellington Transport Strategy Model or the Auckland Public Transport model could be undertaken.

Finally, this study has not explored the impact of extreme levels of unreliability such as delays greater than 10 minutes or service cancellations.

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Appendix A Reliability SP survey questionnaire

This appendix contains screenshots of the online survey as they appeared to users. They have not been edited for presentation in this report.

The screenshots are the actual screens seen by a Wellington respondent who stated that they use the train for work purposes as their most frequent public transport use. Users in Auckland or who used the bus, or who selected another trip purpose, had screens with the wording changed appropriately in place of the screenshots shown in Figures A5–A8 and A14.

Figure A1 Screenshot of the introduction to the survey.

Figure A2 Survey question regarding location.

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In the **last four weeks**, have you made any **return** trips in the Wellington Region by either bus or train?

Please select all that apply.

☐ Bus
☐ Train
☐ None or single trips only

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Figure A3 Survey question relating to current public transport use by mode.

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For what purpose/s did you make these return trips?

Please select all that apply.

☐ Work
☐ Education
☐ Shopping
☐ Medical
☐ Social (includes visiting friends/family, going to a café/bar, movies, sports or cultural event etc.)
☐ Other

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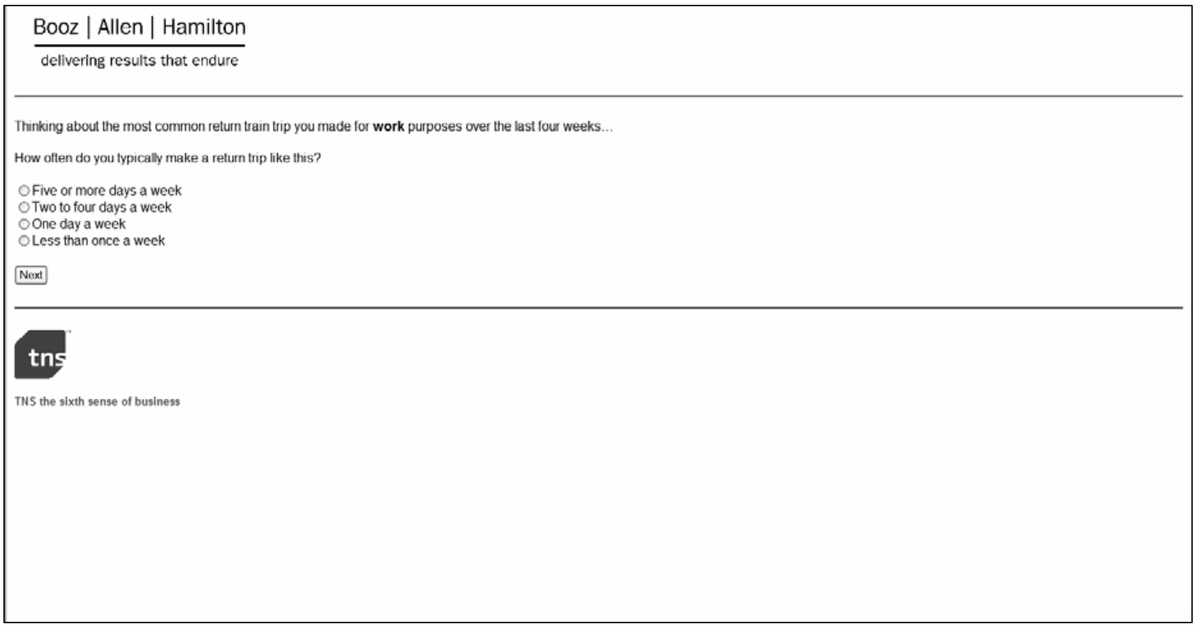
Figure A4 Survey question to determine trip purpose.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Thinking about the most common return train trip you made for **work** purposes over the last four weeks…

How often do you typically make a return trip like this?

- ○ Five or more days a week
- ○ Two to four days a week
- ○ One day a week
- ○ Less than once a week

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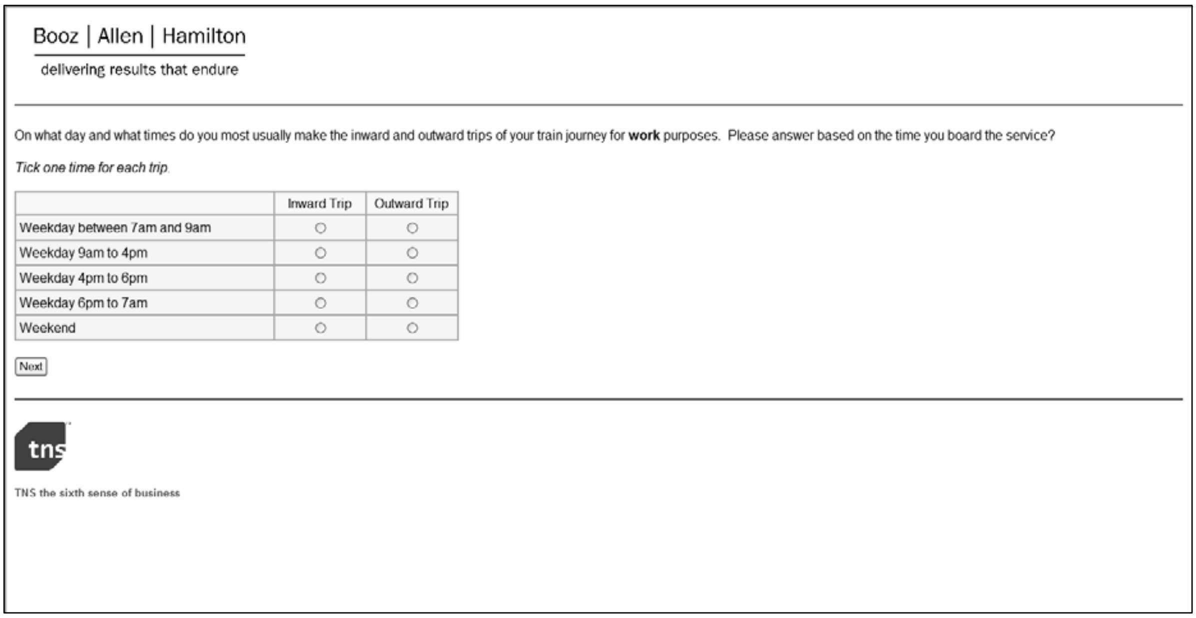
Figure A5 Survey question relating to frequency of public transport use.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On what day and what times do you most usually make the inward and outward trips of your train journey for **work** purposes. Please answer based on the time you board the service?

Tick one time for each trip.

	Inward Trip	Outward Trip
Weekday between 7am and 9am	○	○
Weekday 9am to 4pm	○	○
Weekday 4pm to 6pm	○	○
Weekday 6pm to 7am	○	○
Weekend	○	○

[Next]

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Figure A6 Survey question to determine the trip time.


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Thinking about your weekday, 7am and 9am inward trip…

Where are you usually travelling **from** for this weekday, 7am and 9am inward trip?

- Wellington CBD
- Wellington City (excl CBD)
- Porirua City
- Kapiti Coast
- Hutt City
- Upper Hutt City
- Wairarapa
- Other

Where are you usually travelling **to** for this weekday, 7am and 9am inward trip?

- Wellington CBD
- Wellington City (excl CBD)
- Porirua City
- Kapiti Coast
- Hutt City
- Upper Hutt City
- Wairarapa
- Other

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Figure A7 Survey question relating to trip length (distance).


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Approximately how long do you usually spend **on** the train?

- 5 minutes
- 10 minutes
- 15 minutes
- 20 minutes
- 25 minutes
- 30 minutes
- 35 minutes
- 40 minutes
- 45 minutes
- 50 minutes
- 60 minutes
- 70 minutes
- 80 minutes
- 90 minutes

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Figure A8 Survey question to determine current IVT.

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Approximately what is the cost of the fare you usually pay for this trip?

Fill in one option only and check you have entered the correct amount.

$ [ ] per single trip ticket
$ [ ] per return trip
$ [ ] per 10 trip ticket
$ [ ] per monthly pass

If your ticket is not listed, please estimate what it would cost for a single trip:

$ [ ]

[Next]

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Figure A9 Survey question to discover current public transport fare per trip.

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Approximately how frequent is your service at this time (scheduled minutes between services)?

- ○ 5 minutes
- ○ 10 minutes
- ○ 15 minutes
- ○ 20 minutes
- ○ 30 minutes
- ○ 45 minutes
- ○ 60 minutes
- ○ 90 minutes
- ○ 120 minutes

[Next]

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Figure A10 Survey question related to trip frequency (headway).

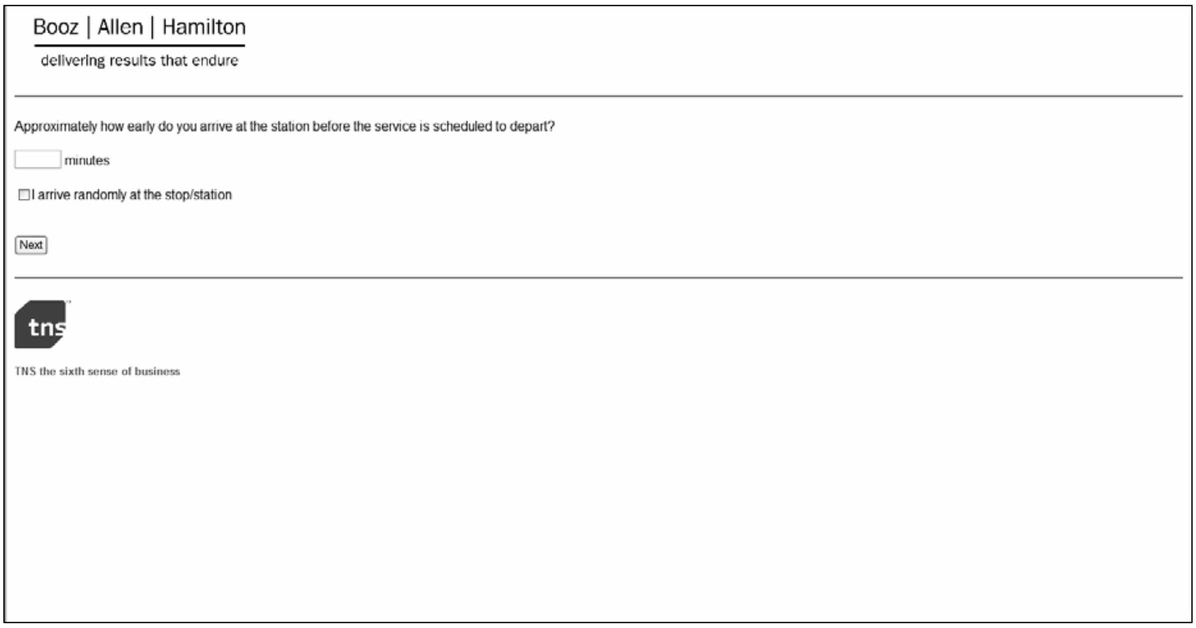
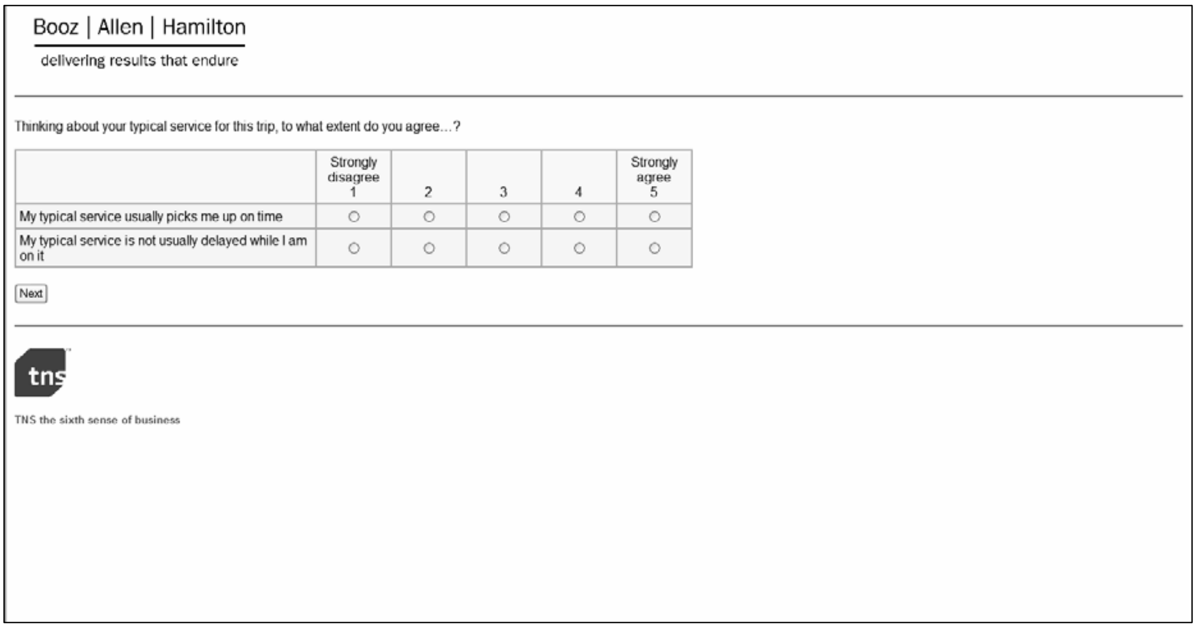


Figure A11 Survey question to determine 'planned' (expected) waiting time.

Figure A12 Survey question to discover the importance of arriving on time.



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Thinking about your typical service for this trip, to what extent do you agree…?

	Strongly disagree 1	2	3	4	Strongly agree 5
My typical service usually picks me up on time	○	○	○	○	○
My typical service is not usually delayed while I am on it	○	○	○	○	○

Next

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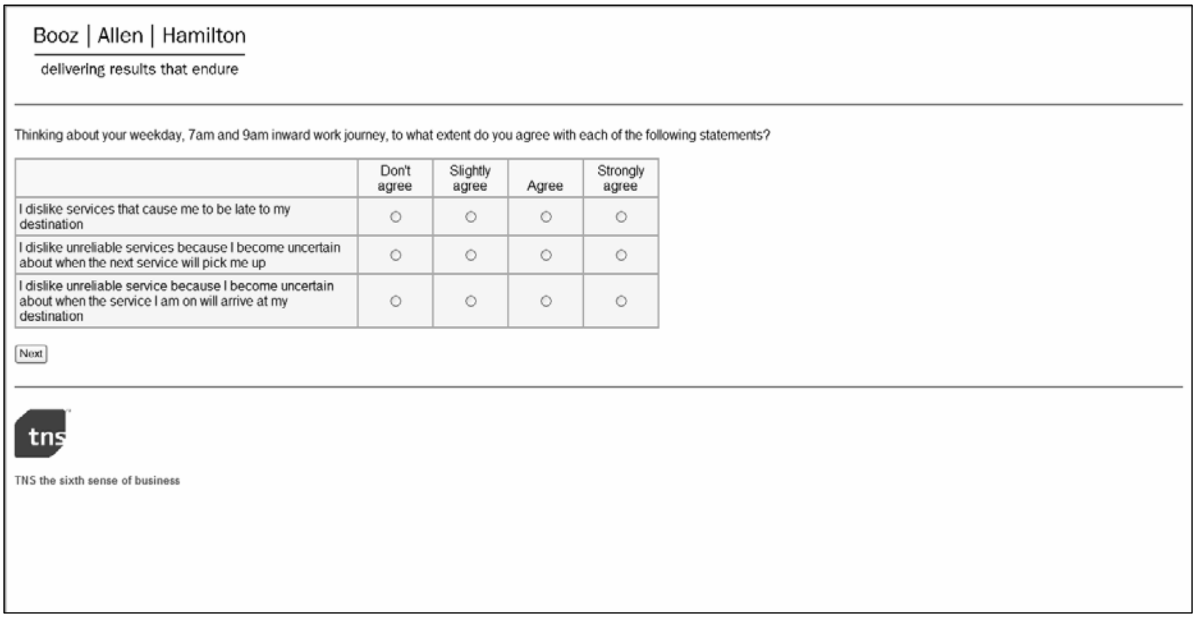
Figure A13 Survey question specifying how well the chosen service meets its schedule (or is perceived to do so).



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Thinking about your weekday, 7am and 9am inward work journey, to what extent do you agree with each of the following statements?

	Don't agree	Slightly agree	Agree	Strongly agree
I dislike services that cause me to be late to my destination	○	○	○	○
I dislike unreliable services because I become uncertain about when the next service will pick me up	○	○	○	○
I dislike unreliable service because I become uncertain about when the service I am on will arrive at my destination	○	○	○	○

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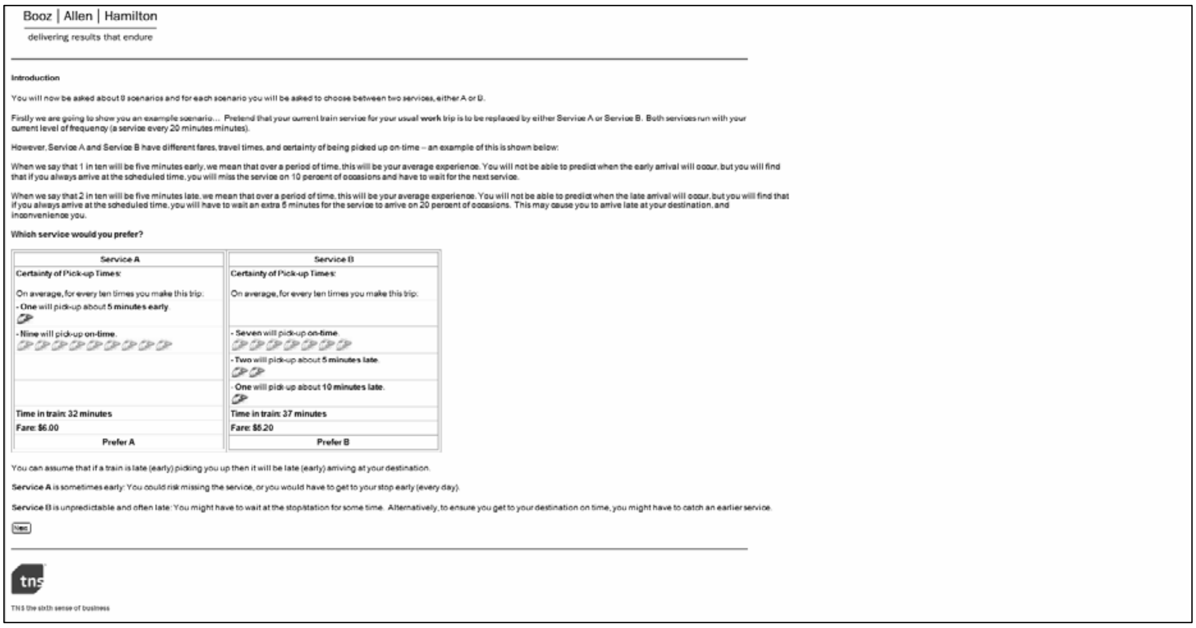
Figure A14 Survey question on attitudes to service reliability.



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Introduction

You will now be asked about 8 scenarios and for each scenario you will be asked to choose between two services, either A or B.

Firstly we are going to show you an example scenario... Pretend that your current train service for your usual **work** trip is to be replaced by either Service A or Service B. Both services run with your current level of frequency (a service every 20 minutes minutes).

However, Service A and Service B have different fares, travel times, and certainty of being picked up on-time – an example of this is shown below:

When we say that 1 in ten will be five minutes early, we mean that over a period of time, this will be your average experience. You will not be able to predict when the early arrival will occur, but you will find that if you always arrive at the scheduled time, you will miss the service on 10 percent of occasions and have to wait for the next service.

When we say that 2 in ten will be five minutes late, we mean that over a period of time, this will be your average experience. You will not be able to predict when the late arrival will occur, but you will find that if you always arrive at the scheduled time, you will have to wait an extra 5 minutes for the service to arrive on 20 percent of occasions. This may cause you to arrive late at your destination, and inconvenience you.

Which service would you prefer?

Service A	Service B
Certainty of Pick-up Times: On average, for every ten times you make this trip:	**Certainty of Pick-up Times:** On average, for every ten times you make this trip:
- **One** will pick-up about **5 minutes early**	
- **Nine** will pick-up **on-time**.	- **Seven** will pick-up **on-time**.
	- **Two** will pick-up about **5 minutes late**.
	- **One** will pick-up about **10 minutes late**.
Time in train: 32 minutes	**Time in train: 37 minutes**
Fare: $6.00	**Fare: $8.20**
Prefer A	**Prefer B**

You can assume that if a train is late (early) picking you up then it will be late (early) arriving at your destination.

Service A is sometimes early: You could risk missing the service, or you would have to get to your stop early (every day).

Service B is unpredictable and often late: You might have to wait at the stop/station for some time. Alternatively, to ensure you get to your destination on time, you might have to catch an earlier service.

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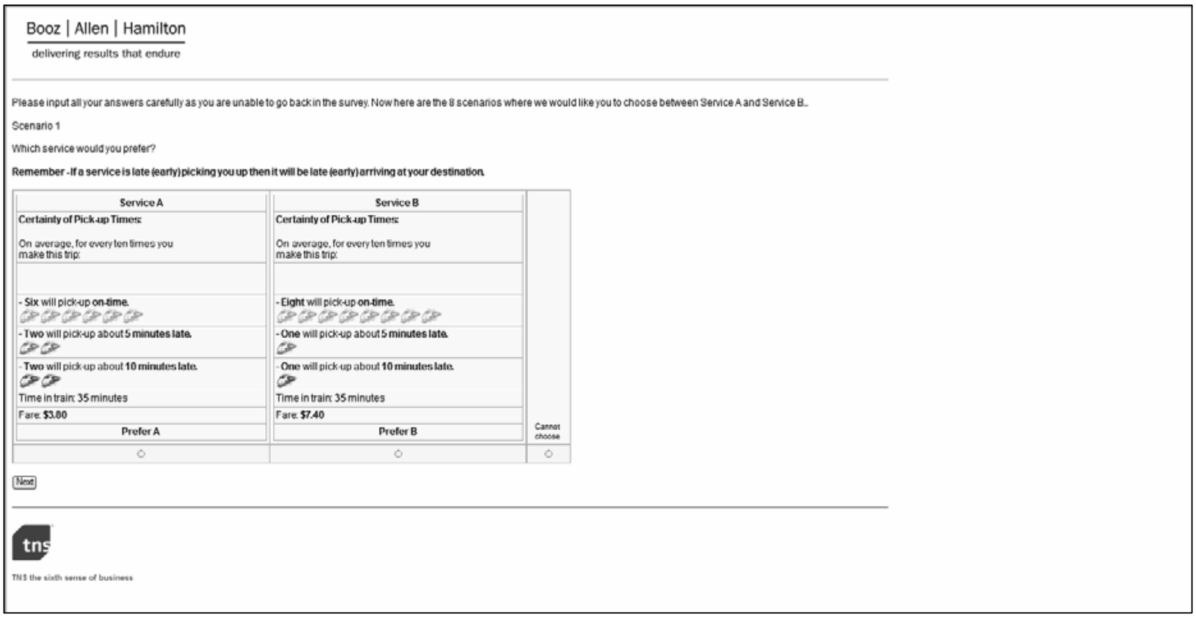
Figure A15 Screenshot of the explanation of how to use the departure time variability survey.



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Please input all your answers carefully as you are unable to go back in the survey. Now here are the 8 scenarios where we would like you to choose between Service A and Service B..

Scenario 1

Which service would you prefer?

Remember - If a service is late (early) picking you up then it will be late (early) arriving at your destination.

Service A	Service B	
Certainty of Pick-up Times: On average, for every ten times you make this trip:	**Certainty of Pick-up Times:** On average, for every ten times you make this trip:	
- **Six** will pick-up **on-time**.	- **Eight** will pick-up **on-time**.	
- **Two** will pick-up about **5 minutes late**.	- **One** will pick-up about **5 minutes late**.	
- **Two** will pick-up about **10 minutes late**. Time in train: 35 minutes	- **One** will pick-up about **10 minutes late**. Time in train: 35 minutes	
Fare: **$3.80**	Fare: **$7.40**	
Prefer A	**Prefer B**	Cannot choose
○	○	○

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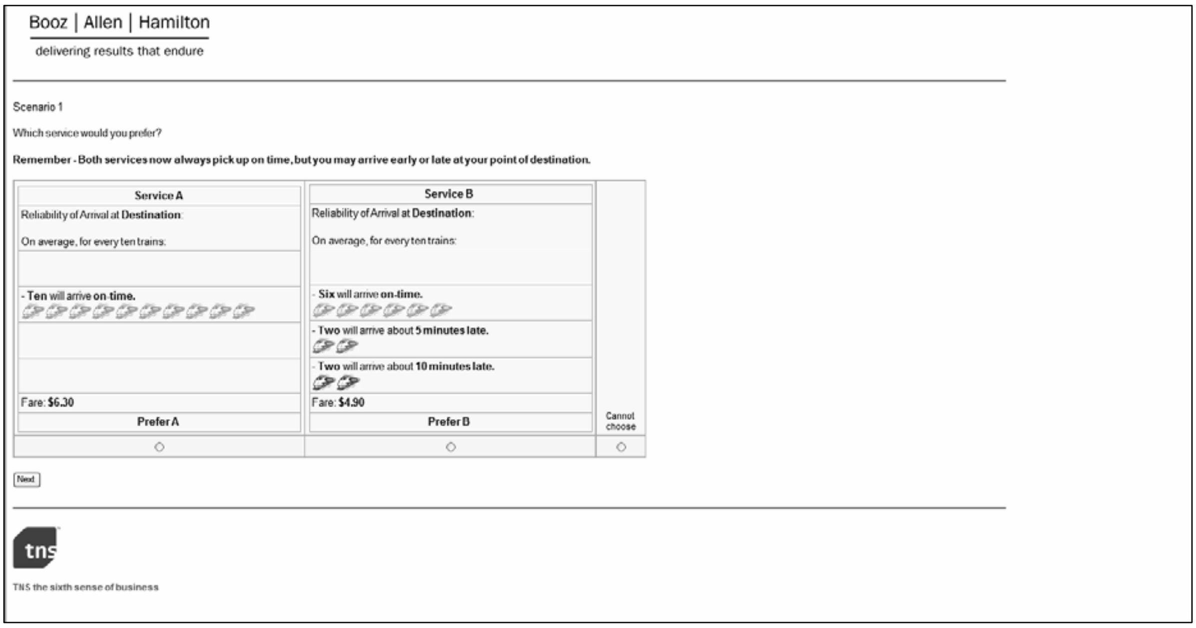
Figure A16 Sample scenario for the departure time SP survey.

Figure A17 Screenshot of the 'rest' between questions.

Figure A18 Explanation of how to reply to the variable IVT SP survey.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Scenario 1

Which service would you prefer?

Remember - Both services now always pick up on time, but you may arrive early or late at your point of destination.

Service A	Service B	
Reliability of Arrival at **Destination**: On average, for every ten trains:	Reliability of Arrival at **Destination**: On average, for every ten trains:	
- **Ten** will arrive **on time.**	- **Six** will arrive **on-time.**	
	- **Two** will arrive about **5 minutes late.**	
	- **Two** will arrive about **10 minutes late.**	
Fare: **$6.30**	Fare: **$4.90**	
Prefer A	**Prefer B**	Cannot choose
○	○	○

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Figure A19 Sample of one scenario presented in the variable IVT survey.


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Finally just a few questions to ensure we have included a broad range of people in our sample. Your personal details will remain confidential to TNS and will only be used to make our estimates more representative of public transport users.

What gender are you?

○ Male
○ Female

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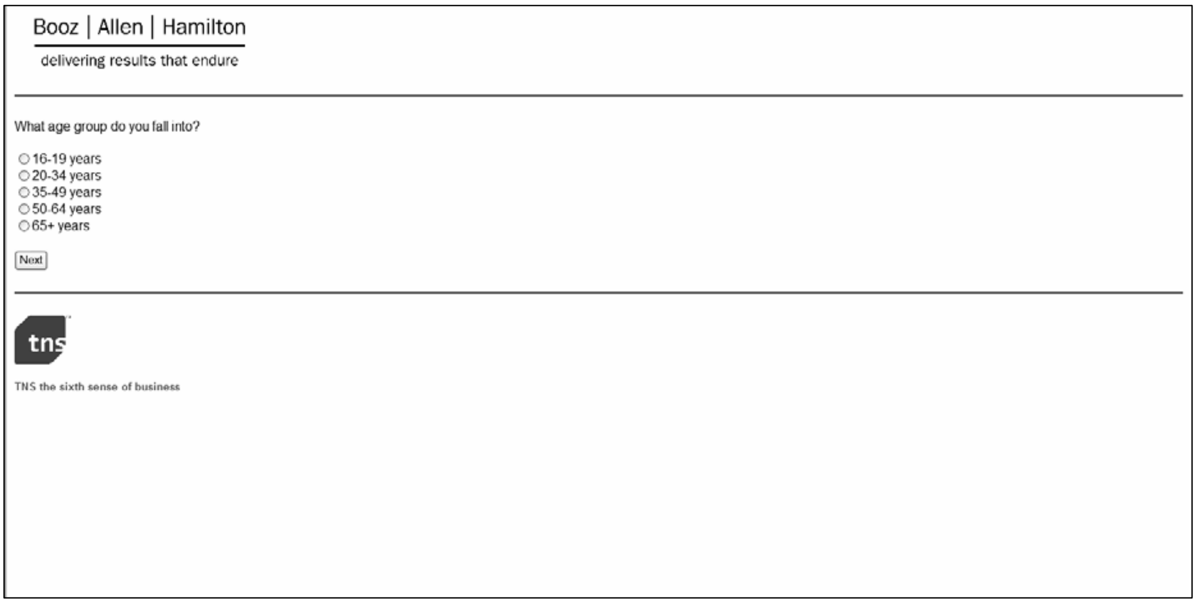
Figure A20 Question to determine demographic details of respondents according to gender.



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What age group do you fall into?

- 16-19 years
- 20-34 years
- 35-49 years
- 50-64 years
- 65+ years

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Figure A21 Question to determine the age of respondents.

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What is your **personal** annual income before tax?

- Less than $20,000
- $20,000 – $39,999
- $40,000 – $59,999
- $60,000- $99,999
- $100,000 or more
- Would rather not say

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Figure A22 Question to determine the economic bracket of respondents.

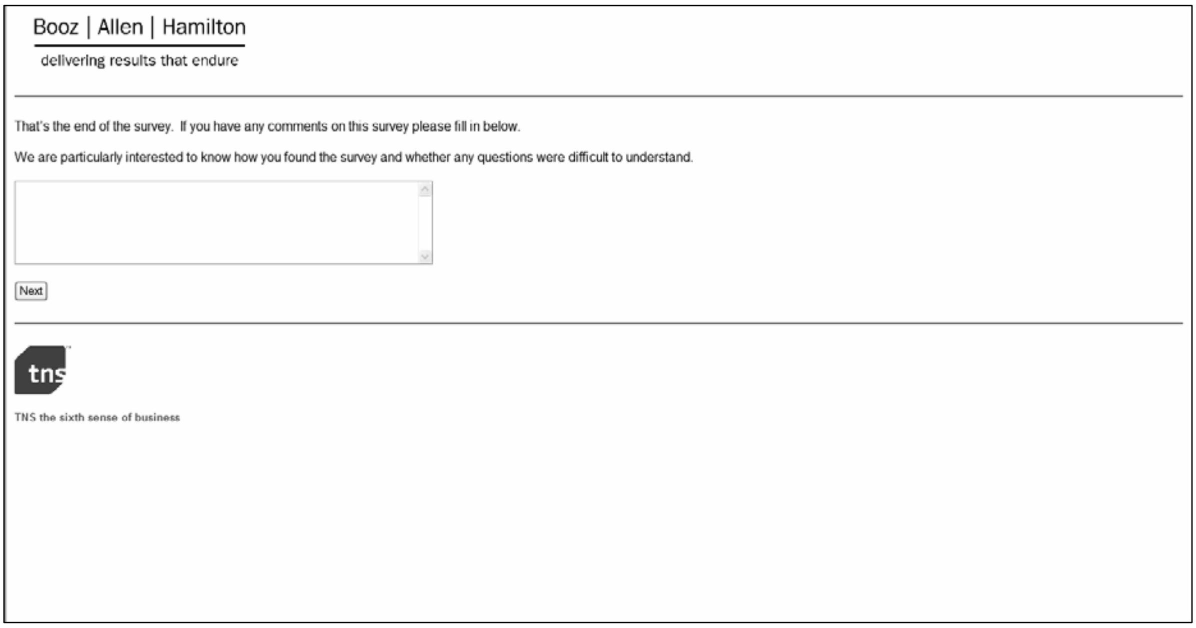

Figure A23 Screenshot of the form inviting further comments.

Figure A24 Screenshot of the complimentary closing to the survey.

Appendix B Model parameter estimates

B1 Stated preference 1 – departure time variability

B1.1 Disaggregate model

Table B1 Disaggregate model: all observations (unweighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-6.06E-01	9.18E-02	-6.59449	4.27E-11	$1.14
IVT	-9.06E-02	8.00E-03	-11.3226	2.89E-15	$10.20/hr
Fare	-0.532723	3.94E-02	-13.5324	2.89E-15	–
EARLY	-0.612756	8.04E-02	-7.62069	2.53E-14	13.5
LATE5	-2.12E-01	4.73E-02	-4.48214	7.39E-06	4.7
LATE10	-0.545704	4.74E-02	-11.5079	2.89E-15	6.0

Table B2 Disaggregate model: all observations (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-3.99E-01	9.52E-02	-4.19653	2.71E-05	$0.61
IVT	-9.28E-02	8.29E-03	-11.2052	2.89E-15	$8.56/hr
Fare	-0.650936	4.40E-02	-14.7832	2.89E-15	–
EARLY	-0.492618	8.02E-02	-6.14261	8.12E-10	10.6
LATE5	-1.42E-01	5.00E-02	-2.83029	0.004651	3.0
LATE10	-0.571519	4.80E-02	-11.9057	2.89E-15	6.2
Log-likelihood	-2530	–	–	–	–

Table B3 Disaggregate model: all observations (weighted/no constant).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
IVT	-5.04E-02	4.73E-03	-10.6589	2.89E-15	$6.86/hr
Fare	-0.440364	2.35E-02	-18.7342	2.89E-15	
EARLY	-0.270842	4.73E-02	-5.72522	1.03E-08	10.8
LATE5	-1.97E-02	2.62E-02	-0.75241	0.451804	0.8
LATE10	-0.291321	2.55E-02	-11.4021	2.89E-15	5.8
Log-likelihood	-2540				

Table B4 Disaggregate model: Wellington rail (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-0.716768	1.69E-01	-4.2506	2.13E-05	$0.98
IVT	-1.50E-01	1.52E-02	-9.90091	2.89E-15	$12.38/hr
Fare	-0.728941	7.57E-02	-9.62824	2.89E-15	–
EARLY	-0.800613	1.46E-01	-5.4946	3.92E-08	10.6
LATE5	-2.09E-01	9.02E-02	-2.31347	0.020697	2.8
LATE10	-0.678881	8.37E-02	-8.10817	2.89E-15	4.5

Table B5 Disaggregate model: Wellington bus (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-8.79E-02	1.59E-01	-0.554153	0.579474	$0.12
IVT	-7.03E-02	1.58E-02	-4.45134	8.53E-06	$5.73/hr
Fare	-0.736553	8.68E-02	-8.48371	2.89E-15	–
EARLY	-3.25E-01	1.29E-01	-2.51907	0.011767	9.3
LATE5	-9.23E-02	8.09E-02	-1.14109	0.253833	2.6
LATE10	-0.53537	7.82E-02	-6.845	7.65E-12	7.6

Table B6 Disaggregate model: Auckland bus (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-0.402835	1.76E-01	-2.28373	0.022387	$0.73
IVT	-6.40E-02	1.33E-02	-4.81094	1.50E-06	$6.97/hr
Fare	-0.550713	7.24E-02	-7.6086	2.78E-14	–
EARLY	-0.402704	1.48E-01	-2.71897	0.006549	12.6
LATE5	-1.41E-01	9.13E-02	-1.54534	0.122264	4.4
LATE10	-0.506119	8.97E-02	-5.64198	1.68E-08	7.9

Table B7 Disaggregate model: bus (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-2.35E-01	1.16E-01	-2.02555	0.042811	$0.37
IVT	-6.52E-02	1.00E-02	-6.51576	7.23E-11	$6.20/hr
Fare	-0.631664	5.54E-02	-11.4114	2.89E-15	–
EARLY	-0.361093	9.71E-02	-3.71703	0.000202	11.1
LATE5	-1.14E-01	6.05E-02	-1.8915	0.058558	3.5
LATE10	-0.520489	5.89E-02	-8.84292	2.89E-15	8.0

Table B8 Disaggregate model: work purpose (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-4.28E-01	1.50E-01	-2.85291	0.004332	$0.69
IVT	-9.21E-02	1.28E-02	-7.20375	5.86E-13	$8.96/hr
Fare	-0.616733	6.76E-02	-9.12724	2.89E-15	–
EARLY	-0.509234	1.25E-01	-4.08452	4.42E-05	11.1
LATE5	-1.17E-01	7.94E-02	-1.47273	0.140824	2.5
LATE10	-0.612296	7.50E-02	-8.16861	2.89E-15	6.6

Table B9 Disaggregate model: education purpose (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-6.73E-02	0.238379	-0.282258	0.777746	$0.09
IVT	-9.10E-02	1.93E-02	-4.70826	2.50E-06	$7.53/hr
Fare	-0.725349	1.11E-01	-6.5597	5.39E-11	–
EARLY	-0.520452	0.20643	-2.52121	0.011695	11.4
LATE5	-1.14E-01	1.18E-01	-0.968776	0.332657	2.5
LATE10	-0.395548	1.21E-01	-3.25761	0.001124	4.3

Table B10 Disaggregate model: other purpose (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-0.645776	1.45E-01	-4.44529	8.78E-06	$0.91
IVT	-9.64E-02	1.49E-02	-6.44876	1.13E-10	$8.12/hr
Fare	-0.712282	7.40E-02	-9.62568	2.89E-15	–
EARLY	-0.376703	1.22E-01	-3.08169	0.002058	7.8
LATE5	-0.262186	7.93E-02	-3.30736	0.000942	5.4
LATE10	-0.644882	7.41E-02	-8.69916	2.89E-15	6.7

B1.2 Mean model

Table B11 Mean model: all observations (unweighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-0.442511	8.41E-02	-5.26148	1.43E-07	$0.83
IVT	-9.01E-02	7.94E-03	-11.35	2.89E-15	$10.18/hr
Fare	-0.531085	3.93E-02	-13.5182	2.89E-15	–
AML	-0.457804	3.71E-02	-12.3394	2.89E-15	5.1

Table B12 Mean model: all observations (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-3.08E-01	8.70E-02	-3.54602	3.91E-04	$0.47
IVT	-9.24E-02	8.26E-03	-11.1861	2.89E-15	$8.51/hr
Fare	-0.65119	4.40E-02	-14.8022	2.89E-15	–
AML	-0.462963	3.76E-02	-12.3051	2.89E-15	5.0
Log-likelihood	-2556	–	–	–	–

Table B13 Mean model: all observations (weighted/no constant).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
IVT	-5.03E-02	4.67E-03	-10.7727	2.89E-15	$6.97/hr
Fare	-0.432981	2.28E-02	-19.0095	2.89E-15	–
AML	-0.226658	1.66E-02	-13.6591	2.89E-15	4.5
Log-likelihood	-2558	–	–	–	–

Table B14 Mean model: Wellington rail (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-0.587583	1.56E-01	-3.7665	1.66E-04	$0.83
IVT	-1.48E-01	1.48E-02	-9.95415	2.89E-15	$12.51/hr
Fare	-0.708641	7.54E-02	-9.40444	2.89E-15	–
AML	-0.571659	6.59E-02	-8.67853	2.89E-15	3.9

Table B15 Mean model: Wellington bus (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-7.37E-02	1.44E-01	-0.512348	0.608408	$0.10
IVT	-6.81E-02	1.59E-02	-4.29615	1.74E-05	$5.41/hr
Fare	-0.754781	8.71E-02	-8.66957	2.89E-15	–
AML	-4.40E-01	6.04E-02	-7.27285	3.52E-13	6.5

Table B16 Mean model: Auckland bus (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-0.238985	1.59E-01	-1.49864	0.133966	$0.43
IVT	-6.27E-02	1.33E-02	-4.72829	2.26E-06	$6.80/hr
Fare	-0.553434	7.20E-02	-7.68568	1.53E-14	–
AML	-0.383909	7.17E-02	-5.35209	8.69E-08	6.1

Table B17 Mean model: bus (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-1.64E-01	1.05E-01	-1.55968	0.118835	$0.26
IVT	-6.44E-02	1.00E-02	-6.43434	1.24E-10	$6.06/hr
Fare	-0.637639	5.53E-02	-11.5229	2.89E-15	–
AML	-0.414684	4.60E-02	-9.01073	2.89E-15	6.4

Table B18 Mean model: work purpose (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-4.06E-01	1.38E-01	-2.94852	0.003193	$0.66
IVT	-9.21E-02	1.28E-02	-7.20651	5.74E-13	$8.95/hr
Fare	-0.61775	6.76E-02	-9.13285	2.89E-15	–
AML	-0.509348	5.83E-02	-8.74028	2.89E-15	5.5

Table B19 Mean model: education purpose (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	1.46E-01	0.219786	0.665232	0.505902	-$0.20
IVT	-8.98E-02	1.91E-02	-4.69116	2.72E-06	$7.51/hr
Fare	-0.716821	1.10E-01	-6.53627	6.31E-11	–
AML	-0.267838	0.097373	-2.75064	0.005948	3.0

Table B20 Mean model: other purpose (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-0.450305	1.30E-01	-3.46113	5.38E-04	$0.63
IVT	-9.58E-02	1.49E-02	-6.43775	1.21E-10	$8.00/hr
Fare	-0.718734	7.41E-02	-9.70605	2.89E-15	–
AML	-0.515233	5.85E-02	-8.81241	2.89E-15	5.4

B1.3 Variance model

Table B21 Variance model: all observations (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-4.37E-02	7.54E-02	-0.578828	5.63E-01	$0.07
IVT	-8.73E-02	8.22E-03	-10.629	2.89E-15	$7.82/hr
Fare	-0.670407	4.42E-02	-15.1634	2.89E-15	–
SD	-0.273296	2.32E-02	-11.8046	2.89E-15	3.1
Log-likelihood	-2556	–	–	–	–

Table B22 Variance model: all observations (weighted/no constant).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
IVT	-0.408057	2.18E-02	-18.7406	2.89E-15	$7.66/hr
Fare	-0.156377	1.15E-02	-13.5459	2.89E-15	–
SD	-5.21E-02	4.65E-03	-11.2071	2.89E-15	3.0
Log-likelihood	-2559	–	–	–	–

Table B23 Variance model: Wellington rail (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-0.320996	1.37E-01	-2.34863	1.88E-02	$0.43
IVT	-1.42E-01	1.48E-02	-9.58388	2.89E-15	$11.55/hr
Fare	-0.738164	7.61E-02	-9.70573	2.89E-15	–
SD	-0.376137	4.14E-02	-9.07963	2.89E-15	2.6

Table B24 Variance model: Wellington bus (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	2.20E-01	1.26E-01	1.7497	0.080171	-$0.28
IVT	-6.35E-02	1.57E-02	-4.03524	5.45E-05	$4.93/hr
Fare	-0.773752	8.71E-02	-8.88443	2.89E-15	–
SD	-2.38E-01	3.66E-02	-6.49517	8.29E-11	3.7

Table B25 Variance model: Auckland bus (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-0.0184283	1.39E-01	-0.133026	0.894173	$0.03
IVT	-5.91E-02	1.32E-02	-4.47862	7.51E-06	$6.32/hr
Fare	-0.561699	7.22E-02	-7.77959	7.33E-15	–
SD	-0.215944	4.40E-02	-4.91015	9.10E-07	3.7

Table B26 Variance model: bus (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	9.75E-02	9.13E-02	1.06765	0.285677	-$0.15
IVT	-6.03E-02	9.96E-03	-6.05763	1.38E-09	$5.56/hr
Fare	-0.650968	5.55E-02	-11.7339	2.89E-15	–
SD	-0.227012	2.80E-02	-8.10763	2.89E-15	3.8

Table B27 Variance model: work purpose (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-1.19E-01	1.20E-01	-0.997671	0.318439	$0.19
IVT	-8.66E-02	1.27E-02	-6.8185	9.20E-12	$8.14/hr
Fare	-0.638485	6.81E-02	-9.37033	2.89E-15	–
SD	-0.307226	3.60E-02	-8.52355	2.89E-15	3.5

Table B28 Variance model: education purpose (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	2.99E-01	0.191866	1.55664	0.119555	-$0.41
IVT	-8.75E-02	1.92E-02	-4.56532	4.99E-06	$7.17/hr
Fare	-0.732317	1.10E-01	-6.6519	2.89E-11	–
SD	-0.155287	0.060709	-2.5579	0.010531	1.8

Table B29 Variance model: other purpose (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-0.131192	1.12E-01	-1.17152	2.41E-01	$0.18
IVT	-8.90E-02	1.48E-02	-6.02164	1.73E-09	$7.29/hr
Fare	-0.732876	7.41E-02	-9.89373	2.89E-15	–
SD	-0.284543	3.52E-02	-8.0744	2.89E-15	3.2

B1.4 Mean-variance model

Table B30 Mean-variance model: all observations (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-2.73E-01	9.92E-02	-2.75284	5.91E-03	$0.42
IVT	-9.15E-02	8.33E-03	-10.996	2.89E-15	$8.39/hr
Fare	-0.654956	4.43E-02	-14.7753	2.89E-15	–
AML	-0.387705	1.09E-01	-3.56634	3.62E-04	4.2
SD	-4.89E-02	6.65E-02	-0.735943	4.62E-01	0.5
Log-likelihood	-2549	–	–	–	–

Table B31 Mean-variance model: all observations (Weighted/no constant).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
IVT	-5.07E-02	4.68E-03	-10.8442	2.89E-15	$7.13/hr
FARE	-0.426898	2.29E-02	-18.6113	2.89E-15	–
AML	-0.132034	4.84E-02	-2.72957	6.34E-03	2.6
SD	-6.99E-02	3.36E-02	-2.07861	3.77E-02	1.4
Log-likelihood	-2556	–	–	–	–

Table B32 Mean-variance model: Wellington rail (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-0.334709	1.76E-01	-1.89644	5.79E-02	$0.45
IVT	-1.42E-01	1.50E-02	-9.51886	2.89E-15	$11.59/hr
Fare	-0.737086	7.65E-02	-9.62947	2.89E-15	–
AML	-0.0233001	1.90E-01	-0.122772	9.02E-01	0.2
SD	-3.62E-01	1.19E-01	-3.03296	0.002422	2.5

Table B33 Mean-variance model: Wellington bus (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-1.60E-01	1.67E-01	-0.954511	0.339825	$0.21
IVT	-6.99E-02	1.60E-02	-4.37418	1.22E-05	$5.64/hr
Fare	-0.743741	8.77E-02	-8.47895	2.89E-15	–
AML	-6.07E-01	1.77E-01	-3.436	5.90E-04	8.7
SD	1.06E-01	1.04E-01	1.01547	0.30988	-1.5

Table B34 Mean-variance model: Auckland bus (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-0.267009	1.78E-01	-1.4972	0.134342	$0.48
IVT	-6.34E-02	1.34E-02	-4.72813	2.27E-06	$6.90/hr
Fare	-0.551212	7.22E-02	-7.63053	2.33E-14	–
AML	-0.450277	2.01E-01	-2.23871	2.52E-02	7.1
SD	4.35E-02	1.23E-01	0.353958	0.723371	-0.7

Table B35 Mean-variance model: bus (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-2.25E-01	1.21E-01	-1.86611	0.062026	$0.36
IVT	-6.58E-02	1.01E-02	-6.5073	7.65E-11	$6.25/hr
Fare	-0.631495	5.56E-02	-11.3613	2.89E-15	–
AML	-0.543646	1.32E-01	-4.11003	3.96E-05	8.3
SD	8.28E-02	7.92E-02	1.04539	0.295844	-1.3

Table B36 Mean-variance model: work purpose (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-3.26E-01	1.58E-01	-2.06489	0.038934	$0.52
IVT	-9.04E-02	1.29E-02	-7.02068	2.21E-12	$8.67/hr
Fare	-0.62562	6.82E-02	-9.1677	2.89E-15	–
AML	-0.342957	1.71E-01	-2.00776	4.47E-02	3.8
SD	-1.08E-01	1.05E-01	-1.03044	0.302802	1.2

Table B37 Mean-variance model: education purpose (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	1.43E-01	0.242468	0.588194	0.556402	-$0.20
IVT	-8.99E-02	1.93E-02	-4.65456	3.25E-06	$7.53/hr
Fare	-0.716238	1.11E-01	-6.45781	1.06E-10	–
AML	-0.276408	0.263003	-1.05097	0.293271	3.1
SD	5.76E-03	1.64E-01	0.03509	0.972008	-0.1

Table B38 Mean-variance model: other purpose (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-0.523206	1.52E-01	-3.4382	5.86E-04	$0.73
IVT	-9.80E-02	1.51E-02	-6.4943	8.34E-11	$8.25/hr
Fare	-0.712127	7.43E-02	-9.58486	2.89E-15	–
AML	-0.667937	1.75E-01	-3.8253	1.31E-04	6.8
SD	0.0976194	1.05E-01	0.932603	3.51E-01	-1.0

B2 Stated preference 2 – in-vehicle time variability

B2.1 Disaggregate model

Table B39 Disaggregate model: all observations (unweighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-8.13E-02	3.53E-02	-2.30142	2.14E-02	$0.10
Fare	-0.85182	8.26E-02	-10.3167	2.89E-15	–
EARLY	-0.206244	4.31E-02	-4.78195	1.74E-06	2.8
LATE5	-2.93E-01	4.18E-02	-7.00207	2.52E-12	4.0
LATE10	-0.673595	4.46E-02	-15.1105	2.89E-15	4.7

Table B40 Disaggregate model: all observations (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-5.06E-02	3.55E-02	-1.42652	0.153718	$0.05
Fare	-1.12E+00	9.52E-02	-11.7232	2.89E-15	–
EARLY	-0.102606	4.24E-02	-2.41744	1.56E-02	1.3
LATE5	-0.281519	4.18E-02	-6.74293	1.55E-11	3.5
LATE10	-0.718824	4.51E-02	-15.9225	2.89E-15	4.5
Log-likelihood	-2544	–	–	–	–

Table B41 Disaggregate model: all observations (weighted/no constant).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Fare	-6.86E-01	5.64E-02	-12.1649	2.89E-15	–
EARLY	-0.0591657	2.56E-02	-2.31432	2.07E-02	1.5
LATE5	-0.177151	2.53E-02	-7.00257	2.51E-12	4.5
LATE10	-0.428805	2.61E-02	-16.4079	2.89E-15	5.5
Log-likelihood	-2546	–	–	–	–

Table B42 Disaggregate model: Wellington rail (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-1.84E-02	6.09E-02	-0.3025	0.762275	$0.02
Fare	-1.06E+00	1.61E-01	-6.62823	3.40E-11	–
EARLY	-0.0278425	7.14E-02	-0.38993	6.97E-01	0.3
LATE5	-0.297051	7.14E-02	-4.15862	3.20E-05	2.7
LATE10	-0.854761	7.95E-02	-10.7485	2.89E-15	3.9

Table B43 Disaggregate model: Wellington bus (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-3.33E-02	5.78E-02	-0.57625	0.56445	$0.03
Fare	-1.17E+00	1.88E-01	-6.20313	5.54E-10	–
EARLY	-0.140395	7.16E-02	-1.96119	4.99E-02	2.5
LATE5	-0.251002	6.91E-02	-3.63437	0.000279	4.5
LATE10	-0.692419	0.0739	-9.36967	2.89E-15	6.2

Table B44 Disaggregate model: Auckland bus (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-1.07E-01	6.77E-02	-1.58573	0.1128	$0.08
Fare	-1.28E+00	1.63E-01	-7.85065	4.22E-15	–
EARLY	-0.125166	8.09E-02	-1.54797	1.22E-01	1.7
LATE5	-0.333543	7.95E-02	-4.19716	2.70E-05	4.5
LATE10	-0.634271	0.08487	-7.47341	7.82E-14	4.3

Table B45 Disaggregate model: bus (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-6.59E-02	4.40E-02	-1.49889	0.133903	$0.05
Fare	-1.24E+00	1.21E-01	-10.2153	2.89E-15	–
EARLY	-0.130982	5.33E-02	-2.45544	1.41E-02	2.0
LATE5	-0.290061	5.20E-02	-5.58262	2.37E-08	4.5
LATE10	-0.667152	0.055606	-11.9979	2.89E-15	5.2

Table B46 Disaggregate model: work purpose (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-4.27E-02	5.54E-02	-0.76993	0.44134	$0.04
Fare	-1.17E+00	1.51E-01	-7.77304	7.77E-15	–
EARLY	-0.0668604	6.65E-02	-1.00592	3.14E-01	0.8
LATE5	-0.294689	6.55E-02	-4.4964	6.91E-06	3.4
LATE10	-0.772058	0.071213	-10.8415	2.89E-15	4.4

Table B47 Disaggregate model: education purpose (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-9.45E-02	8.98E-02	-1.05195	0.292824	$0.13
Fare	-7.41E-01	2.23E-01	-3.32554	0.000882	–
EARLY	-0.124475	1.04E-01	-1.20215	2.29E-01	2.7
LATE5	-0.265604	1.04E-01	-2.55756	0.010541	5.7
LATE10	-0.588706	0.111775	-5.26688	1.39E-07	6.3

Table B48 Disaggregate model: other purpose (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-2.51E-02	5.46E-02	-0.4589	0.646306	$0.02
Fare	-1.56884	1.58E-01	-9.93592	2.89E-15	–
EARLY	-0.176945	6.76E-02	-2.61595	8.90E-03	1.7
LATE5	-0.295685	6.46E-02	-4.57862	4.68E-06	2.8
LATE10	-0.724859	0.069542	-10.4233	2.89E-15	3.4

B2.2 Mean model

Table B49 Mean model: all observations (unweighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-0.0855824	3.44E-02	-2.48505	1.30E-02	$0.12
Fare	-0.72409	6.84E-02	-10.5813	2.89E-15	–
AML	-0.664928	3.48E-02	-19.0933	2.89E-15	5.4

Table B50 Mean model: all observations (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	1.15E-02	3.40E-02	0.338593	0.734917	-$0.01
Fare	-1.22E+00	9.45E-02	-12.8933	2.89E-15	–
AML	-0.476678	2.58E-02	-18.4608	2.89E-15	2.8
Log-likelihood	-2583	–	–	–	–

Table B51 Mean model: all observations (weighted/no constant).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Fare	-7.38E-01	5.59E-02	-13.2093	2.89E-15	–
AML	-0.291611	1.52E-02	-19.2046	2.89E-15	3.4

Table B52 Mean model: Wellington rail (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	3.88E-02	5.90E-02	0.658446	0.510252	-$0.03
Fare	-1.18E+00	1.59E-01	-7.39019	1.47E-13	–
AML	-0.593966	4.84E-02	-12.2809	2.89E-15	2.4

Table B53 Mean model: Wellington bus (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	3.70E-02	5.53E-02	0.669728	0.503031	-$0.03
Fare	-1.32E+00	1.86E-01	-7.09874	1.26E-12	–
AML	-0.43375	4.23E-02	-10.2428	2.89E-15	3.6

Table B54 Mean model: Auckland bus (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-5.34E-02	6.42E-02	-0.83078	0.4061	$0.04
Fare	-1.34E+00	1.62E-01	-8.29297	2.89E-15	–
AML	-0.441217	4.65E-02	-9.4902	2.89E-15	2.9

Table B55 Mean model: bus (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-3.06E-03	4.19E-02	-0.07293	0.941862	$0.00
Fare	-1.34E+00	1.20E-01	-11.0918	2.89E-15	–
AML	-0.437888	3.09E-02	-14.1893	2.89E-15	3.2

Table B56 Mean model: work purpose (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	1.81E-02	5.33E-02	0.339702	0.734081	-$0.01
Fare	-1.28E+00	1.50E-01	-8.56339	2.89E-15	–
AML	-0.52944	4.18E-02	-12.6704	2.89E-15	2.8

Table B57 Mean model: education purpose (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-4.60E-02	8.62E-02	-0.53303	0.594011	$0.06
Fare	-8.21E-01	2.21E-01	-3.71041	0.000207	–
AML	-0.388796	6.34E-02	-6.13109	8.73E-10	3.8

Table B58 Mean model: other purpose (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	5.38E-02	5.16E-02	1.04385	0.296555	-$0.03
Fare	-1.67882	1.56E-01	-10.7457	2.89E-15	–
AML	-0.448904	3.74E-02	-12.002	2.89E-15	2.0

B2.3 Variance model

Table B59 Variance model: all observations (weighted).

Parameter	Coefficient	Std Err	b / Std Err	P(Z>z)	Value
Constant	-1.32E-01	3.46E-02	-3.80521	0.000142	$0.19
Fare	-7.02E-01	6.86E-02	-10.2389	2.89E-15	–
SD	-0.482941	2.69E-02	-17.9494	2.89E-15	5.3
Log-likelihood	-2592	–	–	–	–

Table B60 Variance model: all observations (weighted / no constant).

Parameter	Coefficient	Std Err	b / Std Err	P(Z>z)	Value
Fare	-4.22E-01	4.13E-02	-10.2252	2.89E-15	–
SD	-0.275023	1.50E-02	-18.3054	2.89E-15	5.1
Log-likelihood	-2602	–	–	–	–

Table B61 Variance model: Wellington rail (weighted).

Parameter	Coefficient	Std Err	b / Std Err	P(Z>z)	Value
Constant	-8.50E-02	5.91E-02	-1.43929	0.150068	$0.15
Fare	-5.79E-01	1.23E-01	-4.68746	2.77E-06	–
SD	-0.575472	4.99E-02	-11.5438	2.89E-15	5.2

Table B62 Variance model: Wellington bus (weighted).

Parameter	Coefficient	Std Err	b / Std Err	P(Z>z)	Value
Constant	-8.36E-02	5.66E-02	-1.47794	0.139425	$0.10
Fare	-8.67E-01	1.49E-01	-5.81904	5.92E-09	–
SD	-0.477554	4.53E-02	-10.5372	2.89E-15	6.7

Table B63 Variance model: Auckland bus (weighted).

Parameter	Coefficient	Std Err	b / Std Err	P(Z>z)	Value
Constant	-1.72E-01	6.62E-02	-2.60127	0.009288	$0.17
Fare	-1.00E+00	1.35E-01	-7.43972	1.01E-13	–
SD	-0.468456	5.01E-02	-9.34625	2.89E-15	4.4

Table B64 Variance model: bus (weighted).

Parameter	Coefficient	Std Err	b / Std Err	P(Z>z)	Value
Constant	-1.23E-01	4.30E-02	-2.86516	0.004168	$0.13
Fare	-9.54E-01	9.89E-02	-9.64438	2.89E-15	–
SD	-0.476021	3.34E-02	-14.2457	2.89E-15	5.4

Table B65 Variance model: work purpose (weighted).

Parameter	Coefficient	Std Err	b / Std Err	P(Z>z)	Value
Constant	-1.07E-01	5.40E-02	-1.98645	0.046983	$0.14
Fare	-7.56E-01	1.19E-01	-6.36877	1.91E-10	–
SD	-0.534311	4.40E-02	-12.1462	2.89E-15	5.2

Table B66 Variance model: education purpose (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-1.45E-01	8.82E-02	-1.64001	0.101004	$0.27
Fare	-5.27E-01	1.84E-01	-2.86093	0.004224	–
SD	-0.412208	6.63E-02	-6.21514	5.13E-10	6.6

Table B67 Variance model: other purpose (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-8.45E-02	5.32E-02	-1.58784	0.112323	$0.06
Fare	-1.33425	1.31E-01	-10.1817	2.89E-15	–
SD	-0.525005	4.19E-02	-12.5313	2.89E-15	3.2

B2.4 Mean-variance model

Table B68 Mean-variance model: all observations (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-1.05E-01	3.53E-02	-2.98196	0.002864	$0.12
Fare	-8.88E-01	8.24E-02	-10.786	2.89E-15	–
AML	-0.157764	3.70E-02	-4.2585	2.06E-05	1.3
SD	-0.346968	4.07E-02	-8.53419	2.89E-15	2.8
Log-likelihood	-2583	–	–	–	–

Table B69 Mean-variance model: all observations (weighted/no constant).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Fare	-5.55E-01	4.91E-02	-11.2938	2.89E-15	–
AML	-0.111572	2.20E-02	-5.08038	3.77E-07	1.7
SD	-0.186229	2.28E-02	-8.17692	2.89E-15	2.8
Log-likelihood	-2589	–	–	–	–

Table B70 Mean-variance model: Wellington rail (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-3.34E-02	6.09E-02	-0.54832	0.58347	$0.03
Fare	-1.13E+00	1.60E-01	-7.06252	1.64E-12	–
AML	-0.387503	6.68E-02	-5.80325	6.50E-09	1.8
SD	-0.28365	6.59E-02	-4.30137	1.70E-05	1.3

Table 71 Mean-variance model: Wellington bus (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-4.64E-02	5.81E-02	-0.79968	0.423897	$0.04
Fare	-1.23E+00	1.87E-01	-6.55659	5.51E-11	–
AML	-0.211409	6.36E-02	-3.32496	8.84E-04	1.8
SD	-0.303758	6.68E-02	-4.54876	5.40E-06	2.6

Table 72 Mean-variance model: Auckland bus (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-1.29E-01	6.77E-02	-1.90957	0.056188	$0.10
Fare	-1.31E+00	1.62E-01	-8.07308	2.89E-15	–
AML	-0.253405	6.89E-02	-3.67703	2.36E-04	1.7
SD	-0.261507	7.30E-02	-3.58375	3.39E-04	1.7

Table 73 Mean-variance model: bus (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-8.25E-02	4.41E-02	-1.87189	0.061221	$0.06
Fare	-1.28E+00	1.21E-01	-10.6191	2.89E-15	–
AML	-0.234307	4.61E-02	-5.07972	3.78E-07	1.8
SD	-0.282089	4.90E-02	-5.75713	8.56E-09	2.1

Table 74 Mean-variance model: work purpose (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-5.54E-02	5.56E-02	-0.99715	0.31869	$0.05
Fare	-1.23E+00	1.51E-01	-8.16499	2.89E-15	–
AML	-0.330506	6.01E-02	-5.50264	3.74E-08	1.9
SD	-0.272667	6.12E-02	-4.45209	8.50E-06	1.5

Table 75 Mean-variance model: education purpose (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-1.17E-01	8.97E-02	-1.30164	0.193041	$0.15
Fare	-7.99E-01	2.22E-01	-3.59398	0.000326	–
AML	-0.204861	9.09E-02	-2.25489	2.41E-02	2.0
SD	-0.255824	9.32E-02	-2.74586	0.006035	2.6

Table 76 Mean-variance model: other purpose (weighted).

Parameter	Coefficient	Std Err	b/Std Err	P(Z>z)	Value
Constant	-4.62E-02	5.46E-02	-0.846	0.397551	$0.03
Fare	-1.61409	1.57E-01	-10.2604	2.89E-15	–
AML	-0.197647	5.74E-02	-3.4427	5.76E-04	0.9
SD	-0.352822	6.33E-02	-5.57402	2.49E-08	1.6

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