THE VALUATION OF RELIABILITY FOR TWO-LEGGED BUS JOURNEYS INVOLVING INTERCHANGE

James Andrew Collins, Parsons Brinckerhoff, UK

Pedro A L Abrantes, Passenger Transport Executive Group and Institute for Transport Studies, University of Leeds, UK

P V Chintakayala, Institute for Transport Studies, University of Leeds, UK

ABSTRACT

In spite of some seminal work into the valuation of travel time reliability in the 1990s (see, for example, Noland and Small, 1995 and Bates et al., 2001) this has led to only a handful of published empirical studies over the past 10 years (Hollander, 2006; Asensio and Matas, 2008). One particular problem that has received virtually no attention in the literature is how passengers weigh up and respond to the reliability of the different legs of complex public transport journeys. In this context, the reliability of one leg can have a very significant impact on total travel time due to the risk of a missed connection so it is likely that passengers will rate reliability even higher than for a single leg journey.

This paper reports the results of a stated preference survey aimed at understanding passengers' behavioural responses to the reliability of a two legged urban bus journey in an urban context involving a transfer or interchange at a central station. An initial focus group was held to try to gain an insight into bus user and non-user attitudes and responses to reliability for this kind of journey. As a result we developed the hypothesis that individuals will ensure that they do not miss their connection at the interchange point, and thus reliability of the first leg of a trip can be measured by the extent to which individuals will choose to depart earlier instead of having shorter mean journey and wait times.

An online stated preference (SP) study was developed and implemented to measure the willingness to trade between expected wait time/journey time and reliability. Two main ways of measuring reliability have been proposed in the literature: the mean-variance approach which considers individuals trade off standard deviation of travel time against mean travel time; and the schedule disutility approach which assumes individuals trade off mean journey time against expected earliness or lateness at the destination. We carried out some lexicographic analysis of SP responses which indicated that individuals use a mixture of behavioural rules. As a result we tested a large number of functional forms for the utility function using a multinomial logit model (MNL). Results showed that the most severe constraint for passengers is the possibility of late arrival at the destination and are therefore willing to departure much earlier to avoid that. Our results also shed some light on whether passengers are more concerned about the probability of lateness, mean lateness or standard deviation of arrival times.

Our findings have implications for bus timetabling and we demonstrate how integration of arrivals and departures of connecting services would impact bus demand under different scenarios.

Keywords: Reliability, Interchange, Transfer, Schedule Disutility, Timetabling

INTRODUCTION

The reliability of bus travel is a key component of the passenger's journey experience. However, UK Department for Transport Statistics in Table I show that of all the components of a bus journey, the average satisfaction rating of 70% for bus reliability is lower than the satisfaction for all other bus service features.

Table I - Average bus satisfaction ratings in England, 2007/08 (Source: DfT, 2008)

Service Feature	% Satisfaction
Overall service	82
Reliability	70
Value for Money	73
Bus Stop Information	72
Safety and Security	84
Bus stop/shelter conditions	78
Condition of Bus	82
Journey Speed	83
Staff service/comfort	84
Level of crowding on bus	84

Thus the low satisfaction in bus reliability is likely to be a key deterrent of bus travel. As such, the Department for Transport in the UK sets out punctuality targets which operators are expected to meet, and penalties are imposed if punctuality falls below 70% (DfT, 2005). Local authorities are expected to monitor punctuality, and this can be easily measured through the use of GPS (CLIP, 2009). Table II describes how punctuality is measured in the UK, and shows the targets for each of these measures.

Table II - LTP5 Punctuality Targets (Source: CLIP, 2009)

Indicator	Target
Percentage of non-frequent (5 or fewer per hour) buses starting their route on time (between 1 minute early and 5 minutes late)	95%
Percentage of non-frequent buses passing intermediate Timing Points on time	70-90%
Average excess waiting time of frequent buses (6+ per hour)	1.25 minutes

However, these indicators focus on departure times rather than the arrival time at destinations, and thus place the cost of reliability in terms of excess wait time, rather than measuring the cost in terms of arrival time as would be seen in a typical Small (1982) model. Thus a study on the cost of reliability could inform policy guidelines such that policy reflects the true nature of the cost of a non-punctual bus service, rather than being solely based on a bus operator's ability to meet its timetable.

Scope

There have been numerous past studies on travel reliability. These include studies on continuous travel modes such as the car, and discrete travel modes such as the bus and the train. Much of the past literature uses a stated preference methodology. However there has been very little study on reliability for two-legged transfer trips where an individual has to alight at an interchange then board another service in order to reach their final destination.

This is evidenced in a recent report (SDG, 2008) which overlooked the issue of reliability for transfer trips given that only a small number of bus users change bus during their trips. However, in some cities, a trunk and branch network or a hub and spoke network will require a larger number of bus passengers to make transfers as part of their journey. In fact, Hine *et al.* (2003) estimates that 4% of bus trips involve transfer.

Despite the possibility of bus passengers reaching their destination via a transfer, statistics in Scotland show that 32% of adults state the lack of a direct route as the reason for not using a bus (Scottish Government, 2008). Thus there is a gap in the current literature explaining how unreliability may affect the number of individuals willing to travel by bus given there is no direct route. Further literature in this particular area would complement studies such as Rietveld *et al.* (1999), which describes how understanding the cost of reliability can improve timetabling of public transport services, but which states that little work has been done to date studying reliability and interchange.

Therefore, this paper will focus on explaining perceptions of the cost of different elements of the travel experience during an unreliable two-legged bus trip, such that recommendations can be made regarding timetabling, punctuality targets, and other policy measures.

Aims and Objectives

This paper aims to build on previous reliability studies to develop a stated preference reliability study for two-legged bus trips. The following objectives will be adhered to such that this paper can achieve its aim:

- To identify the factors that affect individuals' perceptions of a two-legged trip and describe how these perceptions may affect the demand for bus travel.
- To determine how unreliability causes disutility for individuals making two-legged trips.
- To determine whether individuals have different valuations of the reliability of the first and second legs of a bus trip. The data collected from the stated preference study should be analysed to obtain these valuations.
- To understand the implications that this paper's findings has on public transport policy.

Overview

We start by carrying out a literature review that explores the research on interchange, and the analysis of travel reliability. We then provide an overview of the methodology and the overall survey results. A more detailed analysis of the results by market segment is then carried out and the final chapter discusses some possible policy and operational implications of the results.

ANALYSING THE IMPACT OF RELIABILITY ON PUBLIC TRANSPORT DEMAND

Public transport reliability is generally referred to with reference to some of form of time variable, with some of the key effects of concern to passengers being the possibility of late arrival at the destination, the need to spend longer than expected doing a certain activity such as waiting, and the general stress associated with uncertainty (described by psychologists as affective effort).

Bates *et al.* (2001) suggest that reliability can be associated with the concept of variability, in that a trip has an expected attribute, be it in-vehicle time, wait time, or arrival time and that the reliability of the trip is measured by the variations from what is expected. These authors point out, however, that individuals may not possess perfect information with regard to expected value and variation, and as such, an individual may measure reliability in terms of punctuality, or adherence to schedule, in that although a bus arrives and departs at the same time each day, this could be two minutes after timetabled, and as such be considered unreliable even though there is in fact no variation.

The fact that individuals can have different ways of measuring reliability poses immediate challenges when attempting to measure behavioural responses, and in particular when designing stated preference surveys. There are two main approaches to modelling travel time variability the mean-variance model and the schedule disutility model (Hollander, 2006).

Mean-Variance Model

The first approach is to assume that individuals consider the variations in travel time as the main source of inconvenience as reflected in the following function (Hollander, 2006):

$$U = \alpha T + \beta \sigma \quad (Equation\ 1)$$

where T is the mean travel time and σ is the standard deviation of travel time.

Schedule Disutility Model

The second approach is to assume that individuals are aware of the potential unreliability in journey times and respond by altering their departure time, trading off the disbenefits associated to possible late arrival with the (likely smaller) disbenefits from an early arrival. Hollander (2006) concludes that this indirect approach produces better results than the mean-variance model in a SP study of bus users.

In the schedule disutility model, individuals have a preferred arrival time and will incur schedule disutility for arriving early or late (SDE and SDL respectively). The utility function can then be represented in the following way (Bates et al., 2001 and based on Small, 1982):

$$U(t_h) = \alpha T + \beta\, SDE + \gamma\, SDL + \theta\, D_L \quad (Equation\ 2)$$

where α, β, γ and θ are coefficients, t(h) is departure time, T is the mean travel time associated with a given departure time, SDE and SDL are the deterministic scheduled early and late arrival times associated with a given departure time, and D(L) is a dummy variable indicating a lateness penalty.

This model implies that the trade off is between travel time and schedule disutility. The seminal study by Small (1982) showed that lateness typically causes greater disutility than earliness, as indicated by the following typical schedule utility function:

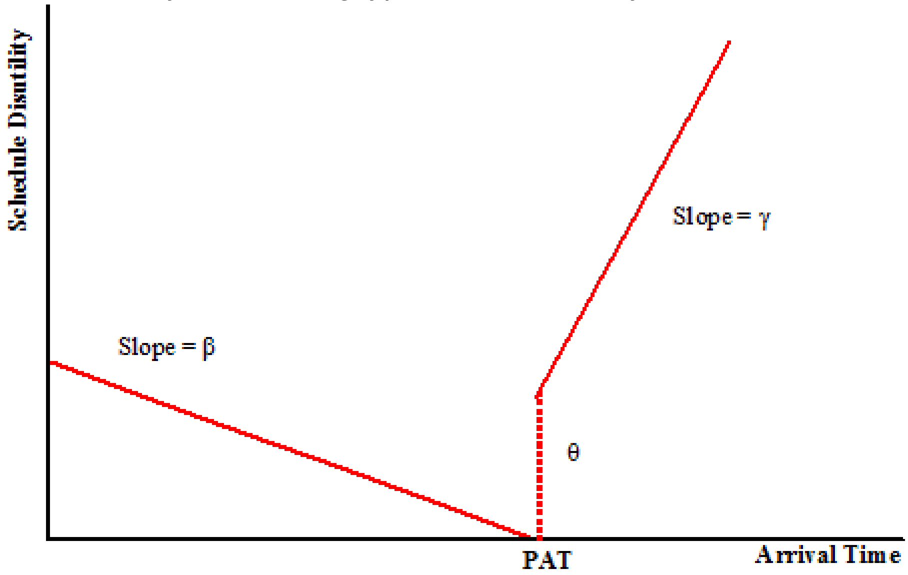

Figure 1 - Typical Schedule Utility Function (Source: Bates *et al*. (2001)

The implication of this is that individuals are likely to be more willing to take an earlier journey in order to avoid being late. This model is fairly simplistic and does not consider uncertainty in travel time and schedule disutility or the discrete departure time choices that would be associated with a public transport service.

Travel time uncertainty, however, arises because of the inherent unreliability of the journey. At any particular departure time, there is therefore a probability distribution associated with arrival times that could be given, for example, by the following normal distribution:

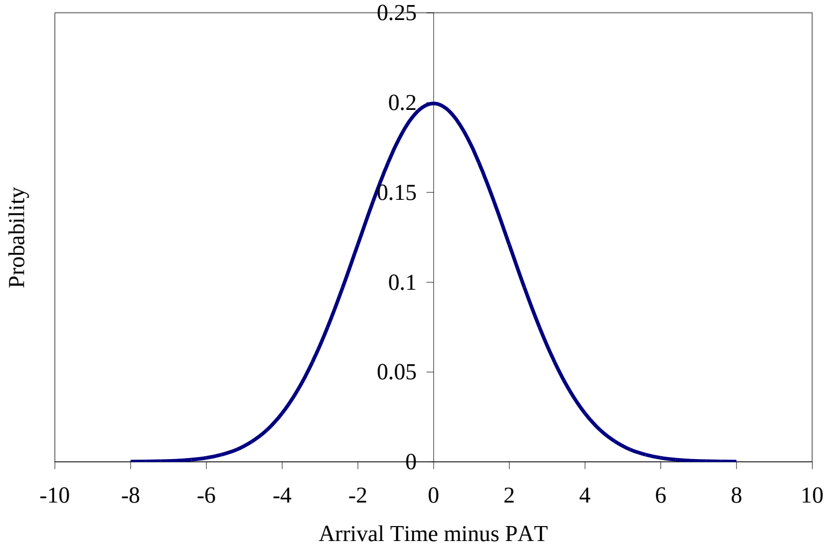

Figure 2 - Arrival Time Probability Distribution Function

Bates *et al.* (2001) suggest that the deterministic schedule utility function (Equation 2) can have a measure of reliability applied to it by replacing the deterministic values of SDE and SDL with an expected value, denoted E(SDE) and E(SDL) and determined by the probability function of a particular travel method. D(L) is also replaced by a probability of being late (PL). Thus the schedule utility function can be re-written as (Noland and Small, 1995):

$$U(t_h) = \alpha T + \beta E(SDE) + \gamma E(SDL) + \theta PL \qquad (Equation\ 3)$$

The implication of this is illustrated in Figure 3. With zero variance, individuals will depart at time A and minimise disutility such that they receive utility amounting to A'. This is represented by the blue line. As variance of arrival times increases due to a slightly unreliable service, individuals perceive departure time A as having a greater cost due to the extra risk of being late. As a result they feel that leaving earlier at departure time B will minimise their disutility. However this earlier departure time results in further disutility of B', and hence shows that the cost of reliability can be measured both in terms of lateness risk, and in terms of having to depart earlier to reduce such a risk. This new utility curve is represented by the red curve, while the green curve shows how increasing variance leads to increasing disutility.

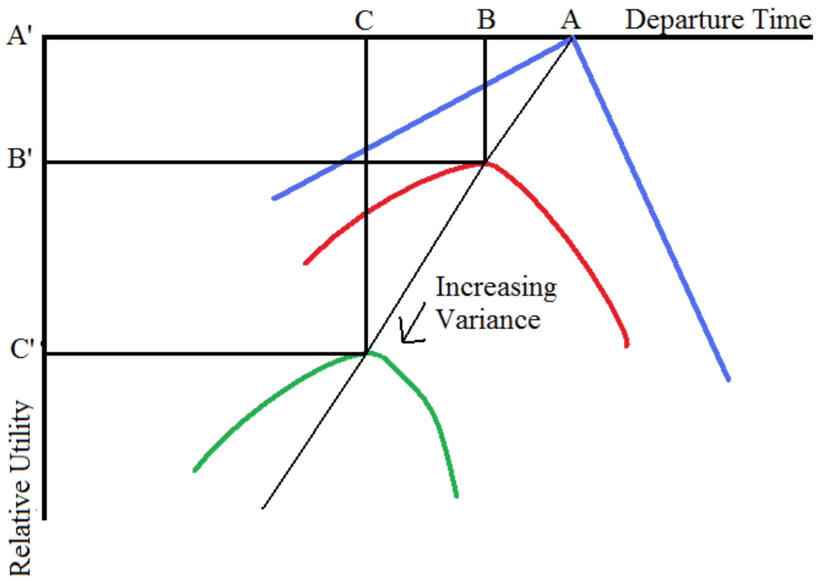

Figure 3 - Additional disutility due to increasing variance (Source: Bates *et al.,* 2001)

Bates *et al.* (2001) have further generalised this model to accommodate the fact that public transport services run at fixed service intervals (i.e. possible departure times are a discrete rather than continuous variable) by including waiting time and associated unreliability. In this context individuals are faced with the alternative choices: to arrive earlier at the bus stop, guaranteeing the scheduled journey and thus having a low E(SDL), but with a higher expected wait time; or to arrive a bit later and have a greater chance of missing the scheduled journey and thus have a higher E(SDL), but with a lower expected wait time. Such a decision would depend on the individual's comparative costs of waiting and lateness.

The issue of reliability becomes more complex in the instance of a two-legged trip, for individuals who need to transfer have less control over guaranteeing a successful connection. Bates *et al.* (2001) provides a graphical representation of the problem, which is determined by the distribution of arrival time at the interchange, the distribution of the departure time of the second leg service, and the headway of the second leg service as shown in Figure 4. This shows how unreliability during a two-legged trip has "*serious implications in terms of the implied cost of unreliability"* (Bates *et al.* 2001, p.213). However, to our knowledge there has been no empirical research in this area to ascertain whether this model holds and how passengers respond in practice to this potential high cost of unreliability.

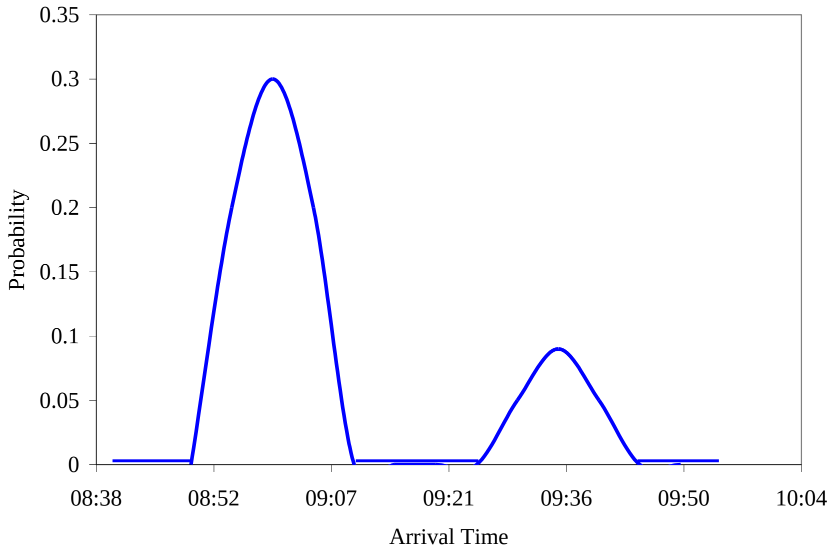

Figure 4 - Distribution of Arrival Time at Final Destination (Source: Bates *et al.* (2001))

Interchange Effect and Seamless Travel

Implicit in Figure 4 is the fact that waiting times at the interchange are also affected by unreliability. This is worsened by the fact that individuals have a more negative perception towards waiting than in-vehicle time, with wait time typically valued at 1.6 times in-vehicle time (Balcombe *et al.* 2004). Moreover, transfers at an interchange have additional costs to passengers. Hine *et al.* (2003) describe three components of this cost: time spent transferring from one service to another; time spent waiting for the connection, and a penalty representing the 'interchange effect,' where passengers have a general feel of inconvenience due to having to stop rather than use a more direct method of travel. Empirical work by Hine and Scott (2000, p.223) supports the idea that interchange has a negative effect on the demand for certain public transport services, stating that "*interchange, as an activity performed as part of a journey on public transport, is viewed as something to be avoided,"* citing evidence of individuals preferring to drive instead and describing a fear of missing a connection or being stranded as a major deterrent for a transfer journey.

One solution that could aid the provision of seamless travel and thus reduce the interchange penalty for passengers would be improved timetabling. Ceder *et al.* (2001) describe a solution where arrivals for as many services as possible are synchronised such that there is little waiting at the interchange. This strategy does heighten the potential impact of any reliability problems due to the increased possibility of a missed connection. Rietveld *et al.* (1999) observed that, in fact, timetables that allow for extra transfer time, or a policy of preventing drivers from departing early are likely to provide an improved end result for passengers.

REVIEW OF STATED PREFERENCE APPLICATIONS

Bates *et al.* (2001, p.214) argue that Revealed Preference (RP) data involving a significant reliability trade-off are very difficult to find and past studies have therefore relied almost entirely on Stated Preference (SP) surveys.

Many initial studies presented reliability as the probability of being a certain number of minutes late at the destination. For example Rietveld *et al.* (1999) presented respondents with the following alternatives:

- Option 1 - no delay.
- Option 2 - a 50% probability of a delay of 15 minutes.

Benwell and Black (1984) presented respondents with lists of possible late times given a stated preferred arrival time (PAT), ordered from best to worst. Interestingly, results showed an even split amongst respondents between those preferring the list with the highest standard deviation and those preferring the list with the highest probability of being late. Whereas the studies above and others such as the work of Black and Towriss (1993) have left departure time out of the choice scenarios, results obtained by Noland *et al.* (1998) seem to indicate that including this attribute can improve model fit considerably.

Another key question is how to represent arrival and departure times to respondents. Bates *et al.* (2001) use a circular clock-face display to present different arrival times in order to avoid respondents interpreting their ordering as an indication of the probability of occurrence. Hollander (2006) presents different possible outcomes as vertical bars representing arrival times and trip duration. This methodology has been subsequently extended (SDG, 2008) to include origin departure times.

Results of Studies

One useful benchmark for comparing results from different studies is the reliability ratio (equal to the value of one extra minute of standard deviation of travel time divided by one extra minute of mean in-vehicle time) which can be obtained from mean-variance models. Based on a review of earlier studies for different modes, Bates et al. (2001) suggest a ratio of 2 whereas Rohr and Polak (1998) estimated the reliability ratio of bus travel at 1.6. Many studies (Black and Towriss, 1993; Asensio and Matas, 2008; Noland *et al.* 1998), however, have suggested much lower ratios, even below 1 in some cases. One possible explanation for this disparity lies with the use of departure time in choice experiments. Participants in a study excluding departure time are likely to be more laid back about unreliability as they assume that they can respond by adjusting their departure time. Thus when passengers are constrained by fixed service intervals, stating departure time would appear to be a sensible course of action.

Evidence from studies based on schedule disutility models are slightly more consistent, with Asensio and Matas (2008) showing β/α and γ/α ratios of 0.48 and 2.34, respectively, while Noland *et al.* (1998) obtained ratios of 0.61 to 0.97 and 1.24 to 2.4, respectively.

METHODOLOGY

Our methodology was based on an internet-based SP survey. Internet-based surveys, much like postal surveys, allow for the clear presentation of choice scenarios and this approach has been successfully used by previous SP studies such as Hollander (2006).

A focus group discussion was held out prior to the design of the SP survey in order to obtain a qualitative assessment of two-legged bus trips as well as experiences and perceptions of bus reliability. The focus group consisted of four professionals aged 22 to 23, three female, one male. The members of the focus group were first prompted to describe their experiences of two-legged bus trips. They were then asked if they would ever choose to use a two-legged bus journey over other possible modes of transport. The third question was what reliability meant to them in the instance of a two-legged trip. Finally, the issue of waiting time was discussed.

One individual expressed that meeting his connection is of paramount importance and thus will plan his journey accordingly. Others pointed to the inconvenience of waiting at the bus stops or interchange between legs, and pointed out that this was of particular inconvenience on homeward journeys when services are less frequent. One individual stated that she would choose a two-legged journey if the service was frequent and reliable. However another said they would always use the car as an alternative as a two-legged trip is “chaotic and stressful.” The other group members pointed to an obligation towards leaving early to ensure they reached their destination in time, particularly during a morning trip to work. There was a general agreement that reliability meant not missing the connection, or not being late at the final destination.

Individuals then described details of the steps they have taken to ensure that they do not miss their connection, and ultimately they would choose to incur the cost of leaving early, having a longer journey time, or spending longer at the interchange rather than face the consequences of missing their connection as they have a desire to ensure that they arrive at their location in time.

SP survey design

As the focus group indicated that reliability was of the greatest concern when faced with a fixed expected arrival time, individuals were presented with a scenario resembling a typical commute, with a preferred arrival time (PAT) of 9:00 am. Respondents were then given two alternative departure times for the first leg of the journey resulting in different expected interchange time between services. For each of these alternatives five different arrival times were shown (representing a typical working week), reflecting the different probability of missing the connecting service as well as the inherent variability in travel time for the second leg of the journey. Interchange was said to take place at a bus station. Respondents are therefore forced to make a trade-off between the disutility of an earlier departure (and potentially longer mean wait time) to guarantee a connection, against the probability of late arrival and/or arrival time variability.

Departure time and mean waiting time were set at two levels assuming that respondents are choosing between two services for the first leg whereas the probability of late arrival and arrival time variability were set at 4 different levels each. The design of the SP choice scenarios was made orthogonal by using a fractional factorial design composed of 16 choice scenarios. These were then blocked into two groups of 8 which were presented to respondents depending on whether their date of birth was even or odd.

Following an initial pilot of the survey it was decided to adopt a list of possible arrival times (as shown in the figure below) instead of a clock-face display.

Option 1	**Option 2**
Bus Departure Time: 8:11 am	**Bus Departure Time: 8:05 am**
Time at Bus Station: 4 min	**Time at Bus Station: 10 min**
Possible Arrival Times:	**Possible Arrival Times:**
1. 9:04 am	**1. 8:59 am**
2. 8:54 am	**2. 9:04 am**
3. 9:09 am	**3. 9:01 am**
4. 8:58 am	**4. 8:59 am**
5. 9:05 am	**5. 9:01 am**

Figure 5 - Revised Presentation of Stated Preference Question

DATA ANALYSIS

The survey was conducted during June and July 2009, with a total of 211 valid responses. Respondents were reasonably well distributed between age groups as can be seen in figure 7 below. 76% of respondents were in employment and 18% in education. 37% are regular bus users (i.e., use the bus at least once a week).

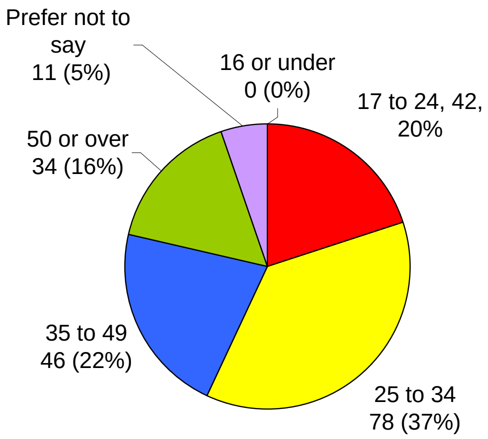

Figure 6 - Complete survey responses by age group

Response patterns

Of the 1688 observations, 52% selected Option 1 (late departure, greater lateness probability). Only two individuals chose Option 1 for every scenario, and there is a fairly even spread of choices amongst respondents. Thus it is clear that most, if not all, respondents made a genuine attempt to base their choices on the data presented.

It was observed that 19% of individuals chose to always minimise their Schedule Disutility of Late Arrival (E(SDL)), Standard Deviation of Travel Time (STD), or their Maximum Lateness (ML), whereas 12% always chose to minimise Expected Wait Time/Early Departure Time. Only 6% of individuals always chose to minimise mean travel time.

Stated Preference Analysis

A large number of utility functions were estimated on the SP data and the best results were obtained for the following two models, with parameter estimates presented in Table III:

$$U = \gamma E(SDL) + \alpha WAIT \quad (Model\,1)$$

$$U = \delta MTT + \gamma E(SDL) + \phi PL \quad (Model\,2)$$

Table III - Summary of Results for Model 1 and Model 2

	Model 1	Model 2
Attribute		
MTT	-	-0.0731 (5.00)
WAIT	-0.0377 (2.51)	-
E(SDL)	-0.0986 (6.13)	-0.123 (8.79)
PL	-	-1.3 (3.39)
Statistics		
Sample Size	1688	1688
Adjusted rho-squared	0.028	0.038
Final log-likelihood	-1135.854	-1122.492
Likelihood Ratio Test	68.357	95.08
Attribute Coefficient Ratios		
γ/α	2.615	-
γ/δ	-	1.683

The ratio of the coefficients of E(SDL) and MTT in Model 2 is low compared to those obtained in previous studies as shown in Table IV. This demonstrates that MTT has a greater impact on the decision making process when choosing between two interchanged services, while the reduced impact of E(SDL) indicates an acceptance of the possibility of being late when making a two-legged bus journey.

Table IV – Comparison of *γ/δ ratios*

Study	γ/δ
Collins *et al.* (2010)	1.683
Asensio and Matas (2008)	2.34
Noland *et al.* (1998)	1.24 to 2.4

In this study, MTT includes wait time, which was used as an alternative to MTT in Model 1. While to our knowledge there are no studies that compare the coefficients of E(SDL) and Wait Time, comparing the ratios of Model 1 and Model 2 in Table III shows that individuals have a higher relative cost of wait time at the interchange, and should therefore be considered a key component of the decision making process within the used stated preference design.

Attempts to include standard deviation within the model did not work well, producing insignificant results. This suggests that many individuals did not specifically look at variation when making their choices, preferring to associate reliability with late time.

Demand segmentation

In this section we apply the two models above separately to different demand segments, namely: Male and Female; Under 35s and Over 35s; Employed and Students; Bus Users and Non-Bus Users.

Gender

Although the coefficient of waiting time for females is not significant, it is possible to explain it by the fewer observations available when the data is segmented. Looking at the ratios, it would appear that women perceive a greater cost of lateness compared to the cost of wait time, and are thus more willing than men to wait at the bus station if it means arriving at the destination on time. It could be that wait time was insignificant for women due to the high priority they place on reducing late time. The coefficient of lateness probability is not significant for males, but the comparative ratios again show that women perceive a greater cost of lateness than men, and are thus more willing to have a longer journey in order to ensure greater punctuality.

Table V - BIOGEME Results for Model 1 Segmented by Gender

	Model 1		Model 2	
	Male	Female	Male	Female
Attribute				
MTT	-	-	-0.0817 (3.82)	-0.0783 (3.52)
WAIT	-0.0574 (2.61)	-0.0265 (1.17)	-	-
E(SDL)	-0.12 (5.05)	-0.0963 (3.96)	-0.131 (6.38)	-0.137 (6.40)
PL	-	-	-0.88 (1.59)	-1.87 (3.19)
Statistics				
Sample Size	816	744	816	744
Adjusted rho-squared	0.031	0.031	0.038	0.047
Final log-likelihood	-546	-498	-541	-489
Likelihood Ratio Test	39.081	35.467	48.43	54.342
Attribute Coefficient Ratios				
γ/α	2.09	3.63	-	-
γ/δ	-	-	1.60	1.75

Age Group

Table VI shows that members of the group aged over 35 are willing to wait for longer or travel for longer if it will reduce late time. The non significant wait-time t-stat suggests that this user group is not overly concerned about wait time.

Table VI - BIOGEME Results for Model 1 Segmented by Age

	Model 1		Model 2	
	17-34	35+	17-34	35+
Attribute				
MTT	-	-	-0.0892 (4.49)	-0.0588 (2.49)
WAIT	-0.0533 (2.63)	-0.0212 (0.87)	-	-
E(SDL)	-0.116 (5.33)	-0.0852 (3.27)	-0.138 (7.25)	-0.114 (5.04)
PL	-	-	-1.34 (2.60)	-1.28 (2.06)
Statistics				
Sample Size	944	640	944	640
Adjusted rho-squared	0.031	0.024	0.043	0.032
Final log-likelihood	-632	-431	-623	-427
Likelihood Ratio Test	44.721	25.408	62.607	33.949
Attribute Coeeficient Ratios				
γ/α	2.18	4.02	-	-
γ/δ	-	-	1.55	1.94

Employment Status

The ratios in Table VII demonstrate a higher cost of expected late time for those in employment than for students. Additionally, the results for the group in employment show coefficients for lateness probability which are greater and more significant compared to those for students, whereas the wait time coefficient is smaller and less significant. This is likely to be explained by the increased pressure to be punctual that is faced by those in employment, consequently resulting in different priorities for these user groups.

Table VII - BIOGEME Results for Model 1 Segmented by Employment Status

	Model 1		Model 2	
	Student	Employed	Student	Employed
Attribute				
MTT	-	-	-0.11 (3.10)	-0.0646 (3.82)
WAIT	-0.0788 (2.20)	-0.0266 (1.52)	-	-
E(SDL)	-0.156 (4.02)	-0.0839 (4.50)	-0.17 (4.96)	-0.112 (6.95)
PL	-	-	-1.2 (1.32)	-1.38 (3.12)
Statistics				
Sample Size	304	1264	304	1264
Adjusted rho-squared	0.047	0.022	0.056	0.032
Final log-likelihood	-199	-855	-196	-845
Likelihood Ratio Test	23.789	42.285	29.786	61.663
Attribute Coeeficient Ratios				
γ/α	1.98	3.15	-	-
γ/δ	-	-	1.55	1.73

Bus Use

The results for bus users and non-users appear somewhat inconsistent. Non-bus users place a higher cost on E(SDL) relative to wait time, whereas bus users seem to have a higher cost of E(SDL) in comparison to total journey time.

Table VIII - BIOGEME Results for Model 1 Segmented by Bus Usage

	Model 1		Model 2	
	Bus User	Non-Bus User	Bus User	Non-Bus User
<u>Attribute</u>				
MTT	-	-	-0.088 (3.62)	-0.0688 (3.46)
WAIT	-0.0533 (2.15)	-0.0277 (1.40)	-	-
E(SDL)	-0.138 (5.13)	-0.0803 (3.79)	-0.159 (6.73)	-0.11 (5.96)
PL	-	-	-1.15 (1.81)	-1.50 (2.96)
<u>Statistics</u>				
Sample Size	632	968	632	968
Adjusted rho-squared	0.051	0.018	0.061	0.029
Final log-likelihood	-414	-657	-408	-649
Likelihood Ratio Test	48.529	28.094	59.178	44.686
<u>Attribute Coeeficient Ratios</u>				
γ/α	2.59	2.90	-	-
γ/δ	-	-	1.81	1.65

DISCUSSION AND CONCLUSION

Summary of Key Findings

This study has produced a number of interesting findings on travellers' perceptions of bus reliability. As expected, the cost of one additional minute of late time is greater than the cost of an additional minute of wait time or journey time. This would indicate that reliability of the second leg is more important if it is assumed that passengers accommodate for an unreliable first leg by departing earlier and/or waiting for longer to ensure a connection. As a result, respondents generally tried to minimise expected late time. This is consistent with the literature, which shows that E(SDL) has a higher cost relative to other attributes.

The analysis of survey results suggests that a list of possible arrival times is an effective way of presenting the variability of arrival times. Respondents gave close consideration to the spread of the late times (i.e. E(SDL)), which produced more significant results than other attributes such as maximum lateness, probability of lateness, or standard deviation of arrival times.

Although in previous work a separate coefficient has been estimated for early time, our study showed that in the instance of a two-legged trip, the early time coefficient is not significant. An explanation for this could be that other attributes are so dominant in the choice process that respondents tend to ignore impact of early arrival.

Older respondents and those in employment were shown to have a much higher cost of late time relative to both wait time and journey time compared to younger respondents and students. Non-bus users put considerable more emphasis on wait time compared to frequent bus users, which is consistent with previous research.

Policy and Operational Implications of Findings

One key area for which our results could have important implications is timetabling. In instances where there is a popular interchange route, timetable designers may seek to create a more integrated public transport service by adjusting departure times of each service. Findings may also have an impact on appraisals of schemes that are likely to affect bus reliability.

Timetabling Measure 1: Adjust Departure Time of Both Legs

If there is a service that currently has a high E(SDL), it is likely to be unpopular with travellers given the disutility demonstrated by this study, who are likely to seek alternative methods of reaching their destination. However, given that E(SDE) is not significant during two-legged trips there would be little annoyance in adjusting departure time of the second leg such that E(SDL) is reduced. For instance, the Figure 7 shows the arrival time distribution of a bus service with two different departure times:

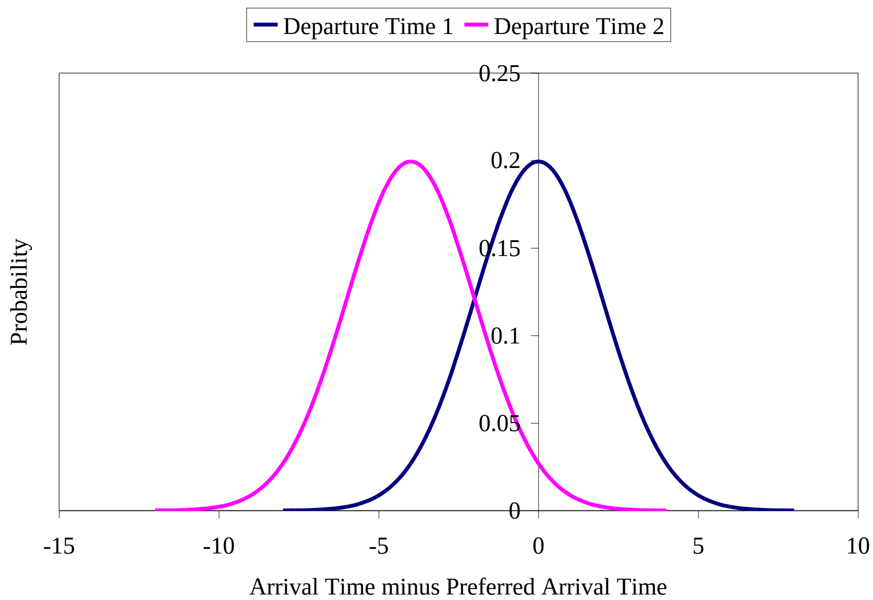

Figure 7 - Probability Distribution Functions of Arrival Time

E(SDL) for Departure Time 1 is higher than for Departure Time 2. However, let's say this service is a popular connecting route amongst bus users making a two-legged trip. A transition from Departure Time 1 to Departure Time 2 would increase the probability of a missed connection, and thus E(SDL) could actually increase. Given the study results, a solution to this is that the departure time of the first leg of a popular connecting service could be moved forward such that the probability of a missed connection is reduced and E(SDL) is minimised.

Essentially if by shifting departure times of both legs of a connecting service, E(SDL) decreases by more than 1.68 times the increase in MTT, then timetabling has improved the utility of passengers making that particular trip, and thus more passengers will be willing to use that particular bus service. Looking at the figure below, the line on the graph indicates the changes in each attribute that will hold utility constant. Any changes below the line will increase utility. This demonstrates that improvements in utility can also be achieved by departing later in instances where traffic can be avoided (and the buses can therefore travel quicker) with different departure times such that the increase in E(SDL) is less than 1.68 times the decrease in MTT.

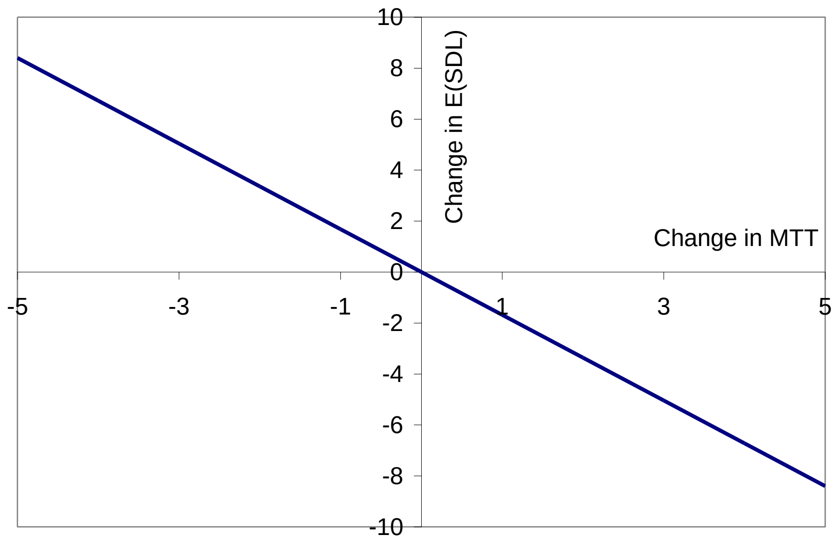

Figure 8 - MTT/E(SDL) Tradeoffs

Timetabling Measure 2: Adjust Departure Time of Second Leg

Another instance where an adjustment to public transport networks would be necessary is when there is a chance of a missed connection during a popular two-legged journey. In this scenario, E(SDL) for bus passengers may actually be reduced by moving back the second leg departure time such that there is a reduced probability of a missed connection. For instance, Figure 9 shows two variations of the arrival time distribution function used by Bates *et al.* (2001). Moving from the earlier Departure Time 1 to the later Departure Time 2 will make some individuals slightly later, but will also reduce the number of individuals who are much later due to the missed connection.

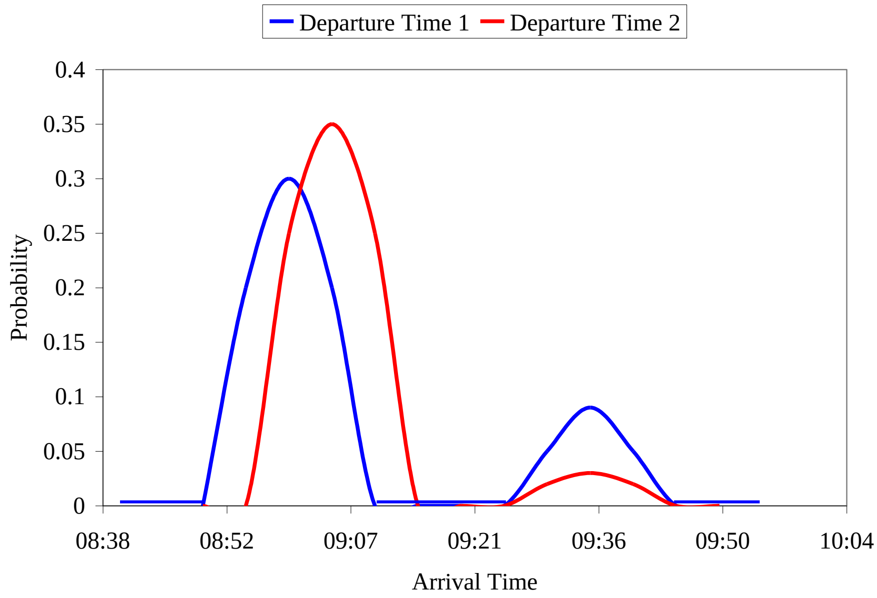

Figure 9 - Distribution of Arrival Times at Final Destination (Source: Adapted from Bates *et al.* (2001))

Thus a later departure time for a popular second leg service could improve demand. There are two possible approaches towards moving back departure times. It could be a timetabled adjustment, or it could just be a policy measure similar to that proposed by Rietveld *et al.* (1999) where the second leg bus is held back for as long as possible to reduce the probability of a missed connection.

However, a permanent adjustment to the timetable would increase the expected wait time at interchange for all passengers, while holding the bus back would increase the wait time for passengers who did not connect from the first bus. Thus our results demonstrate some tolerance towards such an adjustment as passengers are willing to exchange 2.62 minutes extra wait time in exchange for a one minute reduction in E(SDL).

The non-significance of E(SDE) indicates that if a service was held back, then passengers are unlikely to object about the loss of early time. There is however a possibility that passengers using the second leg of a popular connecting service, but who did not use the first leg, may incur a cost in additional wait time and E(SDL) due to adjustments in that particular leg.

Thus changes to the departure time of the second leg of a connecting service should only be recommended if the majority of passengers will benefit from the changes made.

Timetabling Measure 3: Adjust Departure Time of First Leg

Another solution to the possibility of a missed connection is to have an earlier departure time for the first leg, such that waiting time during transfer is increased. Thus although this solution would be expected to reduce E(SDL), the cost would come in the form the change in wait time and departure time. Thus the feasibility of this timetable measure would be determined by the utility benefit of reduced E(SDL) against the combined cost of additional wait time and an earlier departure time.

Timetabling Measure 4: Optimising Arrival Times

The large quantity of lexicographic behaviour observed during the study demonstrated that a lot of individuals have a need to arrive at their destination in time, or at least with the smallest possible amount of late time. Thus it is important that bus services involved in popular commutes arrive at their destination before the preferred arrival time more often than not. Thus if a large group of individuals have a similar preferred arrival time, a bus service can be expected to be more popular if it is scheduled to arrive at or just before that preferred arrival time, whereas it would be less popular if it was scheduled after the preferred arrival time. Thus it is important to schedule for the optimal arrival times where possible when creating a new timetable.

Appraisal of Schemes

The study's findings may also assist appraisal methodologies for different schemes. For instance, it may be necessary for there to be an examination of the feasibility of a new interchange. This study can contribute to that feasibility assessment by setting a rule that if late time is saved through the new interchange, without the addition of significant wait time, then it can have a positive effect on the welfare of passengers. However, if an interchange led to too much wait time without a large enough reduction in late time, or if it caused late time to increase, then it would have a negative effect on welfare and therefore other benefits would be needed if the interchange was to have a positive cost benefit analysis result.

The findings may also be applicable to the appraisals of other schemes. For example, the general finding that many individuals prioritise minimisation of late time suggests that a scheme that reduces this late time will improve welfare for all passengers. If for instance there was a choice between implementing a bus priority system on the route of either the first leg or second leg of a popular connecting service, then these results could be used to ascertain which scheme would most likely improve welfare for passengers. If unreliability of the first leg is causing missed connections and thus increasing expected late time, then priority for the first leg is likely to have the better net benefit. However if it is the unreliability of the second leg is causing increased expected late time, then an appraisal would be more likely to recommend priority for that second leg.

Conclusions

The overall conclusion of this study is that passengers commuting via a two-legged bus trip are prepared to take measures such as increasing their wait time or journey time to ensure punctual arrival at their destination. Thus under the assumption that reliability of the first leg can be measured by the extent individuals are willing to increase their wait or journey time, and the assumption that reliability of second leg can be measured by late time, the study has shown that there is a higher valuation placed on the reliability of the second leg than the first leg. Our results have particular implications for the design of improved interconnectivity at interchanges, highlighting the benefits of the integration measures and endorsing the findings of Hine *et al.* (2003) and Rietveld *et al.* (1999), while partly rejecting the solution of simultaneous arrivals proposed by Ceder *et al.* (2001), given the apparent benefits of introducing a degree of slack in the timetable.

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