THE ATTITUDES OF BUS USERS TO TRAVEL TIME VARIABILITY

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1. INTRODUCTION

The Institute for Transport Studies at the University of Leeds is carrying out research about the reliability benefits from improved bus infrastructure. The study includes both demand and supply modelling, and it is hoped that the final stage of the project will include an economic analysis of the effects on reliability of different bus infrastructure improvement scenarios. Of the various measures for transport system reliability or unreliability, the project focuses on travel time variability (TTV). In the current paper we present results from the first research phase, which deals with modelling the attitudes of bus users to TTV and with their departure time choice considerations.

We are interested in understanding the effect of TTV on bus travellers' decision making in their morning commuting journey. TTV is measured here as the standard deviation of travel times. Our definition of TTV includes day-to-day variations caused by factors that are unpredictable to a rational traveller; namely, the residual, random TTV element that remains after subtracting some components that can be expected. For a more detailed definition of TTV as used here, see Hollander (2005).

The paper is organised as follows. Section 2 reviews existing research about the evaluation of TTV effects and related surveying issues. Section 3 describes the design of a survey to obtain information on attitudes of TTV. Section 4 raises considerations in the choice of model formulation. Two different Multinomial Logit models are presented and compared in section 5. Section 6 briefly describes the results of an attempt to extend the scheduling model to a Mixed Logit specification. Conclusions are brought in section 7.

2. EXISTING LITERATURE

2.1. The effects of TTV

Considerable attention has been given recently to studying the effects of TTV on travellers' behaviour. While it is clear that TTV influences various decisions made by travellers, including route and mode choice, the case for converting these effects to monetary terms, which is of major importance in the current context, is not always clear. Two distinctive approaches exist for modelling the effects of TTV in a way that can lead to economic analysis. The first approach claims that travellers see TTV per se as a source of inconvenience, similarly to the way they treat the mean travel time (MTT); this concept is commonly referred to as “the mean-variance approach”. Mean-variance models use utility or cost functions that deal with TTV directly, often using a variable that stands for the standard deviation of journey time (Jackson and Jucker, 1982; Polak, 1987a, b; Black and Towriss, 1993; Senna, 1994a, b). The alternative approach argues that the entire cost attributed to TTV can be captured indirectly, by modelling travellers’ earliness and lateness considerations when choosing at what time to depart for their journey; this is sometimes called “the scheduling approach” (Gaver, 1968; Knight, 1974; Pells, 1987a, b; Noland et al, 1998; Small et al, 1999). Note that many mean-variance formulations aim at modelling departure time choices, too; but unlike models of the scheduling approach, they do not rely on scheduling variables. The argument that the major impact of TTV is on the choice of departure time is made in all the works mentioned above.

Bates et al (2001) describe conditions under which a mean-variance model can approximate a scheduling model. Noland and Polak (2002) show special cases in which the two approaches are equivalent. Small et al (1999) compare the performance of models of both types, and conclude that “in models with a fully specified set of scheduling costs, it is unnecessary to add an additional cost for unreliability”; other works support this statement. Still, most practical works that involve evaluation of TTV costs use mean-variance models (TRL, 2004; Atkins, 1997; and others). Assumingly, this is mainly because the implementation of a mean-variance model is fairly straightforward and only requires aggregate estimates of MTT and TTV, while applying a scheduling model requires information on the distribution of preferred arrival times and simulation of the mean lateness and earliness.

Most of the models cited above focus on car users’ behaviour. An inter-modal analysis by Black and Towriss (1993) compares mean-variance models for car, bus and rail users, but does not discuss scheduling considerations or departure time choice. For rail travellers, the only other research of attitudes to TTV known to us is Bates et al (2001), who reject the argument that scheduling variables alone can explain the entire reaction to TTV; they state that there is an additional cost attributed to TTV itself. For bus users, the only contribution known to us is made by Pells (1987a, b). Pells’ work extends the discussion about the value of earliness and lateness, but does not include a full scheduling model.

It is therefore still unanswered whether a scheduling model can satisfactorily explain travellers’ reaction to TTV. While for modelling the effect on car users there seems to be evidence for the sufficiency of scheduling variables, the evidence for rail users is to the contrary, and for bus users there is hardly any evidence at all. There is great interest in finding whether bus users will appear to be motivated by scheduling consideration only, similarly to car users (according to Noland et al, 1998, and Small et al, 1999), or also by the nuisance caused by TTV per se, similarly to rail users (According to Bates et al, 2001). For a more detailed review of models that give monetary values to TTV, see Hollander (2005).

2.2. TTV-related surveying

Apparently all attempts to estimate choice models that include TTV variables use stated-preference (SP) techniques. As Bates et al (2001) point out, it is extremely hard to find situations where travellers have a choice between well-defined alternatives that differ in the extent of TTV; revealed-preference techniques are therefore not suitable. In order to evaluate travellers' attitudes to TTV, most studies ask the respondents to make hypothetical choices that reveal the way they trade-off between TTV and other elements of the generalized cost of travel, such as the mean travel time (MTT) or the journey cost. The introduction of a TTV variable raises the issue of how to present this variable in a clear and simple way; a difficulty lies in the fact that analysts measure TTV using terms such as standard deviation, that are not intuitively understood to many travellers (Cook et al, 1999). Hence, many researchers of this area focused their discussion on how to illustrate the concept of a probabilistic travel time distribution to respondents.

Early SP experiments described a given distribution of travel times by noting the *usual travel time* and the *extent and frequency of delay*. The usual travel time was often left as an intuitive term, not defined explicitly; the frequency of delay was normally given in terms such as “once a week”. A typical question in surveys of this type would ask respondents to choose between a journey that always takes 50 minutes (alternative A) and a journey with usual travel time of 40 minutes and a possibility of 20-minute delay once a week (alternative B) (Jackson and Jucker, 1982). We denote this questionnaire formulation by “type 1”. A sub-type of questionnaire (“type 1a”) predetermines a fixed frequency of delay, and when asking the respondents to choose between alternatives, only the usual time and the amount of delay are presented.

In recent years, most experiments used a more explicit formulation, which was originally proposed by Benwell and Black (1994). According to this methodology, TTV pattern is presented as a sequence of several journey times. The number of times presented to define a single distribution varies in different works between 5 and 10. A typical choice scenario would be either departing 15 minutes before the desired arrival time, while experiencing travel times of 12, 13, 14, 16, and 20 minutes on 5 different days (alternative A), or departing 10 minutes before the desired arrival time, experiencing a 5, 7, 9, 12 and 18 minute journey on different days (alternative B) (Noland et al, 1998). We denote this formulation as “type 2”.

Although most recent experiments used questionnaire type 2, as it seems to be better understood, there are also discussions about its disadvantages. Noland et al (1998) mention that using a list of travel times to describe a distribution creates an artificial certainty about the maximum possible delay that could occur. Many authors emphasize that there is importance to the order of the presented travel times: some respondents assume that they are in descending or ascending order, and thus do not read carefully the entire sequence. The most recent designs tried to solve this problem by listing the travel times not as a sequence, but using a circular "clock-face" presentation (Bates et al, 2001).

Not all the SP experiments documented in literature incorporate a cost variable. Surveys where the presented choice alternatives do not differ in their cost cannot be directly used for creating models that give a monetary value for TTV. However, when cost is included, respondents have to make a more complicated choice. Most early SP designs described each time distribution without explicitly noting the departure time. Noland et al (1998) were the first to state the departure time, described as "15 minutes before your usual arrival time". This approach was later adopted by other authors, some of which simply put it as "depart at 08:10". In principle, it is possible to estimate a scheduling model even if departure time itself is not specified; but since in most recent models there is a major role to the occurrence of early or late arrivals, the explicit departure time seems an essential addition (Bates et al, 2001). In contrast, Small et al (1999) deliberately leave the departure time implicit, fearing that too much information is already presented.

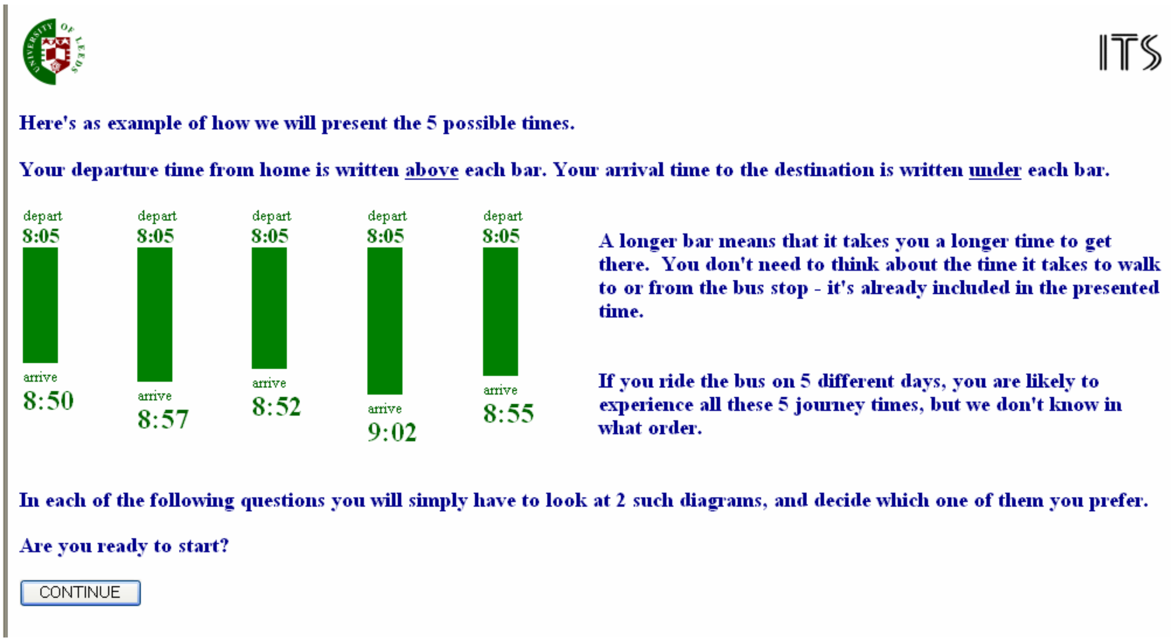
The levels of MTT, TTV, departure time and cost that form each presented alternative should ideally be adjusted to the travel patterns of the respondent, although in a paper-based questionnaire this is normally impossible. Most authors start with defining three levels for each variable and then present a random combination in each question, assuring that none of the presented alternatives dominates the other in all variables (Senna, 1994; Noland et al, 1998; Small et al, 1999). TTV levels normally vary from 0% to 50% (Senna) or from 10% to 30% (Small et al). The range of departure time values can be fixed such that the range of expected arrival times will start two standards deviations before the usual arrival time and end at the usual arrival time (Noland et al, 1998); or alternatively, such that the shift of departure time due to TTV varies between 0% to 15% of MTT (Small et al, 1999). Values of the MTT variable are determined by Small et al such that the middle level is equal to the MTT reported by the respondent, and the lower level does not fall under the free flow travel time. Within the range of values for each variable, Small et al find that the design is more powerful when the low, medium and high levels are now equally spaced.

Characteristics of the reviewed SP methodologies are summarised in table 2. Existing methods are generally suitable for the current research. However, it was felt that in most recent studies, the amount of numerical details presented to the respondent might be confusing. The survey described in the following section attempts to reduce the amount of presented details, while introducing a graphical presentation of the pattern of TTV.

3. SURVEY DESIGN

The model presented in this paper is based on a SP survey that was carried out in November 2004. The study area is the city of York, England; all respondents are bus users who work or study in this area. The questionnaire is explicitly directed to people who use buses every morning, and all the questions refer to the morning commuting trip only. The survey was internet-based: the questionnaire is a series of PHP programs accessed through the survey website.

The questionnaire starts with a short, general introduction page that was mainly meant to make sure that respondents who do not commute by bus in York do not proceed. The following page includes several questions about the respondent's normal travel time, preferred arrival time to the destination, and fare paid; the random attributes presented later in the questionnaire fluctuate around the values that the respondent enters here. The two subsequent pages demonstrate, both verbally and graphically, the idea of TTV and the way it is presented throughout the questionnaire. One of these introductory pages is presented in figure 1.



Here's as example of how we will present the 5 possible times.

Your departure time from home is written <u>above</u> each bar. Your arrival time to the destination is written <u>under</u> each bar.

A longer bar means that it takes you a longer time to get there. You don't need to think about the time it takes to walk to or from the bus stop - it's already included in the presented time.

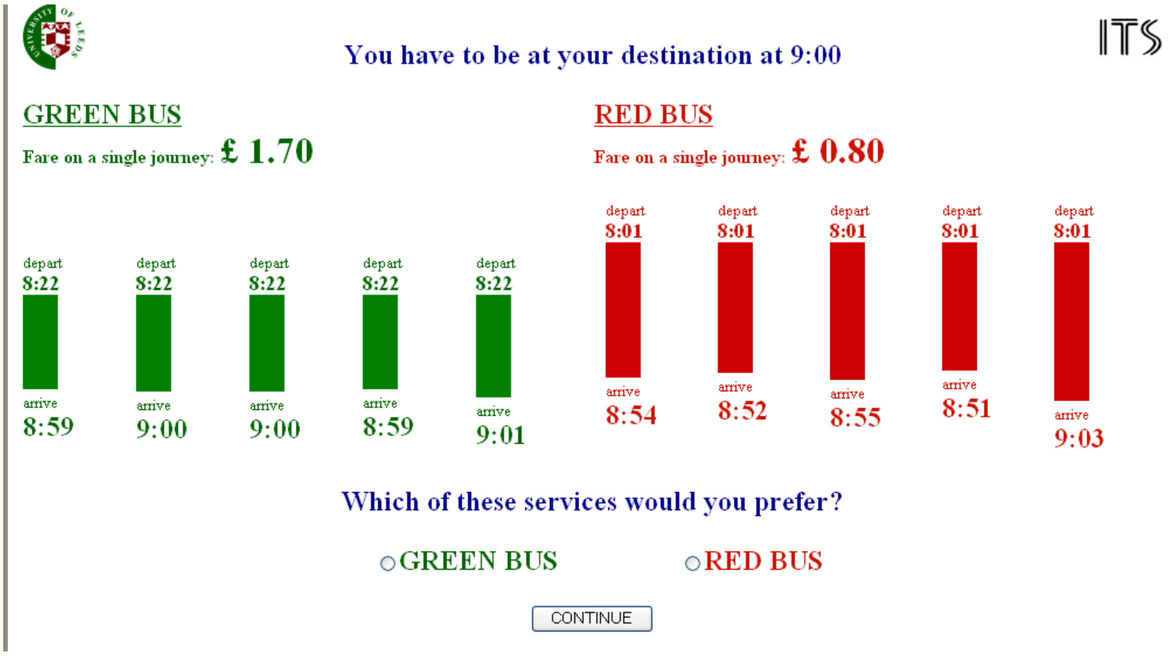
If you ride the bus on 5 different days, you are likely to experience all these 5 journey times, but we don't know in what order.

In each of the following questions you will simply have to look at 2 such diagrams, and decide which one of them you prefer.

Are you ready to start?

Figure 1: One of the introductory pages

The main body of the questionnaire consists of 9 questions, all of the same structure. In each question, the respondent is asked to consider two alternative bus services and choose one of them. Each service is identified by a name ("Red bus" or "Green bus"), fare, departure time from home, and a distribution of 5 possible arrival times to the destination. Journey times are not explicitly stated; they are shown graphically using a series of vertical bars. A longer bar represents a longer journey, and if one of the two alternative services departs later than the other, its bar is shifted down the vertical axis accordingly. Such presentation was found the easiest to understand out of a few options, in a preliminary experiment. A typical question is presented in figure 2. A concluding page comes after completion of the 9 questions, where respondents are asked about their income level and are given space for comments.



You have to be at your destination at 9:00

GREEN BUS

Fare on a single journey: £ 1.70

RED BUS

Fare on a single journey: £ 0.80

Which of these services would you prefer?

○ GREEN BUS ○ RED BUS

Figure 2: A typical question

The MTTs of the two alternatives presented in each question are chosen randomly within the range of 70% to 130% of the respondent's normal time, as stated in the introductory question page. The TTVs are random numbers between 1 minute and 40% of the MTT determined above for each alternative. The fare is chosen randomly between 60% and 150% of the actual fare paid by the respondent. The 5 displayed times that define each distribution are determined as follows. The first is chosen randomly subject to lying no more than two standard deviations away from the mean (either over or under). The second needs to be within 1.5 standard deviations from the mean, and the third within one standard deviation. The forth and fifth are determined such that the predetermined MTT and TTV are met. Departure times are drawn such that earliest possible departure allows the maximum trip length (out of the five displayed) before the desired arrival time, and the latest possible departure allows the mean. A set of constraints guarantees that in each question, none of the two presented alternatives has dominance over the others in all variables.

Responses to the survey were automatically input to a database; the times when each respondent entered and left the survey website were recorded as well. The time records show that filling the entire questionnaire took 5 minutes in average; hence there should not be serious tiredness effects. After sifting improperly or partially filled questionnaires, the database included 244 questionnaires. Most of the questionnaires include answers to 9 questions each, but in several cases, one or two questions were excluded due to suspected errors. The final data file that was used for modelling includes answers to 2165 questions.

4. MODEL FORMULATION

In this section we explain two decisions that were made regarding the formulation of the presented model. The first decision relates to an idea that was brought up in an early stage of the research, to use an OGEV formulation. This was proposed since several authors (e.g. Batley et al, 2001) remind that OGEV is suitable for modelling departure time choice. OGEV (Ordered Generalised Extreme Value) was introduced by Small (1987) for modelling situations where alternatives with neighbouring values of the choice variable are correlated. The basic concept of OGEV makes good sense for departure time choice modelling, because time is continuous, and there clearly is some correlation between adjacent points on the time axis.

Nevertheless, after serious consideration it was decided not to create an OGEV model despite its appealing features. This is mainly because an OGEV formulation would require a pre-defined set of alternative time periods, while in the current context it was believed that a single utility function should be used for all alternative departure times. Since our discrete choice variable is in fact a simplified representation of a continuous variable, the problem with multiple utility functions is that the choice of duration of each period is an artefact, which will inevitably influence the model performance. The need to define discrete periods along the continuous time scale makes the estimation results sensitive to the distribution of travellers' preferred arrival times. Ideally, model performance could be optimised through examining various definitions of the set of periods, but this exceeds the scope of the current study.

Another reason why OGEV does not offer a more powerful model in the current context relates to our definition of TTV, as explained hereinafter. The amount of available data imposes a limit on the minimum duration of a time period, because a sufficient number of observations is needed from each period. In most realistic situations, there is not enough data to enable defining periods shorter than, say, 30 minutes. An OGEV model will offer more realistic relations between the utilities of departures in different periods, compared to simpler models; but in most cases that are relevant to the current study, we will need to compare two departure times that lie in the same 30-minute window. In such cases, an OGEV model will compute the utilities of both alternatives using the same function, just like a model that only has a single utility function, and hence might not justify the special effort that is required for its calibration. The reason why we are mainly concerned about departures that lie very close to each other on the time axis is our interest in the effects of the random TTV, which remains after predictable factors have been eliminated. Departures that lie in different periods do not assist in the analysis of such TTV because the differences in their utilities are influenced by many expectable factors, such as typical differences in the level of demand between the periods.

In conclusion, it was decided to specify Multinomial Logit and Mixed Logit models. A remaining decision that had to be made concerning the model formulation was whether travellers with fixed arrival times should be treated separately from travellers who have some flexibility in choosing when to arrive at their destination. Such flexibility is crucial to the choice of departure time; in previous works, different authors interpreted this in different ways. Some works (Black and Towriss, 1993; Bhat and Sardesai, 2005; and others) distinguish between travellers that ascribe different levels of importance to on-time arrival, while most others do not make this distinction. Models that discuss the cases of fixed or flexible arrival time separately have a better behavioural reasoning, since this is clearly a consideration that travellers take into account when choosing a departure time. However, such models are harder to use for prediction, because they require information about arrival time flexibility as input, and this is hard to obtain. Moreover, the two strictly-contradicting cases of flexible or fixed arrival are not the only ones; in different working or studying places, a whole range of attitudes to late arrival exists. If we wanted to account for this accurately, we would have to either carry out extensive data collection or create a disaggregate model that predicts the level of flexibility, but both options are not possible in the current scope. It was therefore decided to ignore the different levels of flexible arrival, and treat them all in one model. Although this might at first glance seem simplistic, the author believes that ignoring this issue helps the real distribution of flexibility reveal itself more truthfully, as it is indirectly incorporated in every respondent’s answers to the questionnaire.

5. THE MULTINOMIAL LOGIT MODEL

5.1. Mean-variance versus scheduling approach

The main series of modelling attempts was aimed at founding a basic Multinomial Logit model on the survey results. An expected finding is that the fare and MTT coefficients are repeatedly found most significant. Several attempts were made to formulate a utility function that explicitly includes a TTV variable. TTV was found a significant variable when scheduling variables were not included, but its significance dimmed when these variables were added. Bus users seem to be bothered by the effects of TTV on their extent of lateness and earliness to the destination, not by TTV per se. This resembles the conclusions of Noland et al (1998), Small et al (1999) and others concerning car users’ preferences; it contradicts what Bates et al (2001) conclude regarding rail users.

Many different forms of variables that denote the amount of lateness or earliness were probed. In addition to the mean lateness and earliness variables, modelling attempts included the probabilities of arriving too early or too late by various amounts of time, expressed either in minutes or as a percentage of the MTT. Squared values of the mean lateness and earliness, and various combination where lateness and earliness are represented by more than one variable, were tried too as they were found a significant contribution to the model in other works (e.g. Small et al, 1999). The conclusion from these experiments was that when the cost, MTT, mean earliness and mean lateness are included, the contribution of any additional variable is negligible. Furthermore, it was found that the MTT and the mean earliness are best incorporated in the model as one variable. In other words, no sufficient evidence was found that the penalty on time spent at the destination prior to the preferred arrival time is significantly different from the penalty on time spent travelling.

What stems from these results is that the attitudes to TTV are best described using two variables: one that stands for the mean lateness (ML) and one that is the sum of the mean travel time and the mean earliness (MTE). It can be shown that MTE is always equal to the time from the departure till the moment with the mean lateness; this means that some correlation exists between the two variables, since changes in the mean lateness affect both of them. However, since changes in the extent of lateness are also followed by changes in the travel time, the way MTE is affected by lateness differs between short and long journeys, while ML represents lateness independently. The final Multinomial Logit model is described in the left column of table 1.

Another modelling attempt examined the effects of replacing the MTT variable with a variable that stands for the median of travel times. The median was generally found capable of replacing the MTT in the utility function, but the median-based model was slightly less powerful than the mean-based model, and the median variable was therefore left out. The modelling experiments also included an attempt to add a dummy variable that gets a value of 1 only if the “Green Bus” alternative in each question was chosen; if this was found significant, it would mean that respondents had a consistent tendency towards (or against) one of the colours of the presented services. However, the dummy variable was found most insignificant, indicating that there was no such bias.

5.2. The consequences of using mean-variance models

It was mentioned above that although most of the research on the effects of TTV on car travellers has found that these effects are best modelled using scheduling variables, applications of mean-variance models are much more common in practice. We assume that the reason for this is the difficulty in implementing scheduling models: it normally requires using simulation-based methods, and depends on detailed information about individual preferred arrival times. Our Multinomial Logit model confirms that for bus users too, a model based on scheduling variables is more powerful. It is thus important to understand the consequences of the common use of the less powerful model. To do this, an additional model was estimated, including the typical variables of a mean-variance formulation. The final scheduling and mean-variance models are presented in table 1.

	Scheduling model			**Mean-variance model**		
	Fare	**MTE (MTT and earliness)**	**ML (lateness)**	**Fare**	**MTT**	**TTV**
Coefficient	-1.375	-0.07173	-0.1974	-1.179	-0.08208	-0.007792
t-statistic	-14.2	-11.5	-4.1	-12.1	-12.3	-0.5
Willingness to pay (pence per minute)		**5.2**	**14.4**		**7.0**	**0.7**
Initial likelihood	-1534			-1534		
Final likelihood	-1369			-1359		

Table 1: Scheduling and mean-variance models

Comparing the two models gives an additional explanation for the popularity of mean-variance models: the likelihood of both models is almost equal. The low t-test value of the TTV variable clarifies that despite the similar likelihood, the mean-variance formulation lacks the explanatory power of the scheduling model. Examining the willingness to pay implied by each of the models shows that the mean-variance model gives a higher value to MTT and a very low value to TTV.

The following experiment aims at demonstrating the influence of using a mean-variance model on the assessment of TTV-related costs in a realistic scenario. The survey data file, which was used for model estimation, is used here again, but this time we only use the answers to the introductory questions about the respondents' daily travel experience: their MTT, preferred arrival time and fare. The choices in the hypothetical situations are ignored, i.e. the survey data are merely used since they contain information about the likely distribution of journey times and costs. The analysis included the following stages:

1. A spreadsheet was prepared, with a record for each of the 244 individuals that took part in the survey. Each person's record includes the MTT, preferred arrival time and fare of his/her commuting journey.

2. A random level of TTV was added to each record. TTV was not mentioned in the introductory page of the survey and therefore the data file did not include information about the real TTV experienced by each individual. The random values were drawn similarly to the way the levels of TTV were generated in the survey, i.e. as a proportion of the MTT, with the same upper and lower boundaries. This range of values seemed a reasonable representation of real conditions (based on the sources mentioned in the survey design section, as well as Thorburn-Colquhoun, 1995).
3. For each individual (j), 10 random travel times were drawn, assuming a lognormal distribution with MTT_j and $TTV_{j,}$ i.e. the particular mean and variance of this respondent's daily journey.
4. For each individual, 150 evenly-spaced (non-random) alternative departure times were generated. The earliest departure for individual j is $2 \cdot MTT_j$ before his/her preferred arrival time, and the latest is $0.5 \cdot MTT_j$ before the preferred arrival time.
5. For each alternative departure time of each individual, ML and MTE were computed, based on the 10 random travel times. The ML and MTE were added to the record of each individual.
6. For each individual, the optimal departure time (of the 150 alternatives) was chosen deterministically, as the one that maximizes the utility function of the scheduling model. Note that we assume that as our model implies, actual choices are best explained by the scheduling model, even if the cost might be calculated (see stage 7 below) according to the mean-variance model.
7. Based on the chosen departure time of each individual, the cost of each of the utility elements was determined by both the scheduling and the mean-variance models. Note that although MTT and the mean earliness are included in one variable in the scheduling model, in the current analysis they are considered separate elements with the same cost per unit.
8. Elements of the total cost, according to both models, were analysed using a frequency diagram. Figures 3 and 4 show how each of the two models interprets the cost of the analysed sample of journeys.

The scheduling model curve in figure 3 is more skewed to the left than the mean-variance curve; high costs of MTT, as implied by the scheduling model, are less frequent than the same costs in the mean-variance model. This is a direct result of the higher value placed on MTT in the mean-variance model, and is therefore not surprising. The picture painted in figure 4 is much stronger: if we accept the aforementioned argument that the scheduling model is more powerful, figure 4 shows that the mean-variance model immensely undervalues the effects of TTV. If the relations between mean-variance models that are practically used for transport scheme appraisal to their parallel, unused scheduling models are similar to the relation disclosed here, then a massive bias is implied.

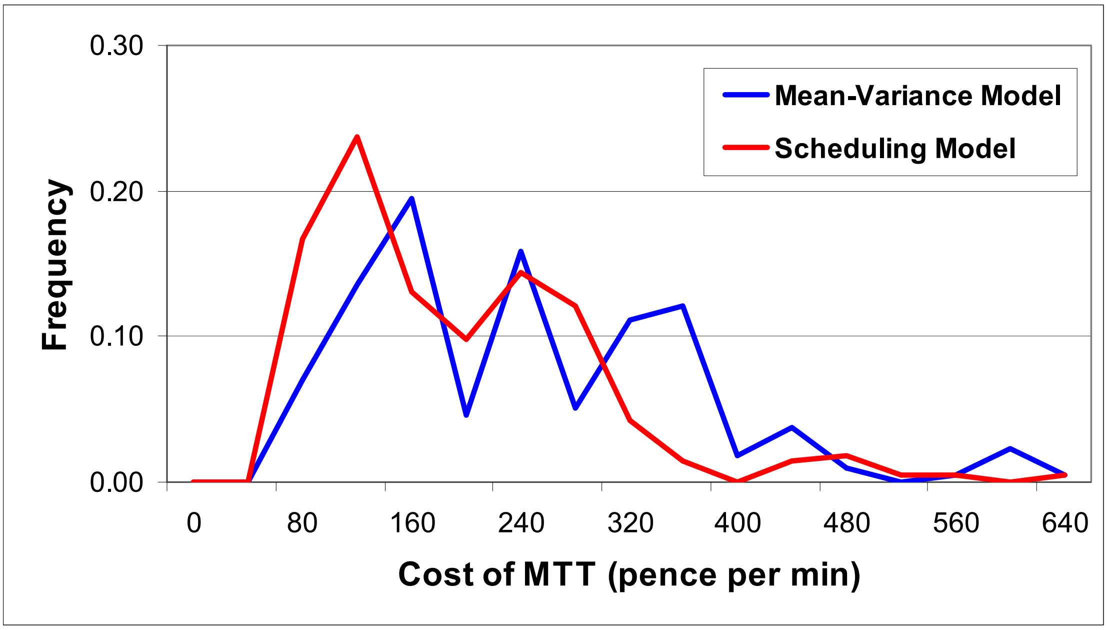


Figure 3: The cost of MTT in the scheduling and the mean-variance models

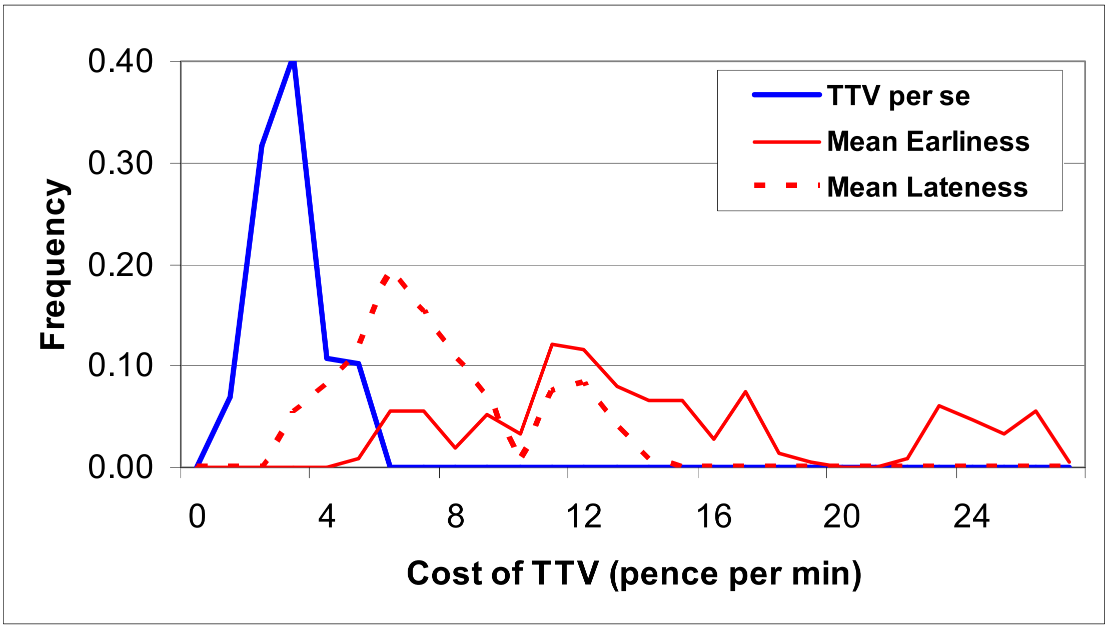


Figure 4: The cost of TTV in the scheduling and the mean-variance models

To conclude the current analysis, the total journey cost across all 244 trips in the data file was summarised, as well as the cost of only the TTV-related elements. When this is done using the mean-variance model, the cost of TTV amounts to 1.0% of the total cost. When the scheduling model is used, the total contribution of the mean lateness is 4.0% of the total, and the mean earliness adds up to 8.1%, hence the indirect cost of TTV is 12.1% of the total cost. It can thus be assumed that using a mean-variance model to assess a scheme that aims at improving bus reliability will result in a drastically reduced chance of this scheme being promoted.

6. THE MIXED LOGIT MODEL

An attempt was made to extend the scheduling model presented above into a Mixed Logit formulation, which accounts for taste variations between different individuals. Many different Mixed Logit specifications were tested, but due to various features of the results, it was feared that none of these specifications led to an adequate distribution of the willingness to pay across the sample of bus users. An extensive series of exercises was carried out, where a sub-sampling technique was used to obtain an external estimate of the distribution of preferences across the studied population; the term sub-sampling refers to the group of techniques that examine the variation within a sample based on separate analyses of small sub-samples. Due to space limits, the experience with Mixed Logit modelling will be described in full in a separate paper; main findings are briefly reported hereby:

1. There is no evidence for the existence of negative value of travel time among any part of the sampled population. But there is evidence that about a sixth part of the population has negative willingness to pay for some elements of travel time; namely, in the current case, for the mean lateness. This is based not only on the Mixed Logit results, that constantly oversize the negative share, but on the more credible sub-sampling experiment.
2. Using unbounded distributions for the model parameters gives irrational results, but using bounded distribution does not in itself guarantee a better model. Determining the bounds from the input data is not easy since it requires finding, within the data, the travellers whose individual choice models have the highest/lowest values, but using these values in the Mixed Logit model is too restrictive.
3. Distorted distributions of the willingness to pay often result from values close to zero within the range of values of the cost parameter. Frequently, this cannot be solved by bounding the distribution of this parameter, because the area around zero remains within the feasible range. Bounding the distributions of the parameters is tricky, because we are actually interested in bounding their ratios, but this cannot be done directly.

4. The statistical tests traditionally used to evaluate Logit models might be misleading when estimating Mixed Logit models; the maximum likelihood and rho-squared penalise any bounding of the parameter distribution, even when such bounding improves model fit.
5. Truncating the distribution of the willingness to pay after model estimation, instead of bounding the parameters, can overcome the aforementioned problems; but the credibility of the resulting distribution entirely depends on the credibility of the method used for determining the boundaries. Since this approach changes the Mixed Logit estimates so that they fit into external estimates, the effort involved in estimating the Mixed Logit model itself seems unjustified.

7. CONCLUSION

The main contribution of the presented work is the estimates of VOTE and VOL for bus users; these will be used, in the forthcoming stage of the presented project, to analyse whether investment in improved bus infrastructure brings considerable reliability benefits. Bus commuters in the study area are found to evaluate the mean travel time, as well as early arrival to the destination, at around 5.2 pence per minute; the estimated value of the mean lateness is 14.4 pence per minute.

Along the way towards these estimates, we have introduced a SP experiment where the distribution of travel times is presented graphically; and have shown that the effects of TTV can be converted into monetary terms through analysis of the consequent pattern of lateness and earliness. We stress that practitioners who wish to assess the consequences of improved reliability must note that using mean-variance formulations results in a serious underestimation of the value of TTV.

An attempt to reach a credible estimate of the distribution of the willingness to pay across the sample of bus travellers using Mixed Logit was found a serious challenge. Using either unbounded or bounded distributions for the model parameters does not lead to plausible estimates of the ratios of these parameters, and external statistical tests are required to assess model fit. We shall elaborate on this experience in a separate publication.

Source	**Includes cost?**	**Modes**	**Form of questionnaire**	**Departure time noted?**	**Respondent's choice**	**Model description**	**No. of usable questionnaires**
Jackson and Jucker (1982)	No	No distinction between modes	Type 1	No	Choose 1 of 2 alternatives	Mean-variance	214
Pells (1987a, b)	Yes	Bus	Type 1	No	Choose 1 of 5 options: "definitely A", "probably A" etc.	Scheduling	207
Bates et al (1987) and Johnson et al (1989)	No	Car	Type 1a	No	Choose 1 of 2 alternatives	Scheduling	Unknown
Black and Towriss (1993)	Yes	Car, bus and rail	Type 2 with 5 items	No	Choose 1 of 2 alternatives	Mean-variance	606
Benwell and Black (1994)	No	Rail	Type 2 with 10 items	No	Choose 1 of 3 alternatives	Unknown	Unknown

Senna (1994)	Yes	No distinction between modes	Type 2 with 5 items	No	Choose 1 of 5 options: “definitely A”, “probably A” etc.	Mean-variance	301
Atkins (1997)	Yes	Bus	Type 1	No	Choose 1 of 2 alternatives	Mean-variance	156
Noland et al (1998)	No	Car	Type 2 with 5 items	Yes	Choose 1 of 2 alternatives	Scheduling / mean-variance	543
Small et at (1999)	Yes	Car	Type 2 with 5 items	No	Choose 1 of 2 alternatives	Scheduling / mean-variance	959
Cook et al (1999), Bates et al (2001)	Yes	Rail	Type 2 with 10 items. Each alternative (operator A / B) has 3 possible departure times	Yes	Rank the 4 best of the 6 combinations	Scheduling / mean-variance	672 pseudo-observations based on 28 questionnaires

Table 2: Summary of TTV-related surveys

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