TI 2003-036/3
Tinbergen Institute Discussion Paper

Valuation of Travel Time and Traveller Information in Multimodal Personal Travel under Uncertainty

Piet Rietveld

Dept. of Spatial Economics, Faculty of Economics and Business Administration, Vrije Universiteit Amsterdam, and Tinbergen Institute.

Valuation of travel time and traveller information in multimodal personal travel under uncertainty

May 2003

Piet Rietveld
Vrije Universiteit
Amsterdam
Prietveld@feweb.vu.nl

Abstract.

The value of travel time plays an important role in cost benefit analysis of infrastructure projects. However, the issue of uncertainty on travel times and the implications this has for estimations of travel time values has received much less attention in the literature. In this paper we compare various modelling approaches to address uncertainty and demonstrate that ignoring uncertainty issues may easily lead to distorted estimates of values of travel time. This is of special relevance in public transport where various trip components may have different valuations and degrees of uncertainty. Our approach sheds light among others on the high time valuations for waiting at transfer points in public transport. Implications are given for the supply of traveller information on values of travel time in public transport.

Keywords:
multimodal travel, public transport, value of travel time, expected utility, uncertainty, unreliability.

1. Introduction.

Generalised costs play an important role in the analysis of travel behaviour such as mode choice and route choice. These costs consist of two main parts: monetary costs and time-related costs. The opportunity costs of travel time may be substantial, and hence their contribution to generalised costs may also be high. Because of this reason, an extensive literature on value of travel time has developed in order to arrive at better explanations of travel behaviour (see Jara Diaz, 2001). The valuation of travel time appears to depend on personal features (income, travel motive), transport modes considered and situational features such as weather conditions. A related development is that the value of travel time has become an important ingredient of cost benefit analyses of transport infrastructure investments and transport policies (see for example Calfee and Winston, 1998). A major benefit of many transport infrastructure projects is that they lead to a reduction of travel time so that well-founded estimates of values of time are essential.

Much less attention has been paid in the value of time literature on the issue of reliability and the implications it may have on travel behaviour and on cost benefit analysis. This is remarkable since several countries are nowadays witnessing serious quality problems with their transport systems so that improvement of reliability gets high priority. As long as speed-improving measures are also reliability enhancing, this may not be a problem. However, speed and reliability do not always go hand in hand, and therefore there is a risk that ignoring the reliability dimension will lead to biased investment decisions.

We distinguish three ways to address reliability problems in transport. First, at the supply side infrastructure (road, rail) and public transport services may be extended and improved. Second, demand management may take place via pricing and other measures in order to reduce demand at times and places in the network where reliability problems are urgent. A third way is the provision of traveller information with the aim to reduce the negative effects of reliability problems for travellers. This aspect will receive special attention in the paper.g

In this paper we have chosen to focus on reliability in multimodal passenger transport. It is here that the issue of reliability is very pertinent, because of the specific problems railway companies and bus operators are facing in several countries. In addition, multimodal trips imply travel chains with differentiated elements some of which -for example waiting at platforms- are highly sensitive to uncertainty problems.

The *aim* of this paper is twofold. First, we want to discuss the implications of ignoring reliability issues in value of time studies. We will show that when reliability is not made explicit in the analysis of value of time, it may lead to distorted estimates. The second aim is that we will consider the impacts of information provision on value of time in transport.

Section 2 discusses some conceptual issues on reliability and related terms. In section 3 reliability implications for the value of time will be discussed under various assumptions. Implications of information provision for the time related costs of transport are dealt with in section 4. Section 5 concludes.

2. Conceptual issues on uncertainty in travel behaviour

Consider a traveller who can choose among n alternatives, for example transport modes or routes. The utility (or generalised costs) of the alternatives depend on criteria such as the monetary costs, travel time (possibly distinguished according to in-vehicle time, waiting time, access time, etc.) and other comfort aspects. These features will be denoted as $x_1, ..., x_J$. Uncertainty means that the traveller does not know the exact values of the choice characteristics. They are subject to variation. Thus, each feature x_j has a density of possible results: $g_j(x_j)$ with mean μ_j and variance σ^2_j.

The nature of this uncertainty may be threefold (see Table 1):

1. The outcome for the criterion is certain, but the traveller lacks knowledge on it
2. The outcome is structurally uncertain because transport networks are subject to disturbances, but the traveller is has complete knowledge on the variation.
3. The outcome is structurally uncertain, and the information available to the traveller is incomplete.

Further, Table 1 contains complete certainty on certain outcomes (case 0) as the reference case.

		Knowledge of traveller:	
		Certain (complete)	Uncertain (incomplete)
Network features:	Certain (deterministic)	Case 0: complete information on deterministic outcome	Case 1: incomplete information on certain outcome
	Uncertain (stochastic)	Case 2: complete information on stochastic outcome	Case 3: incomplete information on uncertain outcome

Table 1. Combinations of uncertainty dimensions in transport networks

As an example of case 1 consider uncertainty on the *monetary costs* of a trip. For a car driver this may relate to the fact that he does not know exactly how much petrol he will use, or what will be the level of a toll. In a similar way a public transport traveller may not know exactly how much he will have to pay for a ticket. Much of this uncertainty can be removed by making information acquisition efforts[1]. The basic trade-off involved here is the burden of the effort of information gathering versus the utility loss because a 'wrong' decision was made. Another relevant uncertainty of this type concerns *travel times* in road transport and *departure and arrival times* in public transport. Here the uncertainty could be removed by looking at route planners for road trips or public transport timetables. The trade-off between the burden of information acquisition and the loss due to a wrong decision is evident in the choice of departure time of public transport travellers. When frequency is low, travellers would typically first consult the timetable before going to the public transport stop. This is a clear expression of the fact that information has value for the travellers, implying that there is a willingness to pay for it.

After the information acquisition has taken place another possible source of uncertainty remains, i.e., when transport systems are subject to disturbances. We use the term *'reliability* for this purpose. The above mentioned density $g_j(x_j)$ needs further clarification to make it a useful concept. First of all, it may depend on the features of individual i itself. For example, in road transport, total travel time will depend among others on speed choice which is partly determined by features of the pertaining individual i . In addition, travel time depends on situational circumstances z such as time of day, type of day (for example weekday versus weekend), weather conditions, the occurrence of a strike or an accident, etc. Thus, the density $g_j(x_j)$ can be generalised to become $g_{ji}(x_{ji}| z)$. Information on $g_{ji}(x_{ji} | z)$ may be available to the traveller in various ways. If he is a regular traveller he may know rather well the shape of the density $g_{ji}(x_{ji} | z)$. However, when he is not a regular traveller he may have a distorted view of this density leading to a misconception of both its mean and variance (see for example Exel and Rietveld, 2002).

Within the context of reliability there is a further distinction to be made between transport services with and without a timetable. In the latter case the term *'punctuality'* can be used. A timetable of a public transport company, possibly combined with a certain tolerance level (trains should not arrive more than 5 minutes late) allows one to observe deviations from a certain standard. In the case of road transport such explicit standards are usually not given, but a tendency to formulate a guaranteed speed on motorways may be observed (for example Ministry of Transport, 2001 formulates a 60 kmph lower limit for speeds on motorways). Such a development would reduce the difference between transport by private car and public transport since in both cases there would a supplier (of infrastructure or services) that utilises certain quality standards.

Research on uncertainty in transport usually addresses travel times. Other relevant dimensions of uncertainty may relate to comfort aspects such as the probability to get a seat in public transport. Thus, one arrives at a density $f_{j'}(x_{j'} | z)$ of comfort level $x_{j'}$. Another aspect of uncertainty is the probability of a safe arrival. This aspect is addressed in the literature under the heading of safety and it will not be further addressed here. Obviously the probabilities of safe arrival are very close to 1. Nevertheless fear of accidents plays an important role in behaviour of many travellers (fear for a car accident, of for travelling by air). The perception of risks after the events on 11 September 2001 has had a strong impact on demand for aviation. Also (lack of) social safety is an important criterion of mode choice in transport.

The distributions of travel time and comfort level may be correlated. In the case of delays or cancelled trains one will probably find that a longer travel time implies a lower probability to get a seat. Also in multimodal trips unreliability of transport time leads to a probability that connections are missed. This does not only lead to longer total transport time, but also to a high share of time spent waiting.

Most studies on uncertainty in transport focus on the choice of route, modality or departure time. However, uncertainty in the transport system may also have an impact on *trip generation and choice of destination*. The occurrence of a strike or the threat of it may induce people not to depart for their commuting trip on a certain day. And, similarly they may choose another shopping centre under such circumstances. In the context of destination choice uncertainty may also play another role, namely uncertainty on the quality of the destination. Shopping behaviour is an example where shoppers looking for a speciality good may visit several destinations before they make their choice. This is part of the literature on spatial search (Gorter, 1991, Maier, 1996). The point is that this type of uncertainty leads to an increase of travel activity (travel is a means to collect information), whereas the other uncertainties would tend to lead to a decrease of travel activity.

3. Uncertainty implications for the valuation of travel time savings in multimodal trips.

In this section I address the consequences of introducing uncertainty in decision making of travellers who consider a public transport trip. Various settings will be described. Special attention will be paid to the implications of travel time uncertainty for the estimation of the value of time.

Assume that a traveller considers a public transport trip consisting of 7 elements, but the approach would also apply to simpler or more complex trips:

1. walking to bus stop
2. waiting at bus stop
3. bus ride
4. walking from bus stop to railway station
5. waiting at railway station
6. train ride
7. walking to final destination.

Let $t_1, ..., t_7$ be the times used for these trip components and let p denote the monetary expenditure made with respect to a trip.

We will address a number of alternative specifications of uncertainty in transport and investigate the implications for the marginal value of travel time savings. The various dimensions are indicated in Table 2.

case	certainty/ uncertainty	constant/variable marginal value of travel time savings mvots	risk attitude: expected utility vs risk aversion	scheduling costs:
1	certainty	constant	n.a.	no
2	uncertainty	constant	expected utility	no
3	certainty	variable	n.a	no
4	uncertainty	variable	expected utility	no
5	uncertainty	constant	risk aversion	no
6	uncertainty	constant	expected utility	yes

Table 2. Alternative settings for the analysis of uncertainty implications on the marginal value of travel time savings.

1. Complete certainty; constant marginal value of travel times.

We start with the reference case of certainty to provide a contrast for uncertainty analysis. Assume that the utility is a linear function of travel times and price, and that uncertainty does not occur:

$$U = a_1.t_1 + ... + a_7.t_7 + b.p \tag{1}$$

The parameters $a_1,...,a_7$ and p are all negative. The marginal value of each travel time component j is defined as the marginal rate of substitution between travel time t_j and price and can be computed as a_j/b. These marginal values are defined as *the change in price necessary to compensate a traveller for a loss of one unit travel time so that the traveller remains at the same level of utility.*

It appears from the literature that the values of $a_1,...,a_7$ are not equal. Some aspects of travel time are weighed more heavily than other aspects. For example, a tendency exists that walking times are valued higher than waiting times. In-vehicle times are valued lower than out-of-vehicle times, and trains tend to be considered more comfortable than busses (see for example Waard, 1989, Wardman, 2001). This would imply

$$a_6/b \leq a_3/b \leq (a_2/b= a_5/b) \leq (a_1/b= a_4/b= a_7/b) \qquad (2)$$

This means that passengers attach higher values to reductions in access modes and in waiting times than they do to increases in speeds. Important determinants of these differences in values of time seem to be:
-comfort levels: sitting in a train is more comfortable than waiting at a platform.
-alternative use of time: walking may be considered as lost time, whereas one may read books while sitting in a train.
-attractiveness of views: public transport may lead the travellers through interesting areas, something which does not hold when they are waiting at stops.
In many studies on the value of travel time distinctions between the various parts of a trip are not made. Let t_{tot} be the total time of the trip. Then the average value of time (VOT) for the complete trip would be

$$\text{Average VOT} = \sum_j (t_j/t_{tot})\, a_j / b \qquad (3)$$

Making a trip faster by increasing the speed of the rail part obviously reduces the time-related costs of the trip. However, it also leads to a *higher* VOT for the total trip because the share of the fast part with its low value of time decreases. From this perspective, a relevant alternative to improve public transport would be to change other network features such as walking time and waiting times at stops in stead of speed increases.

2. Uncertainty valued via expected utility: constant marginal values of travel times.
What are the consequences when uncertainty is introduced? As we indicated above, uncertainty may relate to both lack of knowledge and stochastics in the functioning of transport networks. In an analytical sense the two lead to similar formulations in terms of densities of travel time outcomes $t_1,...,t_7$. But in an empirical sense the two may lead to different outcomes. To keep the discussion compact, we will focus on the unreliability interpretation of uncertainty in this section.

Uncertainty means that there is a joint density of outcomes for $t_1, ..., t_7$: $g[t_1, ..., t_7]$. The issue of reliability mainly concerns t_2 and t_3 (waiting for and sitting in the bus) and t_5 and t_6 (same for train)[2]. Note that due to the various interdependencies this joint density would imply non-zero correlations between the length of the bus ride and waiting time at the railway station. For example, a vulnerable bus system may imply a positive correlation between t_3 and t_5. But there may also be negative correlations: when there is some slack in the schedule, a slow bus will increase the in-vehicle time in the bus t_3, but decrease the waiting time at the railway station t_5. [3]

The valuation of uncertainty can be done in various ways. In the present case we consider *expected utility* as the valuation strategy adopted by the traveller. With constant marginal values of time, expected utility means that a traveller is indifferent between a trip that takes 30 minutes with certainty, and a trip with an uncertain duration uniformly distributed between 25 and 35 minutes. This is a rather simple approach to address uncertainty, because it implies that issues such as arriving early or late, necessity to adjust activity plans, need to inform other people on changes in schedules, stress, loss of time, etc. are not relevant. Nevertheless, it is useful to consider it as a benchmark before addressing more complex cases.

If we may assume that decisions are based on *expected utility* we have:

$$W = \int\ldots\int \{a_1.t_1 + ... + a_7.t_7 + b.p\} \; \{g[t_1, ..., t_7]\} \; dt_1...dt_7 \tag{4}$$

which is equal to:

$$\sum_j \; a_j \; \int\ldots\int \; t_j \; \{g[t_1, ..., t_7]\} \; dt_1...dt_7 + b.p = \sum_j \; a_j \; E\,(t_j) + b.p \tag{5}$$

where $E\,(t_j)$ represents the expected value of t_j.

The conclusion is that in this case the introduction of uncertainty does not lead to particular problems: expected values of the travel time components give sufficient information on the expected utility of alternatives. Variances and covariances of the various t_j can be ignored for this purpose. The value of each travel time component j can again just be computed as a_j/b. Their interpretation is only slightly different: it represents *the change in price necessary to compensate a traveller for a loss of expected travel time of one unit so that the traveller remains at the same level of expected utility.* Under the assumption that decisions are based on expected utility, the only relevant effect of the introduction of unreliability is that it might lead to changes in the average duration of the various trip components. There is evidence that in public transport unreliability has a much larger effect on waiting times than on in-vehicle times. This is shown in Table for a sample of public transport trips where it appears that unreliability leads to a doubling of waiting times whereas in-vehicle times are only marginally affected. Hence the introduction of unreliability will increase the share of waiting times in total travel time, implying an increase in the average value of time for the total trip[4].

	Travel time according to time table	Actual travel time
Waiting time (minutes)	5	11
In-vehicle time (minutes)	55	56
Total (minutes)	60	67

Source: Rietveld et al. (2001)

Table 3. Comparison between travel times (time table versus actual travel times due to unreliability) in a sample of multimodal public transport trips, The Netherlands.

3. No uncertainty; marginal value of travel time not constant.

Consider the case that the valuation of time depends on the length of the travel time. See De Jong et al. (1998) for a discussion. For example, for a passenger sitting in a plane the trip has to take at least say 30 minutes before he can do something useful during the trip. This leads to a valuation of travel time as depicted in Fig 1.

Fig. 1 Example of valuation of travel time as a function of duration of trip.

This means that $a_j.t_j$ must be replaced by: $f_j(t_j)$ where $f_j(t_j)$ is a non-linear function of t_j:

$$U = f_1 (t_1) + ... + f_7 (t_7) + b.p \tag{6}$$

In a situation without uncertainty the marginal value of travel time component j is $d[f_j(t_j)]/d[t_j]/b$. Thus, the marginal value of travel time losses has a definition that is very close to the one in case 1, the difference being that it now depends on the level of t_j. Note, that although this formulation is already more complex than the reference case 1, it can still be considered as a rather restrictive formulation because of its additive character implying that there is perfect substitutability between the travel time components. We now consider how this transfers to the case of uncertainty.

4. Uncertainty valued via expected utility; marginal value of travel time not constant.
The expected utility of a travel alternative is:

$$W = \int\ldots\int \{ f_1 (t_1) + ... + f_7 (t_7) + b.p \} \{g[t_1, ..., t_7]\} dt_1...dt_7 \tag{7}$$

It is clear that this expression is in general *not* equal to $f_1 (E(t_1)) + ... + f_7 (E(t_7)) + b.p$. Thus, the case of certainty cannot be easily translated into the case of uncertainty by making use of the expected value operator E and defining the VOT of travel time component j as $d[f_j(E(t_j))]/d[t_j]/b$. The correct approach to the measurement of the value of time reads as follows. Consider the more general formulation where $f_1 (t_1) + ... + f_7 (t_7)$ depend on parameters $\alpha_1, \ldots \alpha_N$ so that $f_1 (t_1) + ... + f_7 (t_7) = f(t_1, ...,t_7; \alpha_1, \ldots \alpha_N)$. Further, let the joint density $g(t_1, ..., t_7)$ have parameters for expected values of travel times $\mu_1,\ldots,\mu_7$ and their variances and covariances σ_{ij}. Then expected utility can be written as a function that depends on all these parameters:

$$W = F(\alpha_1, \ldots \alpha_N; \mu_1,\ldots,\mu_7, \sigma_{11},\ldots, \sigma_{JJ}) + bp \tag{8}$$

The value of time estimate for trip time j based on this expression is:

$$VOT_j = [dF(\alpha_1, \ldots \alpha_N; \mu_1,\ldots,\mu_7, \sigma_{11},\ldots, \sigma_{JJ})/d\mu_j]/b \tag{9}$$

Thus, it appears that the value of time estimate of trip time j depends on all parameters, including the means and variances and covariances of the travel time components.

Consider as a simple example a trip with only one travel time component (J=1) and where the marginal value of travel time first increases, after which it decreases (cf. Figure 1 for a similar case in the situation of certainty). The parameters α determine the shape of the function f. Note that the certainty case 3 is equivalent to the uncertainty case 4 when $\sigma=0$. Then, given the values of the parameters α and $\sigma=0$ we may replace the axes t and f in Figure 1 by the axes $\mu=E(t)$ and $E(f(t))$ and still have the same picture. When uncertainty plays a role ($\sigma>0$), the introduction of variation around the mean μ means that smoothing takes place for the utility level (see Figure 2). An interesting implication is that due to the unreliability the marginal value of expected travel times gets closer to a constant value. The larger the level of uncertainty the smaller the variations in the marginal value of expected travel time. It follows that in this context the marginal value of travel time depends on the variance of travel times, and that we cannot rule out the paradoxical result that an increase in the variance (keeping mean travel time equal) leads to a decrease of the marginal value of expected travel time. (This happens in Figure 2 at the right side of the inflection point).

Fig. 2 Valuation of travel time as a function of trip duration under certainty ($\sigma=0$) and uncertainty ($\sigma >0$).

5. Uncertainty valued via expected utility with a penalty for standard deviation; marginal value of travel time constant.

Thus far, the implications of uncertainty on the utility of travelling have been rather straightforward to deal with. However, especially when activities are scheduled to start at a certain time, uncertainty on travel times is problematic. This will be addressed in the next case. But also when activities are not scheduled, passengers may consider uncertainty as unattractive. One of the reasons is that uncertainty may affect the comfort of trips: unreliability of services may for example lead to crowded trains. In addition, people may experience various types of stress due to uncertainty (see Exel, 2003 for a review). For example, Janis and Mann’s “conflict model of decision making” describes decision makers “*beset by conflict, doubts, and worry, struggling with congruous longings, antipathies, and loyalties, and seeking relief by procrastinating, rationalising, or denying responsibility for his own choices*” (Janis and Mann, 1977). These decision makers experience cognitive and social stress in decisions that evoke at least some degree of concern or anxiety in the decision maker about the possibility he may not attain the objective he is seeking. Stress arises from “decisional conflicts”, i.e., “*an unpleasant feeling of distress*” from “*simultaneous opposing tendencies within the individual to accept and reject a given course of action. The most prominent symptoms of such conflicts are hesitation, vacillation, feelings of uncertainty, and signs of acute emotional stress whenever the decision comes within the focus of attention*”. The intensity of stress “*appears to depend upon the perceived magnitude of the losses the decision maker anticipates from whatever choice he makes …*” Along similar lines Bell, 1982, and Loomes and Sugden, 1982) discuss the concept of regret and propose a combination of standard expected utility theory and the anticipated personal and social disadvantages of regret.

One of the aspects of regret is that travellers may want to make the best choice. In the case of unreliability they may be afraid that they will find in the end that they chose the ‘wrong’ alternative[5]. A related aspect is that in the situation of unreliability or uncertainty on timetables, public transport travellers may find it burdensome to make on-route decisions. For example, in the case of delays they may consider running from bus stop to railway station (reduce walking time t_4) in order to catch the train. Lack of information on the exact departure time of the train may induce people to hurry where in reality this is not necessary. Or alternatively, if travellers would have known that not only the bus was late, but also the train, they might have hurried to catch it. These phenomena may lead to stress that would not be present in the case of certainty on the outcomes of reliable travel alternatives.

It is interesting to compare this attitude with respect to uncertainties in travel times with uncertainty on monetary outcomes. People tend to be risk averse with respect to monetary aspects, leading to insurance arrangements for a wide range of phenomena[6]. One might argue that when a certain choice situation with monetary outcomes is repeated, people may just add the many positive and negative monetary outcomes and simply decide on the aggregate value. This aggregate would be close to the expected value when the situation is repeated a sufficient number of times. However, this does not appear to be the way in which people decide. In the case of time use, such an adding up procedure of all time gains and losses provides an even less plausible rule for decision making. The valuations of time gains and time losses are very context specific. They cannot be stored like money on a bank account. Therefore if in the monetary realm expected utility often does not adequately represent traveller behaviour, this holds even more so in the realm of temporal decisions.

Thus we assume that travellers do not only consider the mean travel time but also the standard deviation (see for example Markovic, 1987):

$$W = E(U) + c\ \sigma\ (U). \qquad (10)$$

where c is the weight given to the standard deviation relative to the average. Travellers that dislike uncertainty will have a negative value of c. To keep the analysis simple, we assume that marginal values of the various travel time components are constant. In this case:

$$W = \sum_j a_j\ E\ (t_j) + b.p + c.\ \sqrt{[\int \ldots \int \{a_1.t_1 + \ldots + a_7.t_7\}^2\ \{g[t_1, \ldots, t_7]\}\ dt_1 \ldots dt_7 + \sum_j \{a_j\ E\ (t_j)\}^2]}$$

$$= \sum_j a_j\ E\ (t_j) + b.p + c.\ \sqrt{[a_1^2\ \sigma_1^2 + a_1 a_2\ r_{12}\ \sigma_1 \sigma_2 + \ldots + a_7^2\ \sigma_7^2]} \qquad (11)$$

where r_{12} is the correlation between travel time components 1 and 2, and σ_j is the standard deviation of component j. In this case, the marginal value of expected travel time is again just equal to a_j/b, assuming that the variance would remain equal. However, if the variance would also increase this no longer applies. For example, if the standard deviation would be proportional to the mean ($\sigma_j = h_j\ E(t_j)$) an increase in expected travel time of one unit would lead to a decrease in utility equal to $[a_j + c.\ a_j\ \sigma_j\ h_j]$ (assuming that covariances r_{jk} are zero[7]). The corresponding value of travel time would be $[a_j + c.\ a_j\ \sigma_j\ h_j]/b$.

Thus, the issue of valuation of uncertainty depends critically on the extent to which standard deviation and mean are interrelated. For example, with the normal distribution the two are not interrelated, implying h_j=0. However, in skewed distributions such as the exponential distribution or the gamma distribution, one finds that mean and standard deviation are proportional to each other (cf. Rietveld et al., 2001, who demonstrate that the gamma distribution is one of the candidates for distributions of travel times). The point is whether a change in average travel time of say 40 minutes with a standard deviation of 4 minutes towards a distribution of 50 will leave the standard deviation at the level of 4, or whether it will increase to a level 5. In real world situations both extremes and also intermediate cases may occur. One may even have situations where an increase in average travel time is implemented to reduce the standard deviation. An example would be the policy to have longer waiting times of trains at platforms in order to have higher probabilities that travellers will be successfully interconnected.

Consider the case that all travel time components get the same weight. Suppose that the value of travel time is estimated from revealed preference data where uncertainty plays a role, but only average travel times are given. Then the value of time estimate is usually interpreted as a/b. However, what is measured is not a/b, but $[a + c.\ a\ \sigma\ h]/b$. An important observation is that when proportionality between mean and standard deviation would continue to exist, there is no need to worry about the neglect of uncertainty: it is implicitly incorporated in the estimate of the value of travel time. However, there are at least two reasons to be nevertheless concerned about this implicit way of treating reliability.

The first one is that the estimated value of time would be misleading when it comes to the evaluation of reliability enhancing measures. Thus, when time tables of public transport would be changed to have more slack at stops, this would lead to an increase in total travel time, whereas reliability would be enhanced. However, a cost benefit analysis based on the value of time as indicated above would not be able to capture the reliability enhancing effect of the adjusted timetable.

The second problem with the implicit treatment of unreliability is that it may lead to distorted estimates of value of time outside vehicles. The point is that in multimodal trips the variance is usually highest in the waiting times in intersection points. For example, an increase of five minutes (in-vehicle) in part 3 of a trip implies that the waiting time at the railway station may increase from 3 to 28 minutes since the traveller has to wait for the next train assuming a service frequency of two trains per hour. Thus, the ratio of standard deviation and mean may be expected to be much higher for in-vehicle time than for waiting time at platforms. The high value of time usually found for out-of-vehicle time at public transport nodes may well be the consequence of an implicit treatment of uncertainty (Wardman, 2001). This implicit treatment of reliability makes the values of time found particularly unsuitable to evaluate measures aiming at improving the reliability of chains. It also means that the transferability of value of travel time from one context or country to another is no longer valid when levels of unreliability are different.

6. Uncertainty and scheduling costs.

Scheduling costs are relevant when travellers have a targeted time of arrival and incur losses when they arrive late (for example at the work place or at a meeting). The table shows that scheduling plays a definite role in several trip purposes. The share of trips where scheduling takes place is estimated to be between 25 and 30% in the Netherlands (Table 3). Around half of these trips relate to purposes where scheduling costs are probably high (work, business, education). The figures in this table are tentative, one of the reasons being that the issue of scheduling is treated in a rather crude way since differences in the flexibility of schedules are not considered. Many activities do not have a strict target time for starting, but rather broad intervals, the end points of which may start to become important when actual arrival times tend to get close to them.

An interesting contribution to the literature on the valuation of reliability in the context of scheduling costs can be found in Bates et al. (2001). Assume that a trip is made where t* is a desired arrival time (for example the official time at which a business meeting starts). Based on the work of Small (1982, 1992) the utility of a trip is formulated as:

$$U = a_1.t_1 + ... + a_7.t_7 + b.SDE + c.SDL + d.D_L + b.p. \qquad (12)$$

Where t is total travel time, SDE is early schedule delay (the number of minutes arrived before t^*). SDL is late schedule delay (the number of minutes arrived after t^*) and D_L is a dummy that assumes the value 1 when SDL>0.

Trip purpose	Share in total number of trips, % (approx.)	Occurrence of scheduling costs:	Share of scheduled trips with this purpose (%, estimate)	Contribution to total number of scheduled trips (%); based on columns 2 and 4
Work	10	Usually, but less so with flexible working hours	90	9
Business	2	Yes, and high levels of costs	100	2
Shopping	13	Only when near to time of shop closure	10	1
Family visit	9	Usually not	10	1
Education	6	Yes	90	5
Recreation	11	Depends; sport activities are usually scheduled	30	3
Other	9	Depends; bringing and picking up children is often scheduled	40	4
Return home	40	Usually not, depends on anticipated in-house activity after arriving at home.	10	4
Total	100			29

Note: shares of trip purposes are based on Dutch personal travel survey, 1999[8].

Table 3. Distribution of trips according to scheduling pattern

When unreliability occurs expected utility equals:

$$E(U) = \sum_j a_j E(t_j) + b.E(SDE) + c.E(SDL) + d.p_L + b.p \qquad (13)$$

Where p_L is the probability of arriving late. The problem with this formulation is that E(SDE) and E(SDL) have complex forms. Noland and Small (1995) show that this formulation can be simplified and approximated under a number of assumptions (one of them being that people choose an optimal departure time). The resulting expression is:

$$E(U) = \sum_j a_j E(t_j) + \text{const.}\, \sigma(t) + d.p_L + b.p \qquad (14)$$

It should be noted that the standard deviation reads in terms of the total unweighted travel time ($t_1 + \ldots t_7$), whereas the term with the expected values of travel time takes into account the weights: $\sum_j a_j E(t_j)$. The background is that the standard deviation is connected to the issue of being late or early (which is not directly related to the disutility of the various distinct travel modes) whereas in the other term the differences between the transport modes are relevant.

The importance of this result is that although the formulation is based on expected utility without any reference to risk aversion, the final result nevertheless contains a penalty for variation since the standard deviation is part of the formula. The background of this result is that the scheduling costs imply a strong non-linearity in the valuation of travel time. Thus we arrive at the conclusion that risk aversion, being the main element in case 5 is not the only way to arrive at a penalty on the standard deviation of total travel time. Even without risk aversion, the scheduling costs lead to a final result where uncertainty enters the expected utility formula.

For the estimation of the value of time this approach with scheduling costs leads to conclusions that are similar to those in case 5. Ignoring the standard deviation and the probability of a late arrival leads to high estimates for the value of time in the case of scheduled activities. This must be one of the main reasons why a general result from the literature is that value of time for commuting and business trips, is so high (cf. Gunn, 2001). Making scheduling costs and reliability problems explicit may be expected to lead to more equal values of travel time across trip purposes.

4. Effects of traveller information.

Before making a trip, people have subjective ideas on the distribution of travel times of travel alternatives. Figure 3 gives a typical picture of the density of the possible travel time outcomes as perceived by uninformed travellers. A first source of information would be timetables giving the official arrival time of a trip. As already indicated in section 2, travellers have to make efforts to get this information. They may buy the national railway's timetable and spend time in finding their best travel alternative, or they may use travel information service providers on the internet. They spend scarce resources to improve their knowledge on travel alternatives, which is an indication of their willingness to pay for their services, even when they would not actually pay information providers[9].

Figure 3. Distribution of travel times (actual versus perceived by experienced and non-experienced travellers).

A simple example may serve to study the impact of this type of uncertainty on mode choice and the implicit values of travel time involved. Consider a traveller who has two alternatives: car and train, and who is uncertain about travel time and costs of both alternatives. Assume that:

- uncertainty is such that the traveller's knowledge is not unbiased -underestimates and overestimates are equally probable-, and
- travellers base their decision on expected values -they do not bother about variances-

Then provision of information on actual costs and travel times will of course lead to changes in preferred alternatives, but one may expect that it will not have a systematic effect on modal choice. The reason is that the probabilities that information acquisition leads to a change in the choice of travel alternative are balanced.

However, one aspect is missing in this reasoning. Trains depart at certain intervals. Provision of information on departure times will by definition reduce waiting time at the station. This element is absent for the car alternative. Thus, transport modes with scheduled services will *systematically* benefit from information provision. The lower the frequency, the higher the benefit of information provision. Easier access to information sources will stimulate demand of public transport services, especially when frequencies are low.

What does this imply for the estimation of the value of travel time in public transport? Actual travel behaviour is based on perceptions of travel times, rather than on actual travel times. However, researchers usually do not know the perceptions of travellers and hence tend to assume that perceptions are equal to realisations. This may not be a problem as long as systematic errors can be avoided (cf, Small, 1992). But with public transport such a systematic gap between actual travel time of uninformed travellers and travel time according to schedules appears to exist. This will most probably lead to an overestimate of value of time in public transport[10]. Better access to pre-trip information will help to partially overcome this problem, which also implies that biases in estimates of values of time will be reduced.

Another aspect of pre-trip information indicated in Table 1 is that due to unreliability in services official timetable information is not always correct. Hence the traveller would need information about probability distributions of realised travel times. In the above section we assumed that travellers are well informed about the density of travel time outcomes $g[t_1,\ldots,t_7]$. This may be a realistic assumption for experienced travellers who frequently travel between a certain origin-destination pair. However, traveller information systems do not give these probabilities. The newer generations of traveller information systems in public transport may report on large disturbances and planned delays owing to maintenance activities, but they do not inform the traveller on the day-to-day reliability of actual services (see Figure 3). However, for the traveller it would be helpful when he would have information about the probability that a trip with an official travel time of 50 minutes may in reality be 80 minutes or more due to the probability of missing a connection at an interchange point. From a technical viewpoint it is not so difficult to use simulation models based on time tables in combination with stochastic models on disturbances on specific links to arrive at densities of arrival times (see Rietveld et al., 2001). There must be a market for this type of information from the side of the traveller, for example, as a special option in electronic route planners. The uncertainties involved can be analysed at various degrees of refinement. A default option would be to use information for 365 days per year averages on unreliability. Refined options would be to take into account the part of the year to reflect seasonal differences and part of the day.

One of the reasons why information of this type is not provided is that some public transport companies simply do not have sufficient data to support it. The situation in rail based public transport tends to be better than in road based transport. Another reason is that suppliers of information often coincide with, or depend strongly on, suppliers of the public transport services, and these tend to hold the view that it is not good for their reputation to emphasise the day-to-day unreliability of their services. The point overlooked here is that passengers will know anyhow that services are unreliable. Providing them with information at a trip specific level, in stead of at a network level (see Fig. 3) will enable them to better assess the risks of late arrival and will also *prevent them from overestimating* the delays involved.

What are the consequences of the provision of information for the generalised travel costs and travel behaviour? We distinguish three possible uses of information.
First, better information enables travellers to adjust their choices so that generalised costs are lower compared with the situation without this information[11]. Note that the information provided does not necessarily mean that ex-ante generalised costs become lower: for travellers that underestimate costs it may also lead to higher generalised costs. But the costs actually experienced when a trip is made will tend be closer to the costs on which the choice of the alternative was made.

Second, even when information provision does not lead to the choice of another alternative, it may be useful to know an adjusted travel time forecast so that people one wants to meet can be warned by making use of mobile telephone. This is especially relevant in the case of scheduling costs (case 6 in section 3). People to be visited can be told that the meeting starts later, or they can at least be told not to be worried because of the late arrival. This leads to the conclusion that availability of on route traveller information and mobile communication technology has an effect on the disutility of travelling. These technologies tend to lead to lower costs of arriving late.

Third, even when the above two factors do not play a role (for example, when people make a visit to a place where arrival time is not specified), travellers may appreciate information on the projected travel time. When a train is late, most travellers prefer to have information such as ‘the train will arrive 10 minutes late’ in stead of not having such information. This is an expression of the general stress related to travel time uncertainty discussed under the heading of case 5 in section 3.

We conclude that three reasons exist why information provision leads to lower generalised costs of travellers. This implies a certain willingness to pay for information, and hence there is scope for private and public actors to supply this information. The implication for the value of time is that as long as uncertainties are not well specified in value of time studies, one may expect that they lead to overestimates of the value of time. Information provision makes these problems smaller and may therefore be expected to lead to a reduction of generalised transport costs.

5. Concluding remarks.

Uncertainty relates to both lack of knowledge of the traveller and the structural unreliability of transport networks. Both play a role in generalised costs of travellers. In public transport, chains are often complex and time costs of some elements of the chains (for example, waiting at platforms) are much higher than those of other elements of the chain. Reliability is an important issue because it appears to affect waiting time more than in-vehicle time.

Various models on travel time and uncertainty have been surveyed in this paper. It is demonstrated that when uncertainty aspects play a role in actual behaviour but when these uncertainties are ignored in value of time estimations, a tendency may be expected that values of travel time are overestimated. In particular our approach sheds light on the result that waiting at public transport stops for an interchange between modes has high values of time. An obvious explanation is that waiting often takes place in under uncomfortable conditions. An additional point resulting from the present analysis is that since unreliability has a much bigger effect on waiting times than on in-vehicle times, the pertaining variance is also higher and this is reflected by high values of time related to interchanges.

One might expect that the provision of information on public transport is in principle neutral in terms of its effects on public transport use, because some travellers may find that public transport is better than they thought, while for others the opposite case holds true. However, there are some reasons why one may expect that there will be a systematic positive effect on public transport use. First of all, a substantial part of the population may not use public transport at all, so that provision of information on public transport may imply that this alternative becomes part of the choice set of these travellers. Second, time table information of public transport services will have a systematic downward effect on waiting times and scheduling costs, which makes public transport more attractive. These considerations mainly relate to pre-trip information, but also from on-trip information systematic beneficial effects may be expected because on-trip information on delays has a stress reducing effect. Also the possibility to carry out preventive measures during trips to reduce the perceived costs of being late makes public transport more attractive. The overall conclusion is that several systematic tendencies exist why information provision on public transport will lead to higher public transport use. Obviously there is also a countervailing force, i.e., when information provision on competing activities such as travelling by car improves to the same extent. However, for the first two reasons mentioned above it is difficult to find parallels for car use, so that from this perspective there is probably a systematic beneficial effect for public transport. Turning to the implications for the estimation of the value of time, as spelled out in section 4, the provision of pre-trip and on-route information to travellers tends to reduce values of travel times.

The beneficial effects of traveller information imply that there may be a market for this service. A plausible setting would be that there is general information provided to all travellers for free, and that some travellers have access to dedicated and more specific information for which they have to pay a certain amount of money per message. In road transport such informed drivers are known to yield positive externalities to informed drivers (Emmerink, 1998). In the case of public transport these externalities may again play a role (informed travellers may choose other routes, thus leaving more space for uninformed travellers), but the empirical relevance of this case is probably smaller here than with the private car.

For the uncertainty models discussed here it appears that only under very simple conditions one may derive unambiguous values of time. When marginal values of time are allowed to vary, and when utility functions for generalised costs would no longer be additive, the concept becomes more difficult to apply. Results will also depend on the treatment of uncertainty aspects, such as the use of symmetric versus a-symmetric risk aversion formulas and the assumption that travellers interpret probabilities in an adequate way. Thus, there is substantial scope for further research in this field.

Route planners have become wide spread in public transport in many countries. This has greatly improved the availability of information on travel alternatives among potential travellers. However, the issue of reliability has remained underdeveloped in these route planners. Major steps forward would be made when the information on unreliability in public transport operations would be used to provide travellers with more precise information. It is of course useful for the traveller when he knows that 85% of all trains in the country arrive with a delay of less than 5 minutes. But what he really needs is information such as the probability that the interchange at B for his trip from A to C will run smoothly, or that he will miss the connecting bus or train.

Another item for the research agenda in this area is that uncertainty receives a more prominent place in value of time studies. A more explicit consideration of uncertainty would increase the quality of the estimates and improve their contribution to policy analysis. In particular the present value of time estimates in use in many countries are not useful for the evaluation of strategies to improve reliability. This may lead to a bias towards speed oriented policy measures in stead to reliability enhancing measures.

Further research in this area would not only have to address the reliability costs experienced by the traveller, but also those by suppliers of transport services.

- prevention costs (slack in time tables, reserve of drivers and vehicles in particular places to be able to cope with large incidents/disturbances)
- costs of overwork of personnel due to unreliability
- claims of passengers
- loss of passengers related to incidents (short term response: passengers decide not to travel because of a particular disturbance
- loss of passengers due to structural unreliability (long term response)

This implies that strategies aiming at improving reliability levels have ‘double’ favourable effects. However in order to reduce reliability-related costs, improvement of the functioning of networks is not the only strategy. As we have demonstrated in this paper, the provision of information may be an attractive cost-reducing tool for the traveller. And also for the supplier itself well developed information systems on reliability will help to reduce these costs.

References.

Bates, J., J. Polak, P. Jones and A. Cook (2001) The valuation of reliability for personal travel, *Transportation Research E,* vol. 37, pp. 191-229.

Bell D.E. (1982) Regret in Decision making under uncertainty, *Operations Research* 30, 961-981

Calfee J. en C. Winston (1998) The value of automobile travel time: implications for congestion policy, *Journal of Public Economics*, vol. 69, pp.83-102.

Emmerink R. (1998) *Information and pricing in road transportation*, Springer, Berlin.

Exel J. (2003) A survey of behavioural economics, Erasmus University, Rotterdam.

Exel J. and P. Rietveld (2002) Choice set formation in travel behaviour, Vrije Universiteit, Amsterdam

Jara Diaz S.R. (2001) Allocation and valuation of travel-time savings, in D. Henscher and K. Button (eds), *Handbook of Transport Modelling*, Elsevier, Amsterdam, pp. 303-319.

Gorter C. (1991) *The Dynamics of unemployment and vacancies on Regional Labour Markets,* Tinbergen Institute, Amsterdam

Gunn H.F. (2001) Valuation of travel time savings and losses. in D. Henscher and K. Button (eds), *Handbook of Transport Modelling*, Elsevier, Amsterdam, pp. 433-448.

Janis I.L. and L. Mann (1977) *Decision making – a psychological analysis of conflict, choice and commitment*, The Free Press.

Jong G. de, D. Ettema, H. Gunn (1998) Preparatory research into updating values of travel time in The Netherlands, HCG, The Hague.

Levy H. (1998) *Stochastic dominance: investment and decision making under uncertainty,* Kluwer, Dordrecht

Loomes G. and R. Sugden (1982) Regret Theory: an alternative theory to rational choice under uncertainty, *The Economic Journal* 92: 805-824

Maier G. (1995) *Spatial Search: Structure, Complexity, and Implications*. Physica-Verlag, Heidelberg

Markowitz H.M. (1987) *Mean Variance Analysis in Portfolio Choice*, Basil Blackwell, Oxford.

Ministry of Transport (2001) *Nationaal verkeerkeers en vervoersplan,* The Hague.

Noland R.B. and K.A. Small (1995) Travel time uncertainty, departure time and the cost of the morning commute, Paper presented at 74th Annual meeting of the Transportation Research Board, Washington.

Rietveld P., F. Bruinsma, D. van Vuuren (2001) Coping with unreliability in public transport chains: a case study for Netherlands, *Transportation Research A*, vol. 35, pp.539-559.

Small K.A. (1992) *Urban Transportation Economics*, Harwood Academic Publishers, New York

Waard J. van der (1988) Onderzoek weging tijdelementen, Civiele techniek, TUDelft, Delft

Wardman M. (2001) A review of British evidence on time and service quality valuations, *Transportation Research E,* 37, 107-128.

Figure 1. Valuation of travel time as a function of trip duration

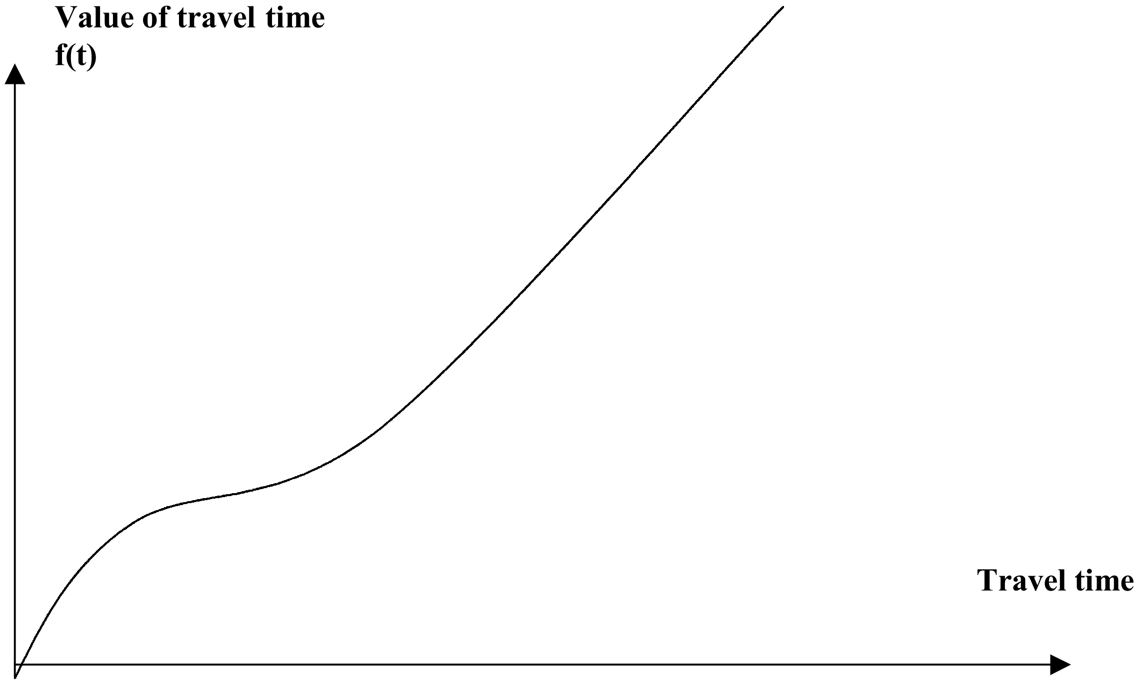


Fig. 2 Valuation of travel time as a function of trip duration under certainty (variance=0) and uncertainty (variance>0).

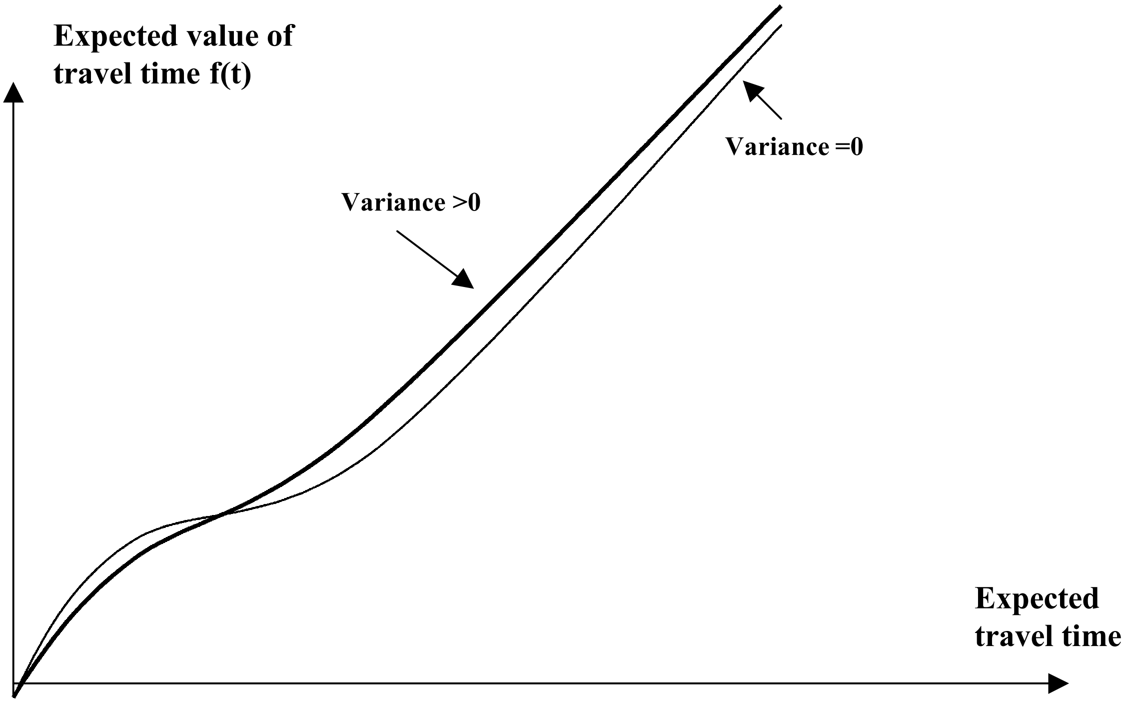
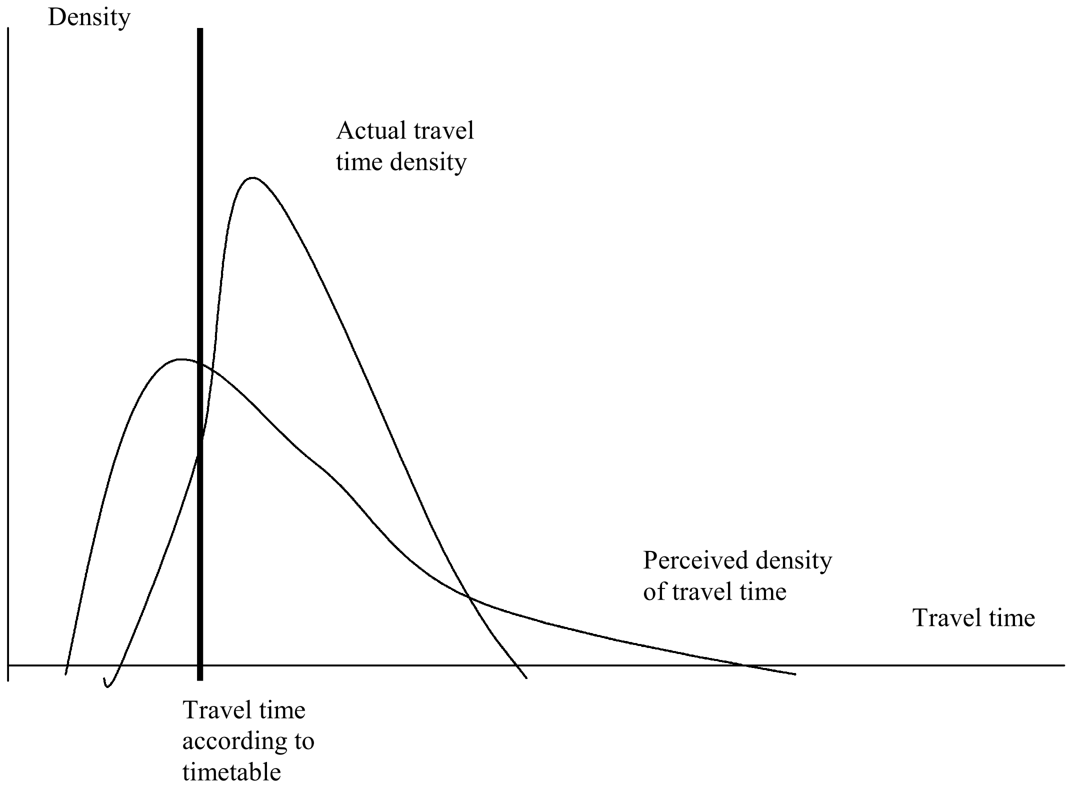


Figure 3. Distribution of travel times in public transport (actual versus perceived)



Endnotes

---

[1] In particular contexts, for example getting a taxi in a deregulated market, the price may be uncertain.

[2] The walking times t_1, t_4 and t_7 may be considered as given. Only in the case of delays people may hurry in order to catch the train, implying that these travel times become smaller. In this case the higher effort to be made implies a higher value of time for these parts of the trip. In the context of uncertainty, information on whether or not there is a chance to catch the next train would certainly have a welfare improving effect.

[3] In the case of certain outcomes where the traveller is handicapped by lack of information, the density may have another form. For example, also t_1 and t_7 may be uncertain in that case.

[4] When unreliability would not affect the average duration of the individual trip components, but only their variances, it would not have any relevance for the choices made and for the marginal value of expected travel time.

[5] This is comparable with the stress and frustration people experience when they have to choose a queue in the supermarket and find that they took the wrong one.

[6] An exception is that many people tend to like games of chance, but in most real world cases they appear to be prepared to pay insurance premiums for rather small risks.

[7] When covariances are not zero, this formulation would also include the terms with $a_j a_k\ r_{jk}\ \sigma_j \sigma_k$. This might have rather unexpected effects in particular cases: a high negative correlation with another travel time component that has a high weight a_k might lead to an outcome that is *lower* than would be the case when uncertainty would not exist.

[8] The share of non-home based trips is estimated to be 20%.

[9] This case is comparable to the ‘transport cost’ method in environmental economics, where time and other resources employed when visiting natural areas can be used to assess the willingness to pay for the natural values involved.

[10] Since actual travel time of an uninformed traveller is systematically higher than travel time according to the timetables, value of time in public transport seems higher than it actually is. The systematic underestimate in travel time would in such studies translate itself into a systematic overestimate in the valuation of this travel time. Depending on the specification of the utility model used, it may also have an effect on the mode specific constant, implying a low attractiveness of public transport compared with other transport modes.

[11] We do not address the issue here that in congested networks information provision may lead to overreaction so that some informed travellers would be better-off when they would ignore the information (cf. Emmerink, 1998). This issue is probably more important in the context of road networks than in public transport networks.