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Uncertain travel times and activity schedules under conditions of space–time constraints and invariant choice heuristics

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Abstract. The aim of this paper is to assess the impact of uncertain travel times as reflected in travel time variability on the outcomes of individuals' activity–travel scheduling decisions, assuming they are faced with fixed space–time constraints and apply the set of decision rules that they have developed over time by learning how to cope with uncertainty in their environment. Features of resulting activity–travel patterns are compared for different travel times. Results of the analyses indicate that uncertain travel times are reflected primarily in changes in the start and end time of activities and the corresponding duration of activities. There is also evidence that some activities are cancelled, suggesting that increased travel times may have made some activity agendas unfeasible.

Keywords: space–time geography, uncertainty, choice heuristics

1 Introduction

Travel choice behaviour under uncertainty has been a topic of growing interest in travel behaviour research. Over the last decade, several theoretical contributions have been made (eg, Arentze and Timmermans, 2004; Chorus et al, 2006a; Sun et al, 2009). In addition, the field has recently witnessed a substantial increase in the number of empirical studies about travel behaviour under uncertainty (eg, Avineri and Prashker, 2005; 2006; Chorus et al, 2006b; Denant-Boèmont and Petiot, 2003; Katsikopoulos et al, 2002).

Three different theoretical frameworks have dominated the field. Early work has been founded on the standard expected utility framework of choice under uncertainty (eg, de Palma and Picard, 2005). On the basis of the popularity of prospect theory (Kahneman and Tversky, 1979; 1992) in other fields, the transportation research community has also explored the usefulness of this approach for travel choice decisions under risk and uncertainty. The adequacy of (cumulative) prospect theory to predict traveller behaviour under uncertainty, mostly in the context of preferred arrival times and route choice decisions, has been explored. For example, Jou and Kitamura (2002) assumed two reference points: earliest acceptable arrival time and official work start time. Later, Senbil and Kitamura (2004) added preferred arrival time. Senbil and Kitamura (2006) incorporated delayed or early arrival travel time variability directly in the utility function. Schwanen and Ettema (2007) adopted a similar framework related to picking up children from the day care facility. Likewise, Avineri and Prashker (2003; 2005; 2006) applied prospect theory to route choice decisions. Han et al (2005) applied notions of prospect theory in a typical framing context. They assumed that travellers compliance rates with travel information do not depend only on the (in)congruence between the information provided and subjective beliefs, but also on whether the information was provided in a positive or negative way.

Elaborating the seminal work of Bell (1982), Fishburn (1982), and Loomes and Sugden (1982), Chorus et al (2008; 2009) formulated a model based on the concept of regret.

This concept is based on the notion that instead of evaluating the utility of each alternative for each state of the world individuals anticipate the possible regret experienced if the chosen alternative performs worse than those not chosen.

Existing theories and models of travel decisions under uncertainty seem to have at least two limitations. First, all these theories assume, implicitly or explicitly, that individuals *ex ante* adjust their departure time and route choice, based on one of these mechanisms, to uncertain travel times. However, if the uncertainty stems from an instantaneous source en route it is difficult to imagine how individuals can anticipate it and make adjustment. Hence, it seems that the adaptation process that has been modelled in these approaches can only happen slowly as individuals experience travel-time variability over time and at some moment in time decide to change their departure time and route choice behaviour. This notion is supported by the results of some learning experiments (eg, Han and Timmermans, 2006). However, there is also abundant evidence of inertia and habitual behaviour. Individuals tend to cope with the uncertainty in their environment through learning. Particular strategies (travel decisions) may be reinforced by positive outcomes or discontinued by strongly negative outcomes. Through learning, individuals tend to develop scripts: context-dependent choice rules that they tend to apply until the environment triggers them to reconsider their current scripts and possibly develop new decision rules or adapt current ones. In that case, uncertain travel times, especially unanticipated, may imply that travellers arrive late and experience that their activity agenda was not feasible after all.

This line of reasoning is more in line with the time-geography approach, where it is argued that space–time constraints act on the feasibility of planned activity–travel (activity-based travel) schedules. Let S be an activity–travel schedule. Assuming that the end time of activity i conducted at location j is $\hat{e}_i$ and the latest start of the next activity $i+1$ conducted at located $j+1$ is $\hat{s}_{i+1}$, then the set of locations $\{K\}$ that can be reached between $\hat{e}_i$ and $\hat{s}_{i+1}$ is defined by the following relationship:

$$t_{k \in \{K\}} = \frac{d_{j,k} + d_{k,j+1}}{v} \leq \hat{s}_{i+1} - \hat{e}_i, \quad (1)$$

where t_k is the travel time required to travel from j to $j+1$ via k ; $d_{j,k}$ is the distance between activity locations j and k , $d_{k,j+1}$ is the distance between k and the activity location $j+1$, and v is the travel speed (which is assumed constant here). Let h_j denote the closing hour of facilities at location j associated with activity i . Then, an activity–travel schedule S is feasible if and only if

$$t_{k \in \{K\}} = \frac{d_{j,k} + d_{k,j+1}}{v} \leq \min(\hat{s}_{i+1}, h_{j+1}) - \hat{e}_i. \quad (2)$$

It is evident that this case of no adaptation whatsoever is an extreme case. Alternatively, individuals may change those facets of their activity–travel patterns which they can still change, such as reducing the duration of activities, changing destination, or cancelling or substituting an activity. In this case, they would apply their current decision heuristics if the travel times experienced are longer (or shorter) than expected.

Therefore, in this paper we set out to explore the intensity of such marginal changes in the implementation of activity–travel agendas due to variability (uncertainty) in travel times, assuming that travellers (in the short run) do not change their decision heuristics.

2 Approach

We start with the basic assumption that a valid model of activity–travel behaviour mimics the decision-making process underlying observed activity–travel patterns. Arguably, not all models qualify, but we contend that computational process models of activity–travel

demand do. Computational process models assume a sequential decision-making process. Observed data about activity–travel patterns are only partially used in the sense that single facets are estimated or induced sequentially, rather than some mathematical specification being estimated simultaneously from the overall multifaceted activity–travel patterns.

The current study is based on the Albatross model system (Arentze and Timmermans, 2004). Albatross is a rule-based model system, based on chi-square-based induction of decision trees that involves a priority-based scheduling of activities that appear on a daily agenda. The various rules making up the decision trees specify the context conditions (including all previous decisions in the assumed sequence) and personal profiles that together activate context-dependent, probabilistic decision rules, pertaining to a single-choice facet. The decision rules represent a set of context-dependent choice heuristics, which are time invariant and in that sense portray behavioural scripts.

In the current implementation of the Albatross model system all input conditions, including travel times, are deterministic. The model does not include any uncertainty in the input variables. Compared with many other activity-based models of travel demand, however, it does incorporate several kinds of constraints and predicts only activity–travel patterns that satisfy the various constraints. In the context of the present study, the space–time constraints, defined by equations (1) and (2), are particularly relevant. On the basis of these spatiotemporal constraints, the system defines dynamic choice sets. Only those actions that are part of these choice sets, and thus satisfy the constraints, are activated probabilistically. That is,

$$p_{kq} = \begin{cases} 0, & \text{if } q \text{ is unfeasible,} \\ f_{qk} / \sum_{q'} f_{kq'}, & \text{otherwise.} \end{cases} \quad (3)$$

Thus, when examining the impact of uncertainty or variability in travel on the feasibility of activity–travel patterns, we cannot identify directly any infeasible patterns as Albatross, by definition, will only predict or simulate feasible patterns meeting the constraints. However, we can obtain indirect evidence of the impact of uncertain travel times by systematically comparing differences between predicted activity–travel patterns under different inputs of uncertain travel times. At the same time, we obtain information about marginal changes to the various facets of activity agendas.

Distance and travel time in Albatross are derived from the Basisnetwork, an official national database used for all transportation models. Each record in this file describes a network link in terms of start and end nodes, average speed by car, length, and type. The average speed was assigned to each network link according to expert judgment. Travel-time matrices are generated from these link-specific speeds. The uncertainty in speed can be captured by random drawing from the standard deviations of the speed distribution. Different draws will then result in different input variables and differences, if any, in the various facets of the overall activity–travel patterns can then be analysed. In principle, different approaches can be used to obtain the probability distributions of the uncertainty in speed and consequently in travel time. In the present study, expert elicitation was used. More specifically, after discussion with experts, some important arterials in terms of connection between different parts of the city to the centre were selected. On the basis of experts' judgment and some measurements, a coefficient of variation equal to 0.10 and 0.20 were considered for highways and roadways, respectively. Using these values, the standard deviation for each link is calculated and a normal distribution is derived according to the average speed and standard deviation for each link. Multiple draws from the distribution result in multiple speeds which serve as different input values for Albatross and results in different travel-time matrices.

From the notion that individuals tend to minimize their mental effort in adjusting their activity–travel patterns to changing conditions, one might expect that a longer travel-time

experience, under constraints, will most likely lead to shorter durations of activities. However, at some stage, the available time window for conducting an activity may become too small, implying that either the same activity of longer duration will be conducted elsewhere so as to save travel time, or that the activity may be cancelled and substituted by another activity that may need less time to complete. The latter may also involve a different destination. In principle, individuals may also consider a change in their choice of transport mode, or in the timing of the activity, but one would expect such changes to occur infrequently. In case of shorter travel times, individuals may increase the duration of one or more activities or additional activities may be inserted in their agenda.

On the basis of these principles and considerations, this study was designed as follows. First, a synthetic population was created for the study area, which was the City of Rotterdam in The Netherlands. This synthetic population was created using iteratively proportional fitting to make the summed statistics across the population of Rotterdam consistent with official statistics related to the marginal aggregate distributions of selected sociodemographic variables and with the correlation structures observed in the National Travel Survey.

Second, the activity–travel patterns of 10% of the synthetic population of Rotterdam were simulated. Third, variability in travel times for a selected set of links in the transportation network was simulated by drawing from an uncertain speed distribution, partly derived from expert elicitation and partly from empirical measurements. Next, the resulting variability in travel times was entered into the Albatross model system to generate activity–travel patterns, assuming that the choice heuristics underlying the model system hold in the short run. Seed points for the various simulations were kept constant to ensure that differences in results are not due to the stochastic error of the model itself. Finally, these predicted activity–travel patterns were compared with the baseline predictions to obtain indirect evidence of the effects of uncertain travel times on the feasibility of activity–travel patterns. More specifically, the activity–travel patterns for the same individual were compared and changes in the patterns in terms of activity participation, duration, start and end times, destination, and transport mode choice were identified.

Figure 1 portrays the corridor of the transportation network that was used for the analysis. It shows that variability in travel times was studied for a major part of the transportation network at the northern and eastern edge of the downtown area. It is the major corridor for both the north–south and the east–west connections. It consists of six links, each consisting of around ten sublinks with different speeds.

3 Analyses and results

As indicated in table 1, travel times in the selected corridor fluctuate between simulation runs around a mean value that was used to calibrate the original Albatross model system. For some runs, the travel time on particular links of the network is higher than this average, while for some other runs it is lower. This means that the simulated outcomes of the model system that mimics the individual activity-scheduling process will differ between runs. In line with the more general literature, we analyzed these simulated activity–travel patterns in terms of variation in their various facets, activity participation, timing, duration, and transport mode at the aggregate level for a selected set of activities, work, bringing or getting (bring/get), social, and leisure. This set of activity types was selected because it nicely spans the spectrum of mandatory and flexible activities. It should be noted that additional analyses could be conducted based on different temporal and spatial resolutions (eg, trajectories, origin–destination matrices, traffic volumes, route choice, number of visits to different destinations) and that further details would be possible by breaking down results by sociodemographic groups and some spatial classification. However, due to the limited space available, here we

Figure 1. [In colour online.] The selected corridor.

Table 1. Speed variability in selected links.

Link identity	Average speed (km per hour)	Standard deviation
A16	80–100	8–10
A20	90–100	9–10
Gravendijkwal	20–40	4–8
Statenweg	15–40	3–8
Schieweg	15–30	3–6
Schiekade	20–30	4–6

focus on some aggregate results. However, the reported results are exemplary of the general findings.

3.1 Activity participation

Figure 2 presents the results of differentiation in activity participation due to travel-time variability. It shows that the variation in activity participation for the total number of activities, described in terms of the coefficient of variation, is considerable, ranging between 0.6% for individuals who tend to stay at home and 6% for people with seven activities in their schedule. The coefficient of variation is even higher for a larger number of activities, due to the very low number of cases.

Figure 2. Effects of uncertain travel times on activity participation (error bars: ± 5 standard deviations).

3.2 Timing

Variation in start and end times for the various simulation runs is shown in figure 3. The vertical axis expresses the number of average elapsed minutes since midnight. It shows that variation in start and end times of activities is relatively large, from 3 minutes for work which has the least variation to 14 minutes for bring/get which is the most variable activity associated with both start and end times. Variation is smaller for the work activities and slightly higher for the social and leisure activities. It is probably highest for bring/get activities, because these are the most flexible.

Figure 3. [In colour online.] Effects of uncertain travel times on start and end times of activities.

3.3 Duration

Table 2 shows the results for duration. On average, in absolute terms, the duration of the work episode is the most affected, followed, respectively, by social activities, leisure activities, and bring/get activities. However, comparing the duration in absolute terms might not be a robust comparison due to the large differences between the duration of different activities. However, in a relative sense indicated by the coefficient of variation, which expresses the standard deviation relative to the mean, work is the least affected, followed by social activities, leisure activities, and bring/get activities. This suggests that the effects of uncertainty or variability in travel times on the duration of activities are less for mandatory activities.

Table 2. Variation in duration of different activity types.

Time	Work	Bring/get	Social	Leisure
Average	430.5	9.8	126.7	102.2
Maximum	433.7	10.0	128.8	103.7
Minimum	427.1	9.6	125.7	100.8
Coefficient of variation	0.005	0.013	0.007	0.008

3.4 Transport modes

Table 3 reports the results for the transport mode facets. It demonstrates that the coefficient of variation is highest for public transport and lowest for car drivers and slow modes. Because transport mode choice decisions are made at the level of a tour, these differences reflect the differential sensitivity of transport modes to travel-time fluctuations.

Table 3. Variation in transport mode.

Mode-choice proportions	Car driver	Slow mode	Public transport	Car passenger
Average	0.385	0.433	0.070	0.111
Standard deviation	0.002	0.003	0.001	0.001
Coefficient of variation	0.006	0.006	0.014	0.009

Figure 4. Variation in travel times for different activity types.

3.5 Travel time

Figure 4 presents the results for average travel time for the whole synthesized population and some activities. The figure shows that, as expected, average travel time varies the least. For the different types of activities, travel time related to work activities fluctuates the least, and for bring/get activities travel time varies the most. It also demonstrates that social and leisure activities have more or less the same degree of fluctuation. The similar travel times and duration may suggest that individuals tend to adjust for any change in travel time immediately by adjusting the duration of the corresponding activity.

4 Conclusions and discussion

In this paper we have documented the design and results of a study to examine the impacts of replacing certain travel times with uncertain travel times on simulated activity–travel patterns using the Albatross model system. This model captures context-dependent choice heuristics of individuals and mimics the process of activity agenda formation and activity scheduling. Therefore, using travel-time fluctuation, as contextual information for the activity-scheduling process allows one to examine the effects of travel-time uncertainty on the outcomes of the scheduling process. This topic of uncertainty has rarely been addressed in studies of space–time prisms.

Results indicate that, at least in this study conducted in Rotterdam, the effect of variability in travel time on some links affects mostly the start and end times of activities in an absolute term, and activity participation in a relative sense (CV). Thus, results suggest that individuals tend to adjust the start and end times of activities and also the number of activity episodes they are involved in to cope with variable travel times. Moreover, results tend to indicate that the degree of variation tends to differ between mandatory and flexible activities.

Although these findings are interesting, some limitations of this study should be kept in mind. Firstly, it should be realised that the findings relate to the selected study area at large. Uncertainty in travel times was only implemented for a certain corridor in the study area and consequently not all individuals face this uncertainty in scheduling their activity–travel agendas. Thus, different scenarios would thus result in different findings. It means that the findings of this study should be assessed primarily in a qualitative sense. Secondly, the behavioural mechanisms depicted by the Albatross model were kept constant, assuming that in the short run people do not adapt to uncertain travel times. In the case of continued uncertainty it is more likely, however, that travellers will adapt their departure times and possibly other facets of their activity–travel schedules to cope with uncertainty in the transportation and urban system.

These limitations also point to interesting options for future work. Firstly, because the uncertain travel times pertain to a particular corridor of the transportation system, individuals living in different parts of the study area will be affected differently. Thus, future research should examine such spatial variability. Secondly, in this paper we have only discussed the averaged aggregate effects from the perspective of the system at large. It would be interesting to examine variation at the individual level as well. Thirdly, individuals of different socio-economic segments may be affected differently as they vary in terms of their choice options. Overall effects may be small but some segments may be more sensitive to travel-time uncertainty than others. Such further analysis is also relevant in the context of the discussion on social exclusion. Finally, future research should develop models of decision making under uncertainty for activity–travel scheduling decisions. We intend to report on such extensions in future publications.

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