A Simulation Model Assessing Impacts of Advanced Information and Communication Technologies on Activity-Travel Patterns

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Abstract

Due to recent developments in advanced information and communication technologies (ICT) and increasing application of these technologies in daily life, there is a clear need to investigate the impacts of these technologies on the transport and urban environment. This paper takes into consideration personalized travel information (recommendations), which can be provided by the next generation of ICT. A model to evaluate the impacts of such information on behavioral dynamics of activity-travel patterns is described. The model is built around a proposed framework, which represents individuals' behavior and decision making process under provision of information. The model mostly focuses on route-choice and destination choice on a daily basis. It considers changing route and destination as the main changes to a daily activity-travel schedule under information provision. The information provider supplies real time information about route conditions and destinations, and gives recommendations to the individuals.

Keywords: activity-travel pattern, scheduling, ICT, route choice, destination choice.

1. Introduction

 Provision of travel information and its impact on activity-travel patterns is receiving more attention among researchers and policy makers due to current developments in advanced information and communication technologies (ICT) and a rapidly increasing application of these technologies. This increasing interest partly comes from the expectation that providing travel information can decrease uncertainty about the state of the network. In addition, it can enhance sustainable accessibility and optimize current infrastructure usage.

 During the past decades, travel information was mostly static, public and descriptive, e.g. information about congestion on a particular route would be given to the drivers via radio. Increasing availability of more advanced information services, such as web-services, navigation systems, and smart phones, emphasizes the possibility of providing personalized and prescriptive information or recommendations anytime and anywhere to the individuals using real-time travel information. Providing such information to travelers is considered to be a potential strategy for influencing individual behavior related to route, mode, departure time, destination choice or even entire trip patterns.

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Consequently this kind of travel information may impact behavioral dynamics behind activity-travel pattern (re)scheduling.

Though many literatures have investigated the impact of information on facets of activity-travel patterns, few studies looked at personalized and dynamic descriptive or prescriptive information. Most of the studies either discussed travel choices given static, public and descriptive information (e.g. Emmerink, et al. 1995; Yim and Khattak, 2002; Arentze and Timmermans, 2004; Chen and Mahmassani, 2004; Chorus, 2007; Sun, 2009) or described the process of information acquisition (e.g., Polak and Jones, 1993; Polydoropoulou and Ben Akiva, 1998; Hato, et al., 1999; Kenyon and Lyons, 2003). Basically, theories and models of travelers’ response were not considered as a noticeable issue and the focus was mostly on willingness to pay. Hence, when it comes to advanced ICT tools, all these studies are somehow limited. It is still not clear how individuals respond to advanced travel information; how they cope with the uncertainty; how they assess the credibility of information; and how they consider these issues in the activity-travel (re)scheduling decisions. The present study investigates these issues in more detail through theoretical analyses, elaborating earlier work by Arentze and Timmermans (2004b), Arentze et al (2004), Han and Timmermans (2006) and Han et al. (2008), and Sun, et al. (2009).

Han et al. (2008) developed a model based on expected utility theory to predict and explain behavior in strategic situations where individuals’ optimal decisions depend on what other individuals are expected to do. They suggested that the utility of a choice alternative depends on the attributes of the choice alternatives (Exogenous Utility), the attractiveness of a choice alternative as a function of the behavior of other individuals (Endogenous Utility), and the heterogeneity in preferences. They also considered the provision of information and uncertainty of individuals about other individuals’ decision in the proposed model. However, the main focus of their work was on Endogenous Utility and the interaction between individuals. Although they identified the importance of heterogeneity in the model, they did not actually consider it in the experiments.

In contrast, Sun et al. (2009) focused on Exogenous Utility and developed a model to study the dynamic impact of advanced information systems on daily activity-travel scheduling and rescheduling decisions. Their model is also based on expected utility theory. They considered different risk taking/avoiding behavior of different individuals to information and also heterogeneity in activity-travel decisions using decision tree structures. The model proposed general utility functions for an individual choosing a choice alternative, concerning the uncertainty of the outcomes. These general utility functions allow the individual to evaluate the expected utility at each node in a given tree in uncertain situations.

The purpose of this study is to propose a model to examine the impacts of advanced ICT on dynamic activity-travel patterns. The model framework is based on expected utility theory and Bayesian principles of belief updating. The model intends to evaluate individuals’ responses to information provision considering different types of received information and who is receiving the information.

The remainder of the paper is structured as follows. First, section 2 briefly describes possible situations that may arise, considering information type and individuals’ responses to it. Then, section 3 describes the conceptual and modeling framework. Finally, section 4 summarizes major conclusions and discusses future works.

2. Travel information

Travel Information can be provided to individuals both pre-trip and en-route. It can be either public, received from a public information service provider like a radio station, or personal, received from a more advanced information service provider via for example a navigation device with capabilities of considering individual’s preferences. It can also be either descriptive (e.g. indication of travel time of a route), or prescriptive (a recommendation). Depending on the type of the information, individuals may respond to the information differently and they may change or not change their activity-travel schedule. In addition, even when there is no information individuals may change their activity-travel schedule considering the real-time situation of the network (environment). Therefore, individuals’ responses to the travel information can be investigated in terms of two main categories; in terms of the existence of information, and in terms of the type of information.
2.1. Presence of information

In case that there is no information, if the real situation is just as the one that the individual expected (e.g. there is no delay in the activity-travel schedule), the individual will continue his/her schedule. Otherwise, when the real situation is different than what the individual expects (e.g. an unexpected delay), the individual may choose to change his/her activity-travel schedule by adapting the departure time, re-sequencing activities, canceling an activity, changing a route, changing the duration of an activity, or maybe even ignore the differences and follow the initial schedule.

In case of travel information two states may occur. First, the real situation is as the one that the individual expected. In this situation, there is no need to adapt the planned activity-travel schedule. Second, there may be a substantial difference between the beliefs about the state of the system and the actual situation, reflected in the provided information. In that case, the individual needs to reconsider his/her schedule. It seems logical to assume that the decision whether or not to reschedule depends on his beliefs about the credibility of the information and whether the difference is big enough to warrant rescheduling.

2.2. Type of Information

As the travel information can either be public or personal, and descriptive or prescriptive, four different states can be identified. When the information is descriptive and public, individuals know that other travelers will have received the same information. Consequently, they may take into account their beliefs about how many other travelers who have received the same information will change their activity-travel schedules. Based on this, they may act strategically and choose the option that maximizes their expected utility, taking into account the effect of possibly strategic behavior of other travelers on their expected utility.

The situation in which the information is descriptive and personal is more complex in that an individual can only contemplate what kind of information other travelers have received. One may expect that because of the fact that the information is personal, individuals act less strategically and primarily consider the consequences of the provided personal information on their planned activity-travel schedule.

The difference between descriptive and prescriptive information in general is that in the latter case, individuals have to translate the recommendation into their mental representation of the activity-travel scheduling decision and assess the expected utility of alternative activity-travel schedules, at least comparing the planned schedule against the recommended schedule. Usually, the recommendation will not involve all facets of the complete activity-travel schedule and therefore an individual will have to consider a set of alternative schedules, including the recommendation. When the information is prescriptive and public, the individual will also need to take into account his/her beliefs about the percentage of other travelers complying with the recommendation and how this will impact his/her beliefs about the states of the system. Depending on the question whether this processing will lead to a different preference of alternative schedules, the individual may follow the information or ignore it.

When the information is prescriptive and personal, other individuals may have less influence on the individual behavior regarding information provision. The individual will choose the alternative that brings the maximum utility without considering his/her beliefs about the compliance of other travelers to the recommendation provided. In this case, the individual may either follow the information or ignore it, primarily considering the utility effects of the recommendation, compared to the expected utility of the planned activity-travel schedule.

Thus, we assume that when travel information is given to a group, strategic choice behavior may play an important role in decision making process. In contrast, when it is given to just one person, beliefs, preferences and past experiences of that person may be more important.

In addition, there is a difference in decision making process when the information is descriptive or prescriptive. Descriptive information gives more and updated information about the state of the network, e.g. real travel time of a particular route. As a result, the individual will process the received information, and then update his/her beliefs about the network state. In other words, information directly impacts the individual’s beliefs which may lead to changing his/her activity-travel schedule.
However, prescriptive information does not give quantitative information and may introduce new choice alternatives to the individual. As a result, the individual will evaluate the choice alternatives and compare them with known ones, and then choose among the choice alternatives.

3. Conceptual and Modeling framework

3.1. Conceptual framework

Examining effects of advanced ICT on dynamic activity-travel patterns and modeling any shifts in the timing and location of activities and travel in response to travel information provision are the key challenges of the present study. We propose the general framework depicted in Figure 1 to show the process of building activity-travel pattern during a certain time horizon. The framework assumes that each individual has a daily agenda including activities with various attributes, such as priority, location, duration, start and end time, etc. The travel as a connection between locations of activities also has different attributes (route, mode, departure and arrival time, etc.). An individual would develop a sequence of activities and trips, which should satisfy space-time, institutional and household constraints and personal preferences. In other words, an individual is assumed to develop a mental activity-travel schedule before starting a day. Individuals are assumed to attach some utility to the various facets of the complete activity-travel pattern and choose the schedule which maximizes this utility. In this schedule, the origin and destination of each trip are identified. In this context, the individual will choose a route considering the transportation network and his/her preferences for each trip.

Reality is however more complex because the state of the transportation and urban system are inherently uncertain. Travel times may vary, even within the same context, and the same applies to many other aspects of the travel and urban environment that may impact activity-travel decisions. In this situation of uncertainty, individuals build up their beliefs about the state of the system (subjective probability of the possible states) based on experience, information exchange in their social network and travel information. It involves updating the credibility of the source as the received information may be at variance with actual experiences. It also means that decisions under uncertainty will be based on expected utilities and risk attitudes. In any case, if the individual receives travel information his/her activity-travel schedule may change as information may change the subjective probabilities. Changes in each individual’s activity-travel pattern in turn may change the state of the network in general. Therefore, the relationships between traffic state, route choice, and activity-travel schedule are directed ones, and they can affect each other backwardly.

Figure 1. General framework for activity-travel behavior.

To elaborate this general framework, we build upon models proposed by Sun et al. (2009) and Han et al. (2007). We suggest that a comprehensive model should combine the characteristics of these two models and consider compliance. Our intention is to develop such a model. Since both these models have used expected utility as their basic underlying theory, we will use this theory to integrate these two models. The concept of expected utility is important since it captures the uncertainty about the state of the environment. Moreover, we propose to use a decision tree structure similar to Sun’s (2009) approach to represent decision making process as it tends to be more flexible than the game theory specification used in Han et al. (2007). This approach gives us the ability to consider uncertainty of choice alternatives at each decision point (node in the road network, completion of an activity). The
following assumptions are made: Individuals are the decision-makers; they have different beliefs and preferences about choice alternatives (heterogeneity); and travel is an uncertain phenomenon.

3.2. Basic concept

Assume that the environment is represented as a network in which nodes are a representation of either activity locations that are described by one or more attributes and/or intersections of the transportation network, and directed links are a representation of transportation links. In this network, individuals are represented as agents and we assume that they can (re)schedule their activities at each node. Since individuals make their decision at nodes we will use the term decision point instead of node in the following. When an individual is conducting an activity at a decision point or traveling between two decision points, he/she may make observations or receive information that can change his/her beliefs about particular aspects of the network. As a result, he/she may reschedule his/her activity-travel at each decision point according to updated beliefs.

Considering the stochastic and non-stationary states of the environment, individuals need to make activity-travel scheduling decisions being uncertain about the outcome. Following Arentze and Timmermans (2004b), Arentze et al. (2004), we assume that individuals use mental scenarios to choose a schedule. That is, individuals define a scenario for each possible (uncertain) outcome using previous knowledge and given information. In each scenario a probability represents an individual’s belief of level of certainty that a particular outcome will be experienced. We use the symbols \( Y \) to refer to the (uncertain) event, \( y_i \) to refer to a possible outcome and \( P^t(y_j) \) to denote the individual’s belief in \( Y = y_i \) at decision moment \( t \).

It is assumed that before the first decision moment (point), i.e. beginning of the day/tour, the individual has an initial schedule. At each decision point the model assumes that an individual generates a (optimal) schedule, for each possible scenario. For each scenario the individual would define an optimal schedule which will give the best result considering his/her beliefs. To refer to the schedule that is optimally adapted to outcome \( y_i \), the symbol \( S_i^t \) is used. Arentze et al. argue that at the decision moment uncertainty about the true outcome still exists, therefore individual has also to take into account all other possible outcomes to evaluate the current schedule. Consequently, for each optimal schedule, another set of schedules (sub variants) referring to the state that the true outcome is other than \( y_i \) should be generated. The symbol \( S_i^t \mid y_j \) is used to refer to the sub variant that is first optimized for outcome \( y_j \).

If one would assume that individuals maximize their utility, the expected utility of the best choice at decision moment \( t \) is defined as:

\[
EU^t = \max_i \{ \sum_j U \left( S_i^t \mid y_j \right) P^t \left( y_j \right) \} 
\tag{1}
\]

where \( U(\bullet) \) represents the schedule utility, and \( P^t(y_j) \) represents the perceived probability of outcome \( y_j \).

In the presence of travel information, the model assumes that the individual holds beliefs about the credibility of given information, reflecting an individual’s beliefs of how likely the received information represents the real state. The individual’s perception of information credibility regarding event \( Y \) is represented by a conditional probability. Consider the example where an event relates to the travel time of a route, and received information is about the travel time of the same route. Therefore, an individual’s beliefs of a route’s travel time \( T \) can be represented as \( P^t(T \mid T) \), where \( T = \{ t_1, t_2, \ldots, t_n \} \) are the possible travel times of that particular route and \( T = \{ t_1, t_2, \ldots, t_n \} \) are the received travel times of the same route given by information service provider. The expected utility after receiving information \( t_i \) then is defined as:

\[
EU_i^t = \max_i \{ \sum_j U \left( S_i^t \mid t_j \right) P^t \left( t_j \mid t_i \right) \} 
\tag{2}
\]

where \( P^t \left( t_j \mid t_i \right) \) is derived from \( P^t \left( t_i \mid t_j \right) \) by backward reasoning using Bayes theorem.

Full credibility exists when \( P^t \left( t_i \mid t_j \right) = 0 \), if \( j \neq k \) and \( P^t \left( t_i \mid t_j \right) = 1 \), if \( j = k \) which means that the received information is completely identical to the real travel time. Zero credibility exists when \( P^t \left( t_i \mid t_j \right) = \frac{1}{n}, \forall k, j \), which means that received travel time is completely random and is not related to the real travel time.
3.3. Updating of beliefs

As it has been mentioned before, the individual has beliefs about the outcome of an event, which in present study are individual’s beliefs of travel time of a route. These beliefs about the outcomes of an event are not constant. Consequently, the probabilities, $P(\bullet)$, representing these beliefs are not constant either. Each time an individual receives information about an event or experiences a new situation his/her beliefs about outcomes of the event may change. That is to say, individuals learn when they travel certain routes. We propose to use Bayesian Belief Network (BBN) to represent the relationship between individual cognitive learning processes and travel information. That is to say, we use BBN principles to update the conditional probability representing individual’s beliefs of travel time under the provision of travel information.

In a BBN, variables are represented as nodes and dependency relationships between them as links. In this case, a link runs from $X$ to $Y$ indicating that $Y$ is dependent on $X$. Node $X$ is called a parent node of $Y$. Considering that travel information can either be in the form of a recommendation or the value of travel time the impact of travel information on individual’s perception of real travel time can be depicted as shown in figure 2. This framework represents the belief updating process in the provision of the travel information in the situation that the individual does not consider other individuals’ choice behavior.

![Figure 2. Belief updating process.](image)

In this framework, $R$ represents recommendation, $T$ represents the travel time, and $RT$ represents the received value of travel time by the information source. As the framework shows, $R$ and $RT$ depend on $T$. In addition, $R$ also depends on the objective that is behind the recommendation and comes from policy makers decisions. In other words, each recommendation that is given to the individual may have an objective following for example equilibrium for the whole transportation network and therefore may or may not be consistent with an individual’s preferences.

A similar framework can be used in the case that the individual thinks strategically and considers other individuals’ decisions in the updating process which is depicted in figure 3.

![Figure 3. Belief updating process considering strategic choice behaviour.](image)
Figure 3 represents the travel updating belief process in the provision of information. In this framework $T_r^t$ represents the travel time of route $r$ at the moment $t$, $T_{r+1}^{t+1}$ represents the travel time of route $r$ at $t+1$ after all individuals have responded to travel information considering their strategic behavior, $R_T$ is the received travel time of route $r$, Others resp. represents other individuals’ behavior after receiving the information and type represents the information type which can be either personal or public.

3.4. Decision making process

The process described in the previous section can be accommodated in a decision tree (alternatively, a Bayesian decision network can be used). Figure 4 is a simple example, showing two possible schedules and three possible outcomes for each schedule. Extension to more schedules and a larger number of nodes is however straightforward. Core of the representation is the concept of the utility of a schedule, conditional on the outcome of events, plus the subjective probability or beliefs that that certain outcome will happen. The latter can be extended by viewing these beliefs as a function of inherent variability in the states of the event, information provision, the credibility of the information and the accumulated effects of the strategic or non-strategic behavior of other travelers in reaction to information provision. If the information provided concerns a recommendation, individuals need to process this recommendation in terms of schedules considered and in terms of the outcomes of events. Finally, these various components need to be integrated to arrive at a final choice. If an individual maximizes expected utility, the utility of a schedule, conditional on an outcome or set of outcomes will be weighted by corresponding beliefs depicting risk. Alternatively, one can assume different risk attitudes, leading to different integration processes.

4. Conclusion

The next generation of information and communication technologies may lead to new opportunities for transport demand management. Expected ubiquitous environments may lead to the situation that accurate, dynamic, real time information about the state of particular aspects of the transport and urban environment, such as travel times on routes, can be provided and/or accessed. In addition, services can be developed which give individual travelers personal advice, considering the state of the transportation and personal plans and general preferences.

The modeling of the impact of such new technology on aggregate route and destination and possibly other facets of activity-travel patterns faces new challenges as it has to take into account in an integrated and consistent manner, the utility individual derive from alternative schedules, considering various sources of uncertainty, the credibility of the information, and anticipated reactions of other travelers, strategic and/or non-strategic, that accumulated and contribute to the uncertainty in the system. Models taking all these facets into account do to the best of our knowledge not yet exist.

Given the limited number of pages available for this paper, we have focused on three topics. First, we have described different situations of information provision, differentiating between public vs. private and descriptive vs. prescriptive to derive the scope of any relevant model and argue the central mechanisms such a model should
contain. Second, we have discussed the key concepts and formalism that seem valuable, provided the key equations that can be used to describe how individual choose between alternative activity-travel schedules under conditions on uncertainty that can be attributed to various sources. Third, we have argued why a Bayesian belief network representation allow reasoning about the direct and indirect effects between type of information, credibility, behavior of others and beliefs and how it can be used as an encompassing framework for integrating these different concepts and mechanisms that to date have been addressed using very different modeling frameworks. Unfortunately, page limitations did not allow us to spell out all detailed model equations not to add details about data collection and estimation. Such issues will be addressed in future papers and publications.

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