Modelling daily activity schedules with fuzzy logic

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Abstract

During the last decades, we have witnessed an increasing refinement of behavioural models in transport research, especially due to the need of a better understanding of the mechanisms underlying the travel behaviour.

Even if the relationships between travel demand and human activities are well documented in the literature and it is unanimously recognized that the travel has to be analysed in an integrated set of decisions regarding the other human activities, the models are not fully developed, especially due to the complexity of the phenomena.

This paper focuses on the activities timetable, and the changes involved by the trip time variability on the daily activities. A delay in a trip or an early arrival can contribute to changes in the timing, location of the next activities, to the deletion/addition of some activities. The changes are related to the dimension of the time savings/delays, to the nature and location of the linked activities, and to the personal and household characteristics.

The model presented in the paper uses fuzzy logic rules for "explaining" the effect of variability in travel time on the benefits perceived by an individual with the changes, and to model different actions that the individuals take in order to re-establish the steadiness of the timetable (routine of the family activities). The model uses as inputs different statistic socio-demographic data obtained from a data set of academics and students in Bucharest, in 1998.

Keywords

activity analysis, scheduling, fuzzy logic, International Conference on Travel Behaviour Research, IATBR

1. Background

Studies of travel behaviour responses to uncertainties have focused on the choice of alternatives for the trip in which the uncertainty is faced. Recent stated preference studies have included trip time variability as a key attribute of the trip profile presented to respondents (Noland et al. 1998, O'Fallon et al. 2002). These studies measure behavioural responses like choosing an alternative route, mode, location, and changing the time of day. Such answers do not fully address the types of alternatives available to the individuals, should they experience an unexpected travel savings or delay.

Once the individuals have made a route, mode location and time of day choice, their response to an unexpected travel time is not limited to an alternative travel choice for that trip. In many instances they must endure the unexpected circumstance of the trip and alter subsequent plans in their day's activity schedule. Bates et al. (1987) found that the most likely response to an unexpected change in trip duration is acceptance (cited in Stern et al. 1998: 178). Acceptance is compensated with changes to the duration and the location for subsequent activities.

What are the responses of individuals who experience unexpected changes to their travel schedule? This question was put to activity diary respondents, who were given a hypothetical scenario related to one trip they made during the survey day. The responses were varied. Most individuals attempt to re-establish their current schedule by lengthening or shortening the duration of the immediately affected activity. However, other responses include reordering of subsequent activities, reallocation of task to other members of the household, relocating subsequent activities, and the deletion or the adding of a new activity.

This paper focuses on the decision alternatives households choose when facing an unexpected travel time delay or saving. We investigate the commonality of solutions provided by respondents by accounting for the differing circumstances of each respondent. The factors that affect the response include: the degree of flexibility of the remaining scheduled activities, in terms of duration, frequency and location; the length of the delay or saving; the time of day when variation is incurred; the duration of next activity; the number of household members involved in subsequent activities and the characteristics of the household.

2. Activity scheduling

Households schedule activities. The process of scheduling may be thought of as hierarchical, with mid-long term decisions about mobility being the first stage (Ben-Akiva and Bowman 1997, Papacostas and Prevedouros 2001). These long term decisions then impact on the daily (weekly) schedules of activity participation. (Axhausen and Gärling 1992, Ettema et al. 1994, Ettema and Timmermans 1997, Arentze et al. 2000, Doherty et al. 2002).

Short term scheduling is done concomitantly by household members, accounting for shared resources and joint participation. In most instances there is no formal schedule, but individuals use a tacit awareness of the activity patterns of other members. If no formal schedule exists, the challenge for the analyst is to infer the unstated schedule from the actual activity patterns of the household. The analyst may view the activity patterns as an outcome of a skeletal timetable (Axhausen and Gärling 1992) drawn up by the individuals before the commencement of the day. This timetable schedules activities loosely around the windows of opportunity, as perceived by the individual. As more information becomes available - i.e. the size of the windows of opportunity is known with a greater certainty - the individual adjusts this schedule accordingly.

The above description of daily activity planning has an interesting implication on the use of utility maximising class of models for activity analysis. Typically, such models consider that individuals maximise utility by allocating time to home and out of home activities. Taken to its logical extreme, such models indicate that an individual would repeat the scheduling process each time there is a disruption to the existing timetable. However, the predominant response to the hypothetical disruption was an attempt to re-establish the existing timetable. This indicates that the utility/disutility of an uncertainty of travel time may be measured by the impact on the current schedule.

A major consideration when researching behavioural responses to activity schedules is the type of activities undertaken by the individual. It is reasonable to assume the response to an unexpected time delay or saving will be different when the next activity is rigid to when the next activity is flexible. The flexibility of an activity is a function of its location, start/finishing time, and duration. Visiting a friend may be quite flexible in terms of start time and duration, however the location is fixed. Work and business activities are usually described as rigid, because they are often constrained by arguments. However, strict classification of activities into rigid or flexible classes is complicated because of the multi-dimensional aspect for the "flexibility" of an activity; added to those already given are: priority (business meetings may be rigid for all other dimensions, yet they may be deleted or postponed if another urgent matter arises) and participation (i.e., is it essential a particular household member conducts that activity?).

Table 1 presents the daily activities in terms of priority, location, starting time, duration and participation. The activities are graded by their flexibility. Certain activities, such as work, appear under different grades of flexibility, due to the manner in which they may be conducted. Also, it is possible that each activity described does not fit perfectly within a grade. The potential for overlap is the motivation for using fuzzy sets to classify inputs into the model. Fuzzy sets permit degrees of membership.

Finally, activities that are so-called ‘flexible’ are often subject to exogenous constraints. For example, a concert at the theatre and a soccer match have a fixed start time and duration, and a delay in traffic will almost certainly mean a disutility is experienced, but no rescheduling. In these cases, the duration of the participation in the activity is reduced, and the benefits obtained from pursuing the activity vary accordingly (Kitamura and Supernak 1997).

Inversely, an unexpected time savings (a “good run” on a normally congested freeway) will also cause a disutility, as the savings may not allow the opportunity to insert an additional activity into the schedule and waiting being disagreeable.

Table 1 Flexibility of daily activities

Very rigid	Rigid	Somewhat flexible	Flexible
Employment (main job) - fixed time for starting the activity, fixed duration, location (office)	Employment (main job/second job) - certain duration, fixed location	Employment (main job/second job) - flexible duration, possibility to work from home Domestic activities (maintenance and repairs)	Domestic activities (meal preparation, clean up, laundry and clothes care, gardening, home improvements) Personal care (sleeping, washing, eating, health care)
Education (attendance, off-site training, different courses) - fixed location, starting time, duration	Entertainment activities (visiting entertainment and cultural venues, sport events) – fixed location, starting time, duration Social interaction (visits, meeting people) – fixed time, location	Education (study, research, library) - flexible time, duration, location Purchasing goods, services – flexible location, duration, starting/finishing time set	Household management (paperwork, bills, packing, mail organization etc.) Childcare (physical and emotional care, teaching, helping, playing, reading, talking etc.)
Child care (pick-up, drop off), drop off anybody to airport, etc. – fixed location, starting time, duration	Child care (lessons, visiting school) – fixed location, duration	Social interaction (visits, meeting people, religious activities) – flexible time, duration, location	Recreation and leisure (visiting entertainment and cultural venues, sport, reading, arts, audio/visual media, communication, relaxing) – flexible time, location, duration

Other factors included in the model were the time of day when the savings/delay was incurred, the duration of the next activity, and the magnitude of the savings/delay.

The moment when the disturbance occurs in the timetable will have impact in the course of action taken. A delay in the morning is very likely to knock on many more activities than a delay in the way home in the night. At the same time, the opportunities to solve the “conflict” in the timetable are more numerous over the day, and the responses vary considerably.

If a considerable change (delay) in the timetable appears late in the evening, the resolution is less elaborated and usually involves changing the timing of the next activity and deletion of activity.

Obviously, the decision depends on the duration of next activity and the size of travel time saving/delay. If the following activity is not stringent (social interaction, recreation, let's say) and the delay is comparable with the window allocated in the skeleton timetable, the most common response is to reschedule the activity.

The magnitude of the time saving/delay dictates the type of "corrective" action in the sense that very small changes are ignored or they are easily accommodated in the timetable by changing the starting time of the following activity; but significant modifications need a bit more deliberation. Large time savings allow possibilities of accessing more preferred destinations or including new activities. Large time delays arisen within rigid schedules are the most annoying, and they lead most of the time to deletion of activities in the timetable.

The model given below explores the factors that affect the type of responses and provides the potential action taken by individuals when facing changes in the travel time, as well as an index measure of utility/disutility associated with it.

3. Modelling background

Rule-based systems model problem-solving activity and adaptive behaviour, where the traditional way to represent human knowledge is the use of "IF-THEN" rules. Fuzzy logic is a generalisation of the classic logic systems, offering the conceptual framework for modelling knowledge representation in an environment characterised by uncertainty and imprecision. While traditional set theory defines set membership as a Boolean predicate, the fuzzy sets allow us to represent the membership functions as a possibility distribution (Zadeh 1965 and Kosko 1992).

Fuzzy systems are based on degrees of membership[1]. For example, a shopping destination is "flexible" (easily substituted with other destinations) or is "somewhat flexible" (accessing alternative destinations is possible but not preferred). The degree of belonging to "flexible" or "somewhat flexible" is defined by membership functions, which permit overlapping.

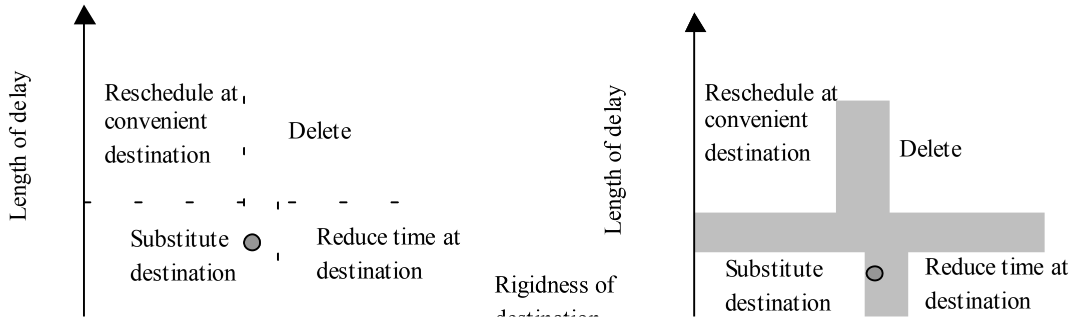
[1] A description of the Fuzzy Rule-Based Systems (FRBS) framework is presented in 3.4 and the familiar reader could skip to there without any loss of understanding.

Fuzzy logic manages to model complex non-linear input-output relations as a synthesis of multiple simple input-output relations (fuzzy rules). The boundary of the rule areas is not sharp, but 'fuzzy.' The system output from one rule area to the next rule gradually changes.

The difference between crisp and fuzzy rule-based systems is related to how the input space is partitioned (see Figures 1(a) and (b)). To instantiate, a small time delay is experienced before a scheduled shopping activity (not necessarily on the trip to the shopping destination).

In Figure 1(a), if all shopping trips have flexible destinations, in the event of a small delay the individual will choose a more convenient location. Furthermore, should the delay be moderate or long, the individual will delete the shopping activity from the day's activity schedule (our point is just to the right of the border between "reschedule" and "delete"). In Figure 1(b), the rules share a "grey area". The individual may choose an alternate destination or choose to reduce the time taken when shopping. The resolution between the alternatives depends on other inputs (the diagram shows only two input dimensions) and shape of the membership functions specified by the analyst.

Figure 1 Rule partition of a two-dimensional input space



Fuzzy logic is used to represent propositions such as: "My work start time is not very rigid", "My schedule is very tight.", or "I am very happy when I can fulfil all activities included in my diary". Such statements are difficult to translate into more precise language without losing their semantic value. In addition, using crisp sets to classify the individual's circumstance as a function of trip related factors, does not adequately reflect the error in the analysts' judgement. Indeed, using crisp sets may lead to no two individuals facing the same circumstance, removing the potential for generalisations. Finally, in our scheduling problem, any two households may seem to face the similar circumstance, yet behave differently. Fuzzy sets offer heuristic solutions to real-world problems and allow for the possibility of multiple solutions.

3.1 Fuzzy concepts

Fuzzy systems represent truth (via fuzzy logic) and membership (via fuzzy sets) by a value on the range [0, 1], with 0 representing absolute *Falseness* and 1 representing complete *Truth*. For example, “We’ve been waiting a long time in the station.” or “The delay was long.”, each describe a situation where an unexpected wait for a train has occurred. If the delay was 15 minutes, we might assign the statement the truth value of 0.75. The statement “The waiting time is a member of the set of large delays.” indicates membership, which may be expressed in symbols as $m_{\text{Large delay}}(\text{Waiting time}) = 0.75$, where m is the membership function, operating on the fuzzy set of large delays.

It is important to stress the distinction between fuzzy systems and probability. Both operate over the same numeric range, but whereas the probabilistic approach yields the natural-language statement “There is 75% chance that the delay is large.”, the fuzzy terminology corresponds to “The degree of membership of the delay within the set of large delays is 0.75.” The first view supposes that the delay is or is not large (still caught in Tertium non datur) and we have 75% chance of knowing. By contrast, The FS supposes that the delay is “more or less” long, corresponding to the value of 0.75.

The adjectives and membership functions for time savings/delay used in the model are presented in Figure A1 of Appendix A.

It is clear that any waiting time in excess of 15 minutes will have a membership value at least as great as 0.75 and any waiting time less than 15 minutes will have a membership value no more than 0.75. Also, the waiting time of 15 minutes belongs to the set medium. The membership values are only constrained by the range [0, 1] for each set, they do not need to add to one over all sets.

Strictly, a fuzzy set is a collection of ordered pairs $A = \{x, m(x)\}$, and $m_A(x)$ is the membership value for element x in set A. A normalised set is a set such that it contains at least one element with a membership value of 1. While not obligatory, normalised sets are the standard in fuzzy systems. Subsets are found in fuzzy systems and are useful to add strength (very large) or ambiguity (somewhat or fairly large) to a statement; these are known as linguistic hedges or modifiers. Conventionally, the square function is used to represent *very* and the cubed function is used to represent *extremely*. Also, the square root function is used to represent *somewhat*.

The membership functions are determined using subjective evaluation and elicitation (expert opinion), measurement, or adaptation through learning algorithms. There is a large variety of possible membership functions, but the simplest functional forms (triangular, trapezoidal) are preferred.

3.2 Fuzzy operators

The fuzzy operators used in this paper are the set complement, union and intersection. Unlike classical set theory, there is not a definitive operator for each and different examples appear in the literature (for a review, see Klir and Folger 1988). We have chosen to use the original formulations of these fuzzy operators:

Complement: $m_{\text{not } A}(x) = 1 - m_A(x)$ (1)

Union: $m_{A \cup B}(x) = \max[m_A(x), m_B(x)]$ (2)

Intersection: $m_{A \cap B}(x) = \min[m_A(x), m_B(x)]$ (3)

The set complement appears familiar because of its similarity with probability, but the two should not be confused. Probability acts on sets with a total or not at all membership (a rectangle of height 1). The probability value reflects the degree of knowing whether the element is within a set. In a system of disjoint sets, the probability that an element is not in set A is equal to the probability that it is in any of the other sets. This is not the same as (1), which is zero if the element is actually in the set (the event occurs) and one otherwise. Of course fuzzy membership functions permit values other than zero or one.

In much the same way, the union (2) and intersection (3) operate on total or not at all memberships. Their essence may be summarised as follows:

Union - The membership value for a union is at least as big as the membership value for any of the constituent sets. The maximum function represents the strongest of any class of union operators.

Intersection - The membership value for an intersection should be no greater than the membership value for any of the constituent sets. The minimum function represents the weakest of any class of intersection operators (cf: Klir and Folger 1988: 37).

There are other properties that the union and intersection functions exhibit, but these are beyond the scope of this paper.

3.3 Fuzzy logic

Where classical (two-value) predicate logic renders propositions as either true (T) or false (F), fuzzy logic deals in *degrees of truth*. Equally, it deals with *degrees of falseness*. As with classical logic, a fuzzy predicate is: x is A (e.g., 15 minutes is a "Large_Delay" or 0.4 is small). However, unlike classical logic, the truth value for the proposition is itself a fuzzy set with varying degrees of membership. The simplest of truth sets is a one-to-one mapping of the membership function, for example, if $m_{Large\ delay}$(15 minutes) = 0.75 then m_{TRUE} (15 minutes is a large delay) = 0.75.

Returning to the first example for the delay experienced before a scheduled shopping activity, the delay may be characterised as *small* (5 mins) and the activity is *flexible* (4 on the 1 to 5 scale, 5 being the most flexible). If crisp sets are applied, the truth value for the proposition "the delay is small and the destination is flexible" is 1, and the strategy is "change destination". Applying fuzzy logic to the sets presented in the Appendix A we have:

m_T(neg_small and flexible) = min($m_{negsmall}$(-5) and $m_{flexible}$(4)) = min(0.65, 0.4) = 0.4 .

However, other truths apply. Examples are:

m_T(neg_small and very flexible) = 0.16,

m_T (small and flexible) = 0.2,

m_T (small or neg small and flexible) = 0.4

m_T (neg small and not_flexible_nor_rigid) = 0.4 (4)

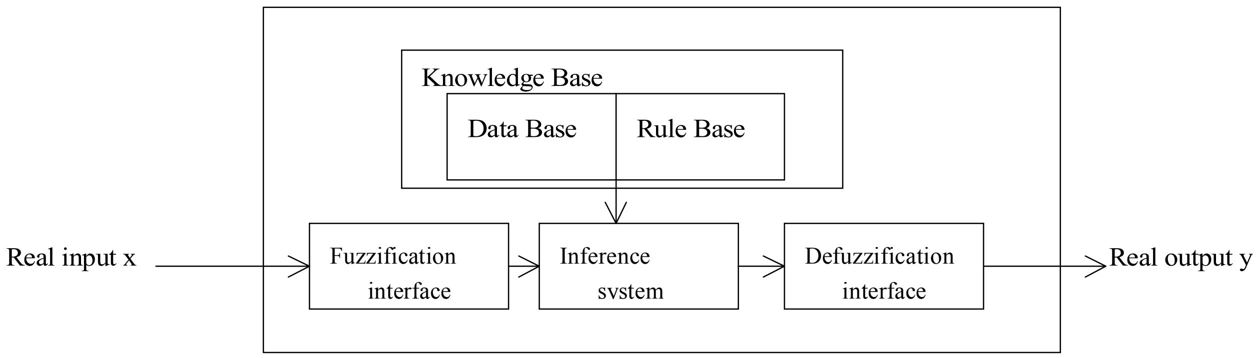
It is natural to question which *truth* applies. To the logician it does not matter; these truths are membership values to the alternate truth sets. It is, however, important to the individual who must resolve the delay by adjusting his/her schedule, as well as to the analyst who is studying the responses. This returns us to the beginning of section three - that fuzzy logic is a framework for modelling knowledge representation in an environment characterised by uncertainty and imprecision (Nguyen and Walker 2000). A Fuzzy Rule-Based System (FRBS) is used to resolve strategies used by respondents to cope with unexpected changes in their daily schedules; the application demonstrates the usefulness of fuzzy sets to structuring the varying circumstances for the group, as well as the multiple strategies available to each member.

3.4 Fuzzy rule-based system

Fuzzy rule based systems (FRBS) are used to resolve the multiple truths associated with fuzzy logic. In particular, a system of logic is applied to obtain a single consequence (action) when a single (real valued) input may belong to many truth sets and each consequence (IF-THEN do action) may apply for many truths. In short, the FRBS assigns fuzzy membership values to a real valued input, applies linguistic modifiers and COMPLEMENT, AND, and OR operators and resolves the fuzzy consequences to provide a single valued output -- the action.

The two types of FRBS (fuzzy expert system) that take real values inputs, fuzzify these, infer the fuzzy output, and return a real value output are attributed to Mamdani and Takagi-Sugeno-Kang (Cordon et al. 2001). The fuzzy logic (FL) model we present uses Mamdani FRBS with the structure presented in Figure 2.

Figure 2 Basic structure of Mamdani FRBS



Cordon et al. (2001): 3

The Knowledge Base stores the available knowledge about the problem in the form of fuzzy "IF-THEN" rules. The antecedent (the rule's premise) describes to what degree the rule applies, while the conclusion (the rule's consequent) assigns a membership function to each of one or more output variables. Most tools for working with fuzzy systems allow more than one conclusion per rule.

The Database refers to the linguistic rules and membership functions defining the semantics of the linguistic labels; the granularity and form of the input space partition has a major influence on the system classification/prediction capacity.

The Rule Base regards the collection of “IF-THEN” linguistic rules build with AND and OR operators. For each rule, the antecedent (the rule's premise) describes to what degree the rule applies, while the conclusion (the rule's consequent) assigns a membership function to each of one or more output variables.

[BS1]The inference engine for a FRBS combines the input values and the knowledge base. Each input passes through the system, first undergoing a process of fuzzification, where its membership values are assigned. Next, a selection of appropriate rules is made (rules of inference are applied). Finally, rules are applied to select a single value output - known as defuzzification. The inference engine includes:

- *fuzzy interface*, that transforms the crisp input data into fuzzy values that serve as the input to the fuzzy reasoning process; the rule activation modifies the FS in 2 ways:
  - multiplication (product) - it squeezes the membership function;
  - correlation (minimum) – it trims the peaks in the functions;
- *inference system*, that infers from the fuzzy input several outputs; there are three rules for combination: maximum (envelope); sum (Kosko); select single best (not at all combination);

The scaled output from a rule is a fuzzy set. The graph of that fuzzy set specifies the degree to which each possible output value is a member of the response specified by the rule.

The choice of the rule combination methods depends essentially on the desired output (smoothly changing responses or choices).

- *defuzzification interface*, that converts the fuzzy sets obtained from the inference process into a crisp action that constitutes the global output of the fuzzy system.

4. The model

The fuzzy logic model is used to generalise the individual’s decision rules, where the inputs are subjective. For each activity respondents indicated if the activity is compulsory or discretionary, if the activity is flexible in terms of starting/finishing time, duration, and location. In addition, the length of the delay/savings and the expected duration of the following activity in the schedule were considered. The latter was necessary to compare the window of opportunity or the deviation from the schedule with the duration of the next activity. This comparison helped us to estimate whether the deviation can be removed and the steadiness of timetable re-established or not. Finally, the time of day, when the deviation from the timetable appears, was considered by its impact on the individual's schedule.

The fuzzy rule based system (FRBS) uses four input variables and two output variables. Each linguistic variable has several linguistic labels and the membership functions define their semantics (e.g., next activity can be *very rigid*, *rigid*, *not rigid nor flexible*, *flexible*, *very flexible*). In Appendix A we present the membership functions used for the variables[2].

Triangular and trapezoidal[3] membership functions are used in this research. The initial membership functions were derived using an equidistant uniform partition, and then were refined/tuned observing the behavior of the entire process (trial and error process).

Our fuzzy rules modify the adjectives with VERY, SOMEWHAT and NOT operators and include AND and OR. All the rules apply at all times, but some have more influence than others (the weights are established on the empirical data).

The presented model offers 'solutions' for "getting back in track" when a change in travel time occurs in different combinations of daily activities performed in the morning, mid-day, afternoon, night. It also performs non-fuzzy computations and calculates the satisfaction/benefits with the change in the timetable.

4.1 Empirical setting

A survey conducted in Bucharest, in November 1998, collected 1027 travel diaries from students and academics. The travel diaries recorded the types of activities undertaken as well as the start and end times; travel times were calculated (summary statistics are given in Table 2). In addition, a segment of respondents were given a scenario with a hypothetical change to the duration for one of their trips. For each of these respondents a varied length of saving/delay was given and this was to apply to a specified trip number from the sequence of their trips.

The responses were open ended, but respondents were directed to provide information on how they would manage the unexpected change to the duration of the trip by discussing any subsequent changes their day's activity schedule. They were also asked to rate the inconvenience (or benefit) experienced due to the change.

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[2] The software package used in this study is CubiCalc from Hyperlogic Corporation.

[3] "Delgado et al. (1998) enunciated that trapezoidal shaped functions might adequately approximate all remaining non-linear membership functions, presenting the advantage of their simplicity as well" (Cordon et al., 2001:.23)

Table 2 Descriptive statistics

Indicator	Average	Standard deviation
Number trips/day	3.09	1.45
Number activities/day (at home and out of home)	14.7	8.89
Travel time/day (min)	101	62
Average travel distance/trip (km)	5.2	4.76

While the survey mechanism was an open-ended question, we did note a degree of consistency in among the responses. Where possible, the respondents changed as little as possible their schedule. This was achieved by cushioning the impact with the next activity -- starting early and staying longer (trip time savings) or starting late and reducing the duration (trip time delay). However, other responses included: change of location, re-ordering the remaining activities, deleting or adding an activity, consolidating remaining activities (trip chaining) and alternative modes of transport for subsequent trips (less than 4% of the cases).

Similar to Schönfelder and Axhausen (2001)'s results – cited in Schlich and Axhausen 2003, p.19 - we noticed very little spatial variability and few respondents indicated the change of destination in their responses. This can be due to the range of time savings and delays, but we also believe that people use predominantly few locations for their activities.

The fuzzy rule based system we propose uses 'prior knowledge' (normative assumptions made by the analyst) and data supplied by the respondents in the survey. Allowing for the "imprecision" of the inputs, probable responses made by the decision-makers are determined by classifying the type change to the individual's schedule

From the responses we built 56 non redundant rules that accounted for the different scenarios, the different activity schedules and the different responses (coping strategies).

4.2 Fine tuning the model

The performance of the model has been assessed using the hit ratio and the errors in prediction (differences between the model output and stated response).

We 'altered' the membership functions, changed the scaling functions, and lastly, the fuzzy rules were considered as candidates in tuning the fuzzy system.

The best structure is presented in Appendix C and is characterised by: product scaling, combine with select single best, add rules with same consequent, max defuzzification and resolve ties by selecting midpoint.

Some of the findings are presented in the following:

- we noticed that the modification of the membership functions implies modifications of the context in which the fuzzy system operates;
- substantial modifications of membership functions changed profoundly the FRBS behaviour, and in many situations required the complete reformulation of the rule base;
- a single modified membership function had a medium size effect.

We also built another model with three additional inputs: gender, joint activities, importance of next activity. Despite of the elaboration of the model, the performance was not better, therefore we decided to stay with a smaller number of variables (up to 4-5 antecedents), which was more comfortable and was proven to be appropriate (Cordon et al. 2001).

We tested the "sensitivity" of the model for different number of rules and weights (0.7-1). Replacing a single rule had a very local effect.

The weights varied in the range (0.7-1) did not impact significantly in the output of the model.

Another important remark was that the shape of output adjectives was irrelevant for centroid defuzzification with product scaling, but extremely significant when max-height was used.

5. Findings

The model provides responses to the timetable change and associated level of satisfaction with it. These are the most frequent solutions adopted: *do-nothing* (for savings less than 5 mins), *change the starting and ending times of the next activity, change the duration of the next activity* (for delays or savings less than 15 mins), *change the location and the participation, remove the activity from timetable* (for delays more than 15 mins), *or add a new activity in the timetable* (for savings more than 15 mins), *with their associated level of dis/-utility, depending on the nature of the time saving (window of opportunity or delay).*

The solution provided by the fuzzy rules model is the same as the solution given by the interviewees in 82-87% of the cases and similar results have been obtained when training a feed-forward back propagation neural network. This is a useful validation of the model.

Table 3 illustrates the hit ratio for two types of models and two split values for training-testing samples:

Table 3 Hit ratio (model accuracy)

Discrete-choice best output adjective		Discrete-choice best rule	
70-30 training-testing	80-20 training - testing	70-30 training-testing	80-20 training - testing
82%	87%	71%	74%

The utility/disutility and benefits of the changes were calculated using different values for travel time, for savings and for delays.

We used three different ratios for value of travel saving/value of travel delay: 0.6, 0.7, and 0.8. The highest prediction accuracy in our study corresponded to the ratio of 0.7. However, we cannot make any inferences from this observation.

6. Conclusions and future research

The activity-based travel analysis is increasingly acknowledged as being essential for travel demand analysis (Bhat and Koppelman 1999). This behavioural basis allows us to understand all the elements that dictate the location, time, reason and manner of performing activities and the trip-related decisions. The paper presents a FRBS for modelling daily decisions related to activities schedule. The attempt made tries to confirm the fact that by their daily planning of activities, the individuals try to obtain benefits and minimize dissatisfaction, looking for a stable schedule with little variation in rescheduling the activities; this is done into a very complex system of restrictions governing their decisions – choices – learning experience.

The solutions for re-establishing the skeleton timetable provided by the model are very similar to the decisions that respondents indicated in the survey and they show that:

- the influence of prior commitments (institutional, family) is essential on the decision;
- the big deviations from the travel time are associated with significant changes in the timetable (deletion, addition of activities), whereas the small ones are usually translated into modified timing of the next activity;

- the early arrivals are as annoying as the delays if the time window created cannot be used for a new activity or translated to the next activity;
- the inertia and lock-in behaviour is present in numerous cases, and some solutions do not vary with the travel conditions;
- the individuals are happy to maintain a constancy of their travel time budget;
- the individuals that usually allocate some extra time (buffer, slack/recovery time) for trips in order to cope with the variability of traffic, use as solution for getting back in track (when a delay occurs) the timing; if an early arrival is foreseen, the solution is almost invariably the addition of a new activity.

Unlike the findings of Stern (2002) regarding the deliberation process, in this research the decision is made in order to re-establish the steadiness of the skeleton timetable.

"Deliberation is a time-consuming cognitive process that involves information seeking about the consequences (Ei) of recognisable actions (Ai), weighting of the pay-offs (Yi) of the events, and comparing the weighted consequences to establish a preference (choice) state. The deliberation process is manifested by vacillation until a choice is made and action is taken". – p. 219.

The model also determines the utility/disutility associated with the change and highlights once again that a travel-time saving can be perceived as dissatisfaction if the individual does not have the opportunity to allocate the time saving to other activities in the timetable.

The main benefits of the fuzzy logic approach are: the treatment of individual behaviour and travel patterns, with individual solutions, and the simplicity of the approach. The model also permits generalisations on decision rules used by households. The FS affords a broader, richer field of data, and the manipulation of that data is simpler than the traditional methods. New rules can be built to reflect the reinforcement learning and adaptation (Arentze and Timmermans 2003) and embed more lexicographic or elimination-by-aspects elements (Axhausen and Gärling 1992).

There are however limitations of the research that the authors will address in the future:

- Testing the impact of income group, type of trip (productive or not), frequency, chaining on the decision and their relation to windows of opportunity and reliability; disappointingly, at this stage the gender did not play a significant role in the schedulling process; this is probably due to the small sample and to the fact that most of it consisted of students living in campus; their routine is similar between genders, but different from the one for families with commitments;
- Considering the non-motorised trips as well; the paper concentrates on motorised travel and less on foot or by bicycle, and the reason was the unreliability of motorised transport; but this applies to non-motorised too if they share the same road;
- Resolving the conflicts over a longer time horizon; the present model assumes that the individuals resolve the timetable conflicts within the same day; a more realistic approach would be to highlight the changes involved by adding/removing one or more activities for the next days; this would be particularly relevant, especially with the new findings of Timmermans et al. (2002) on activity-travel patterns from five

countries in three continents (North America, Europe, and Asia); the authors found similarities in the number of activities, travel behaviour across countries, and an interesting result is that the weekend is used to finish the activities that could not be performed during week;

- Besides, a more rigorous classification of activities in terms of degree of freedom would help to evaluate the changes in utility in the rescheduling process (e.g. frequency, duration etc.).

We also see as research opportunity in the future the investigation of the risk attitude of the individuals in the re-scheduling process. The more adverse the individuals, the higher the value of uncertainty (and higher penalties for delay) – the much more appreciated the good transport services, providing "narrow" distribution functions for the travel time. The adverse type persons are believed to take into account in their sequencing considerable windows for securing the mandatory activities, while the risk neutral or seeking persons are looking at mode values or averages, moving averages or different combinations depending on their predispositions and personality features, on the degree of freedom they experience in their activities and on the available information.

Other potential enhancements relate to the response: the model we present is rather concerned with the timing and adding/removing activities in and from the schedule, than with the possibility of changing the activity chains or the location. Moreover, the study could not include at this stage any switching behaviour during movement from one place to another.

Finally, another survey, better designed, would be beneficial for calibration and generalisation purposes. The sample used in the 1998 survey included only academics and students in Bucharest.

7. References

*** (2000) Cubicalc. The Third Wave in Intelligent Software, Hyperlogic Corporation, Escondido, USA.

Arentze T.A., Hofman F., Van Mourik H. and Timmermans H.J.P. (2000) Albatross: A multiagent rule-based model of activity pattern decisions, *Transportation Research Record*, **1706,** 136–144.

Arentze, T. and Timmermans, H. (2003) Modeling learning and adaptation processes in activity-travel choice, *Transportation*, **30**, 37-62.

Axhausen, K.W. and Garling, T. (1992) Activity-based approaches to travel analysis: conceptual frameworks, models, and research problems, *Transport Reviews* **12**(4), 323-341.

Bates, J.J., M. Dix, and T. May (1987) Travel time variability and its effects on time of day choice for the journey to work, in *Proceedings PTRC Summer Annual Meeting*, 293-311, Education and Research Services, London.

Ben-Akiva, M.E. and Bowman, J. L. (1997) Activity based travel demand model systems, in *New Horizons in Transport Planning*, 27-46, McMillan.

Bhat, C.R. and Kopelman, F.S. (1999) A retrospective and prospective survey of time-use research, *Transportation* **26**, 119-139.

Cordon, O., Herrera, F., Hoffman, F., and Magdalena, L. (2001) *Genetic Fuzzy Systems: Evolutionary Tuning and Learning of Fuzzy Knowledge Bases*, World Scientific, Singapore.

Doherty, S.T. (2000) An Activity Scheduling Process Approach to Understanding Travel Behaviour, The 79th Annual Meeting of the Transportation Research Board, Washington D.C., January 9-13.

Doherty, S.T., E.J. Miller, K.W. Axhausen and T. Gärling (2002) A conceptual model of the weekly household activity/travel scheduling process, in Stern, E., Salomon, I., and Bovy, P.H.L. (Eds.) *Travel Behaviour. Spatial Patterns, congestion, and Modelling*, 233-264, Edwards Elgar, Cheltenham.

Ettema, D. and Timmermans, H. (1997) Theories and models of Activity-Patterns, in Ettema, D. and Timmermans, H. (Eds.) *Activity-Based Approaches to Travel Analysis*, 1-36, Elsevier Science, Oxford.

Gärling, T. (1994) Behavioural assumptions overlooked in travel choice modelling, The 7th International Conference on Travel Behaviour, Valle Nevado, Santiago, June 13-16.

Jones, P.M., Koppelman, F, and Orfeuil, J.O. (1990) Activity Analysis: State-of-the-art and Future Directions, in Jones, P. M. (Ed.) *Developments in Dynamic and Activity-Based Approaches to Travel Analysis*, 34-55, Avebury, Aldershot.

Kitamura, R. and Supernak, J. (1997) Temporal Utility Profiles of Activities and Travel: Some empirical Evidence, in Stopher, P. and Lee-Gosselin, M. (Eds.) *Understanding Travel Behaviour in an Era of Change*, 339-350, Pergamon Press.

Kitamura, R. (1988) An evaluation of activity-based travel analysis, *Transportation* **15**, 9-34.

Klir, G.I. and Folger, T.A. (1988) *Fuzzy Sets, Uncertainty, and Information*, Englewood cliffs, Prentice Hall.

Kosko, B. (1990) Fuziness vs. Probability, *International Journal of General Systems* **17**, 211-240.

Kosko, B. (1992) *Neural Networks and Fuzzy Systems*, Prentice Hall.

Lu, X. and Pas, E. (1999) Socio-demographics, activity participation and travel behaviour, *Transportation Research* **33A**(1), 1-18.

Nguyen, H.T. and Walker, E.A. (2000) *A First Course in Fuzzy Logic* (2nd Ed.), Chapman & Hall/CRC.

Noland, R.B., Small, K.A., Koskenoja, P.M, and Chu, X. (1998) Simulating travel reliability, *Regional Science and Urban Economics* **28**(5), 535-564.

O'Fallon, C., Sullivan, C., Hensher, D. (2002) Understanding Constraints Affecting Decision-Making by Morning Car Commuters, *Institute of Transport Working Paper*, ITS-WP-02-13, Institute of Transport Studies, The University of Sydney.

Papacostas, C.S. and Prevedouros, P.D. (2001) *Transport Engineering and Planning* (Third Ed.), Prentice Hall.

Schlich, R. and Axhausen, K.W. (2003) Habitual travel behaviour: Evidence from a six-week travel diary, *Transportation* **30**, 13-26.

Stern E. (1998) Travel Choice in Congestions: Modeling and Research Needs, in Gärling et al. (Eds.) *Theoretical Foundations of Travel Choice Modeling*, 173-199, Elsevier, Amsterdam.

Stern, E. (2002) Behavioural thresholds of commuters under congestion, in Stern, E., Salomon, I., and Bovy, P.H.L. (Eds.) *Travel Behaviour. Spatial Patterns, Congestion, and Modelling*, 218-232, Edwards Elgar, Cheltenham.

Supernak, J. (1992) Temporal utility profiles of activities and travel: uncertainty and decision making, *Transportation Research* **26B**(1), 61-76.

Timmermans, H., van der Waerden, P., Alves, M., Polak, J., Ellis, S., Harvey, A.S., Kurose, S., and Zandee, R. (2002) Time allocation in urban and transport settings: an international, interurban perspective, *Transport Policy* **9**, 79-93.

Zadeh, L.A. (1965) Fuzzy Sets, *Information and Control* **8**, 338-353.

Appendix A: Membership functions used in the model

Figure A1 Adjectives for time savings/delays (“neg_large”, “neg_small”, “small”, “medium”, “large”)

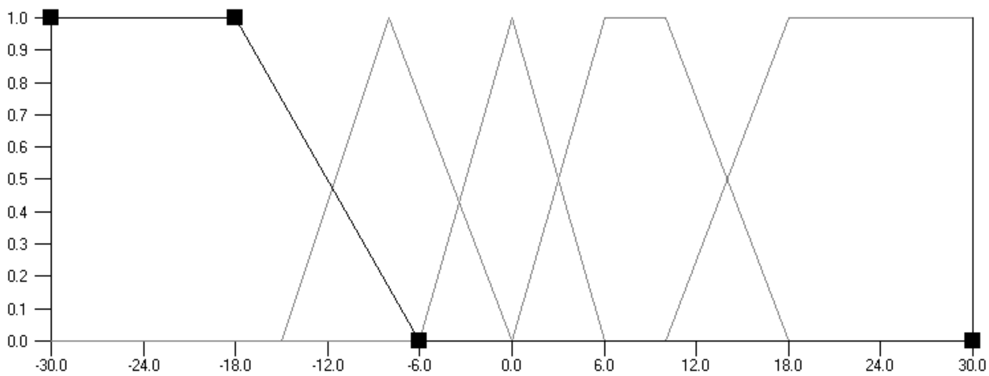


Figure A2 Adjectives for time-of-day ("night", "early-morning", "morning", "noon", "early-afternoon", "late_afternoon", "evening")

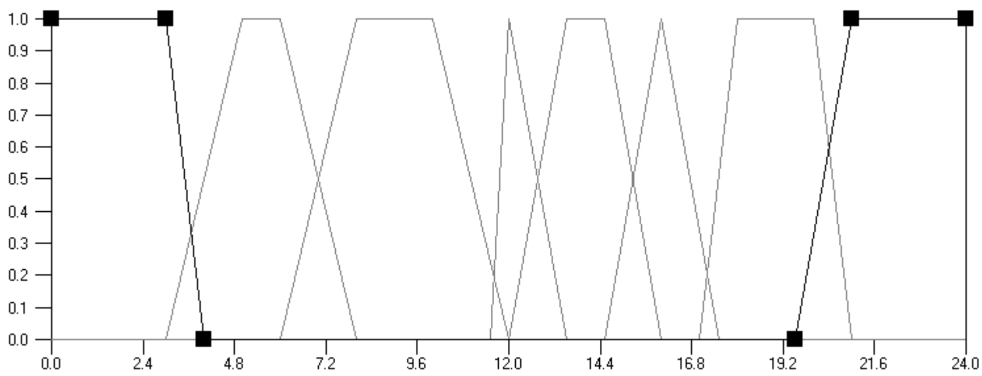


Figure A3 Adjectives for next activity ("rigid", "not_rigid_nor_flexible", "flexible")

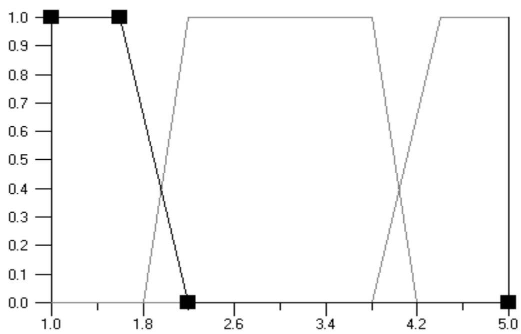


Figure A4 Adjectives for duration next activity ("short", "medium", "long")

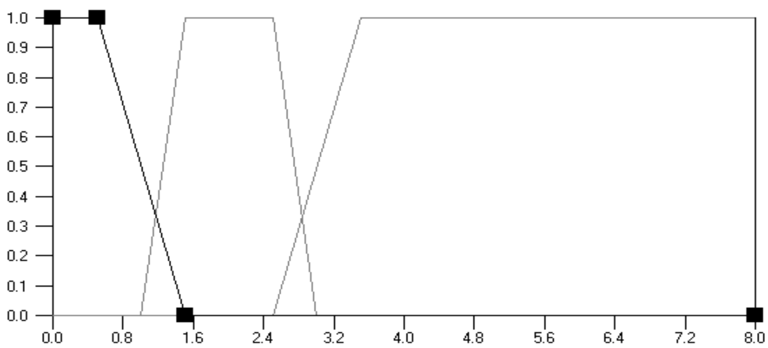


Figure A5 Adjectives for utility ("negative", "neg_small", "zero", ""pos_small", "positive")

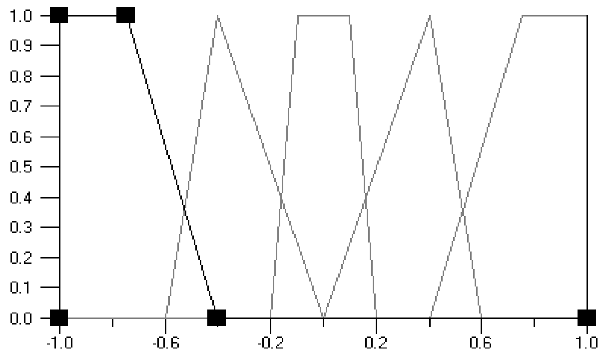
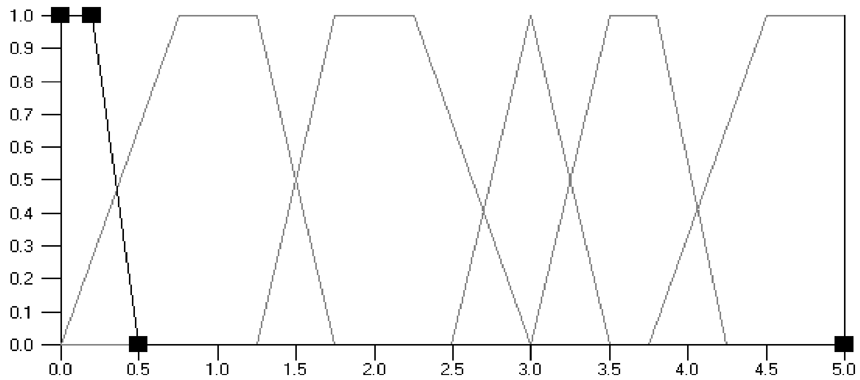


Figure A6 Adjectives for action ("do_nothing", "change_time_next", "change_duration_next", "change_location_next", "remove_next", add_new")



Appendix B: Example of rules

(1.0) IF (next_activity is very_rigid) AND (time_savings is small) AND (time_of_day is early_morning OR time_of_day is morning) AND (duration_next is medium) THEN make utility zero, action do_nothing;

(1.0) IF (next_activity is rigid) AND (time_savings is neg_large) AND (time_of_day is early_morning) AND (duration_next is large) THEN make utility neg, action change_time_next;

(0.8) IF (next_activity is flexible) AND (time_savings is neg_large) AND (time_of_day is noon OR time_of_day is afternoon) THEN make utility neg, action remove_next;

(0.8) IF (next_activity is flexible) AND (time_savings is large) AND (time_of_day is evening) THEN make utility positive, action add_new;

Appendix C: The best model

To guarantee a discrete response we used Single best combination with different defuzzification procedures. The best predictions have been obtained with maximum height defuzzification.

This rule strategy combines rules with the same consequent, by adding their activations, then picks the output fuzzy set with the maximum sum.

Figure C1 The best model