MODELLING DAILY ACTIVITY SCHEDULES WITH FUZZY LOGIC

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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, Mahmassani et al 2002, O'Fallon et al 2002). These studies measure behavioural responses like choosing an alternative route, mode, location, and changing the time of day. Such responses do not fully address the types of response alternatives available to the individual should they experience an unexpected travel savings or delay.

Once the individual has 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.

What are the responses by 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 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 (Papacostas and Prevedouros 2001). These long term decisions then impact on the daily (weekly) schedules of activity participation. (Axhausen 1992, Ettema 1994 and 1997, and Arentze 1999).

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 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

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class of models for activity analysis. Typically, such models maintain 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 predominate 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.

The model given below explores the factors that affect the type of responses given by individuals as well as measures an index of utility/disutility.

3 Modelling background

Rule-based systems have been successfully utilised in modelling human problem-solving activity and adaptive behaviour, where the traditional way to represent human knowledge is the use of "IF-THEN" rules. Fuzzy logic can be considered 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; Kosko, 1989).

Fuzzy systems are based on degrees of membership[2]. For example, is a shopping destination flexible (easily substituted with other destinations) or somewhat flexible (accessing alternate destinations is possible but not preferred)? The degree of belonging to flexible or somewhat flexible is defined by membership functions, which permit over-lapping. Fuzzy logic allows us 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) all shopping trips have flexible destinations and in the event of a small delay the individual will choose a more convenient location. Furthermore, should the delay be moderate or long the action of the individual is to delete the shopping activity from the day's activity schedule. 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.

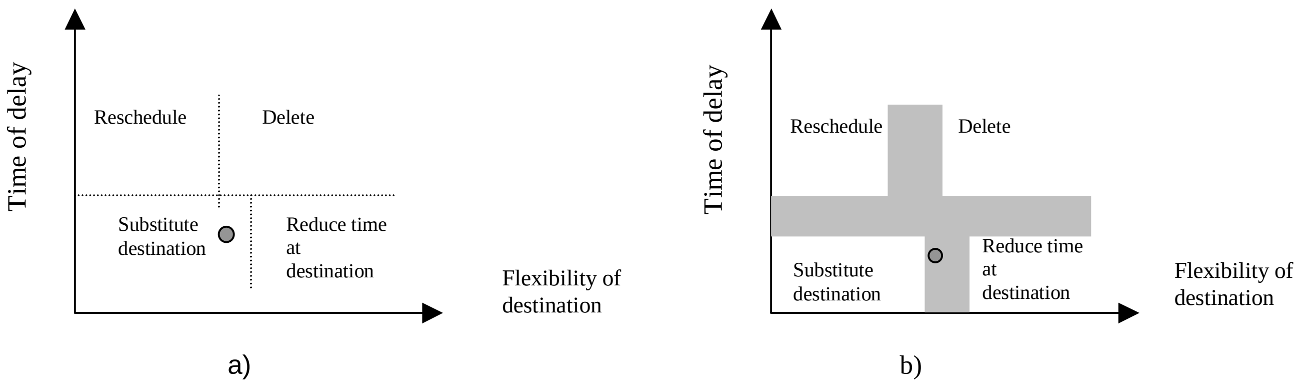

Figure 1. Rule partition of a two-dimensional input space

Our motivation for using fuzzy logic models is the need to represent propositions such as:
"My work is not very rigid", "My schedule is very tight." or "I am very happy when I can fulfil all activities included in my diary".
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 the case where no

[2] A succinct description of the FRBS framework is presented in Appendix 1.

two individuals are the same in character or in circumstance, removing the potential for generalisations. In our scheduling problem, any two households may seem to face the same (similar) circumstance, yet behave differently. Fuzzy sets offer heuristic solutions to real-world problems and allow for the possibility of multiple solutions.

4 The model

The fuzzy logic model is used to generalise the decision agent's 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 we propose uses ‘prior knowledge’ (normative assumptions made by the analyst) and data supplied by the respondents in a survey conducted in November 1998 in Bucharest, Romania.
It allows for the “imprecision” of the inputs and returns probable responses of the decision-makers to different changes appeared in their daily timetable and losses of the time savings/delays in terms of the capacity of assigning these times to the linking activities of transport.

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 2 we present the membership functions used for the variables.

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).

The flexibility of the activities linked by trips was considered to be the most important input. In Table 1 we display the taxonomy of the daily activities in terms of location, starting/finishing time, duration and participation, as used in the fuzzy model.

Table 1 - 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	Personal care (sleeping, washing, eating, health care)
		Domestic activities (maintenance and repairs)	Domestic activities (meal preparation, clean up, laundry and clothes care, gardening, home improvements)
Education (attendance, off-site training, different courses) - location fixed, starting time, duration	Entertainment activities (visiting entertainment and cultural venues, sport events) – fixed location, fixed starting time, duration	Education (study, research, library) - flexible time, duration, location	Household management (paperwork, bills, packing, mail organization etc.)
	Social interaction (visits, meeting people) – fixed time, location	Purchasing goods, services – flexible location, duration, starting/finishing time set	Childcare (physical and emotional care, teaching, helping, playing, reading, talking etc.)

[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, 2002, p.23)

Child care (pick-up, drop off), drop off anybody to airport, etc. – fixed location, fixed starting time, fixed duration	Child care (lessons, visiting school) – fixed location, fixed 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
	Personal business (meetings, civic obligations) - fixed time, location	Recreation and leisure (sport and outdoor activities, games, hobbies, crafts) – flexible time, duration, fixed location	

The deviations due to traffic conditions, time of day, and the duration of the next activity were simulated according to the empirical data. All inputs were processed through a series of fuzzy decision rules – as described in modelling background.

We interviewed people on various scenarios with late/early arrivals in different locations, at different moments of day, and depending on the rigidness indicators for the neighbour activities and on the individual participation we obtained information on the potential ways of changing the daily activities schedule and the satisfaction perceived by the individuals with the changes. These responses were used when we built the fuzzy rules (82 non-redundant rules for the compact FRBS).

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.

5 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 4 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. But a single modified membership function had a medium size effect.

We also built another model with two additional inputs: 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, 2000).

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.

6 Preliminary findings

The model provides responses to the timetable change and associated level of satisfaction with the change*: change the duration of the next activity, change the location and the participation, remove the activity from* *timetable, or add a new activity in the timetable, 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 feedforward back propagation neural network. This is a useful validation of the model.

Table 2 illustrates the hit ratio for two types of models and two split values for training-testing samples:

Table 2 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 are 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.

7 Conclusions and future research

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 benefit of the fuzzy logic approach is that the model treats individual behaviour and travel patterns and provides individual solutions. It also permits generalisations on decision rules used by households.

The model offers solutions for re-establishing the skeleton timetable that are very similar to the decisions that respondents indicated in the survey. The models also determines the utility/disutility associated with the change and highlights that even a travel-time saving can be perceived as dissatisfaction if the individual does not have the opportunity to allocate the window of opportunity to other activities in the timetable.

There are however limitations that the authors will address in the future.
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. 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.).

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. At this stage the adjustment is limited to the modification of start and end times of activities, with comparing the available window period with the duration of the activities to be embedded in the schedule. 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.

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Appendix 1

There are two types of FRBS dealing with real values inputs and outputs: Mamdani and Takagi-Sugeno-Kang. The FL model we present uses Mamdani FRBS with the following structure:

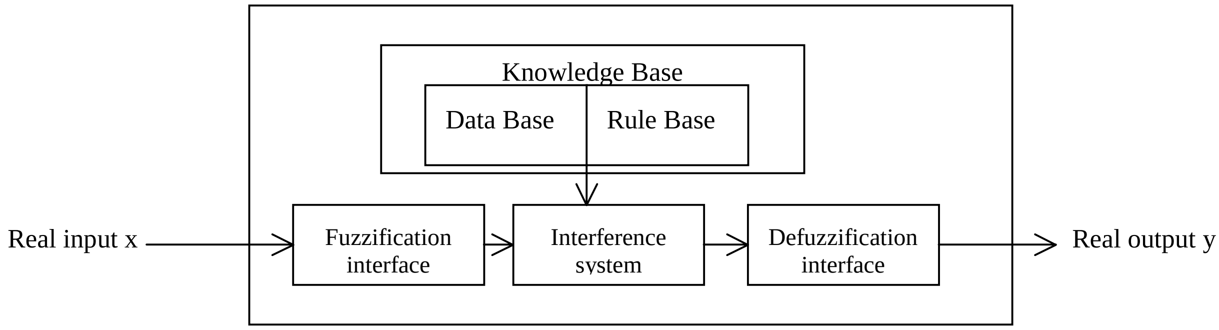

Figure 2. Basic structure of Mamdani FRBS (Cordon et al., 2001)

The Knowledge base stores the available knowledge about the problem in the form of fuzzy "IF-THEN" rules. 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 linguistic rules build with AND and OR operators.

The bottom part of FRBS is the inference engine including:

- <u>fuzzy interface</u>, 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;
- <u>interference system,</u> 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).

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

Appendix 2

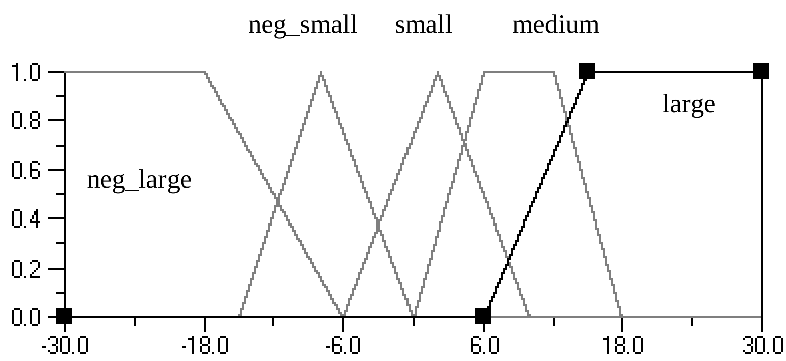

Figure 3. Adjectives for time savings/delays

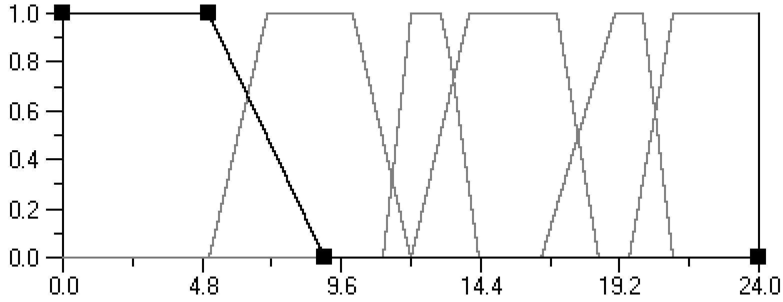

Figure 4. Adjectives for time-of-day ("early-morning", "morning", "noon", "afternoon", "evening", "night")

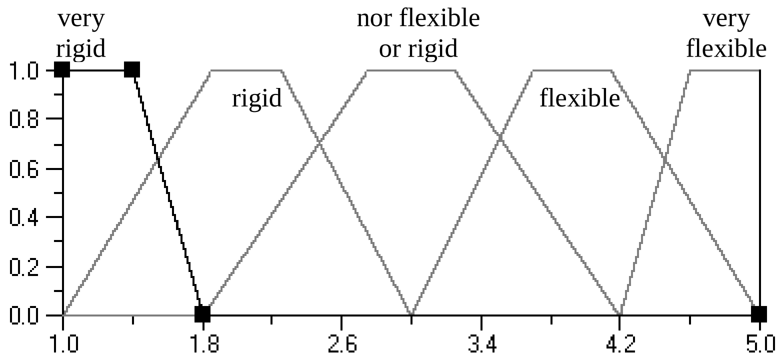

Figure 5. Adjectives for next activity

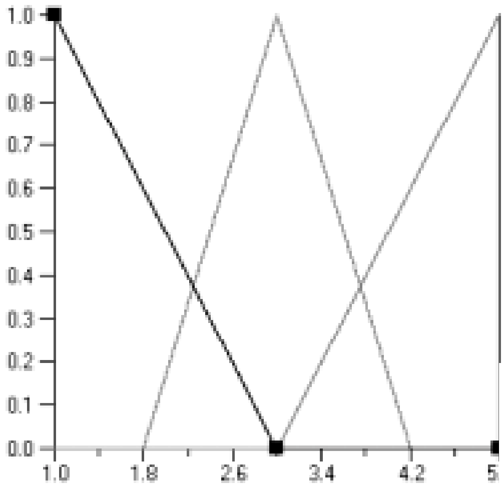

Figure 6. Adjectives for duration next activity ("short", "medium", "long")

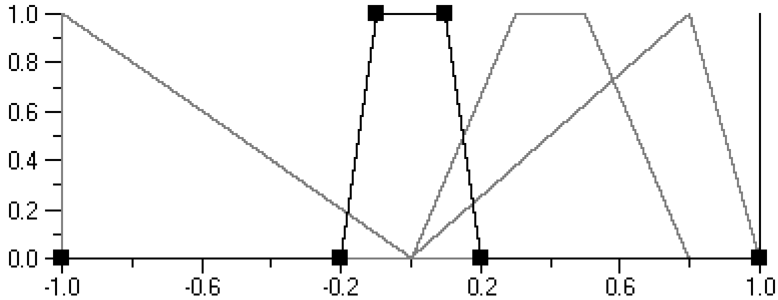

Figure 8. Adjectives for utility ("negative", "zero", "pos_next", "pos_other")

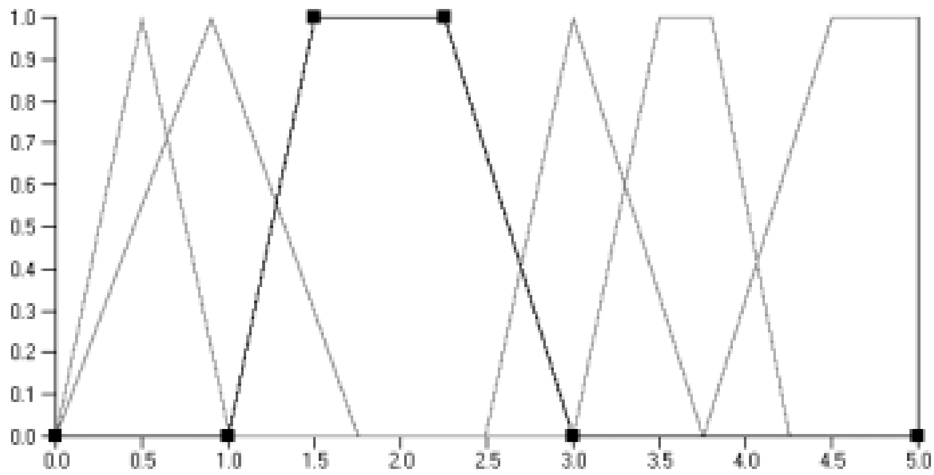

Figure 9. Adjectives for action (“do_nothing”, “change_time_next”, “change_duration_next”, “change_location_next”, “remove_next”, add_new”)

Appendix 3

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 small OR duration_next is medium) THEN make utility zero, action change_time_next;
(1.0) IF (next_activity is smw_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 medium OR time_savings is large) AND (time_of_day is evening) THEN make utility pos_other, action add_new;

Appendix 4 “Best model”