

RECENT AND EXPECTED DIRECTIONS IN MODELLING TRANSPORTATION

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1. INTRODUCTION

Across the world, the increased professionalism in transportation and urban planning has coincided with the development and use of models of land use and transport demand. Many government planning agencies and consultants now use some variant of the four-step approach to transport demand forecasting to estimate the demand for infrastructure or predict the likely consequences of transport and land use policies. This four-step approach first derives the total amount of transport generated in a set of zones, then distributes this demand across transport modes, allocates it to destinations, and finally assigns the allocated demand to the transportation network. The level of sophistication used in these steps differs across countries and cities, depending on the available data and dominant practice. Thus, while some rely on the spatial interaction and entropy-maximizing models, developed in the 1960s, others use trip-based or even tour-based, multinomial logit models of destination choice, or nested logit models of combined destination and transport mode choice. Similarly, while some may still use shortest route assignment algorithms, others may adopt dynamic equilibrium assignment.

Since a decade, the need for more sophisticated models has been voiced more intensely. Several empirical situations where the traditional four-step modelling approach failed accelerated this discussion. For example, many European countries experienced a rapid increase in women's participation in the workforce. Consequently, their travel behaviour changed. The reduced available time for non-work activities increased their propensity to organise their activities in terms of multi-purpose, multi-stop tours. Traditional trip-based models by definition did not capture this phenomenon.

In addition to such demographic change, the traditional models failed in some typical planning cases. For example, transport policies aimed at not using the car for the work commute predicted a substantial reduction in mobility. However, it turned out that other household member used the car left at home for other activities, either reducing the positive impact or even resulting in increased mobility. The reason traditional four-step models failed to predict this effect was that they did not incorporate any mechanism for task allocation and car use at the household level; they were typically individual-level models often considering the activities separately. Another example, relevant to many European countries, was the discussion about more flexible opening hours of stores in the evening or on Sundays. It was difficult to predict the effects of these policies using traditional models because these models did not incorporate any constraints on travel behaviour. Finally, to give one more example, the discussion on sustainability increased the need for considerably more detailed transport forecasts.

In the mid-1990s, as part of the Clean Air Act, the US government started a program for a new generation of so-called activity-based models of transport demand. Funding for several development projects was provided. Several other countries in the world soon followed, and many cities and consulting agencies started to explore the potential of this new generation of models. The academic community not only started this discussion but also dramatically increased its endeavours to develop models of activity-travel patterns. It was realised that transport is a demand, derived from the conduct of activities at the household level. Hence, in order to better understand and predict transport patterns, one needs to predict which activities are conducted where, when, for how long, with whom, the transport modes involved, route choice and the implied sequence of activities and stop patterns.

Considerable academic progress has been made since and the first applied experience has become available. The field may be ready for a large-scale adoption of this new generation of transport models. In this regard, it is important to note the US Transportation Research Board is about to install a committee on moving activity-based model to practice.

In this key-note address, I will first briefly discuss the different types of activity-based models that have been suggested in the literature. I will first concentrate on these models and then discuss very briefly their impact on shifting ideas about how to develop integrated models of land use –transport demand. Next, I will briefly go into the implications of this new modelling approach to data collection. Finally, I will explore the relevance of this new approach for transportation planning in developing countries and speculate about expected directions in the future.

2. ACTIVITY-BASED MODELS

The shift toward activity-based analysis first of all has stimulated a tremendous amount of research activities focused at the various facets of activity patterns and time use. We will not discuss these studies in any detail. More relevant to this presentation is the work on comprehensive models, examining a multitude of facets simultaneously. These attempts can be classified into two general streams: utility-maximising models and computational process models. Utility-maximising models assume that individuals schedule their activities such that their utility is maximised, subject to a set of constraints, although constraints are usually not included in much detail. Activity scheduling behaviour is not addressed specifically, but follows automatically from the prediction of full activity-travel patterns. The best known of these approaches can be best viewed as the logical extension from trip through tour to activity-based models, relying on the nested logit model. In contrast, computational process models rely on a set of decision rules to predict activity-travel patterns.

2.1 Utility-maximising models

One of the first models in this tradition is the one developed by Adler and Ben-Akiva (1979). They assumed that individuals evaluate a number of complete, one-day activity-travel patterns and choose the pattern that maximises their utility. A multinomial logit model was used to predict the choice of activity pattern. The probability of choosing a particular activity-travel pattern was assumed to be influenced by characteristics of the pattern, such as the number of sojourns and tours made for various purposes, the total travel distance travelled by particular modes, the destinations visited, time expenditures to various activity classes and socio-demographics. This seminal work led to the development of more sophisticated models of activity-travel patterns.

2.2 Logit models

2.2.1 Starchild

The best known and most advanced of these models is STARCHILD, developed by Recker *et al.*, 1986a, 1986b.

Similar to Adler and Ben-Akiva, activity scheduling is viewed as the choice between types of activity patterns. It is assumed that the utility of any specific activity pattern is comprised of the utilities of each of its time-component parts. Each activity segment of an activity pattern was represented as a triad consisting of (a) travel time (if any) to the activity, (b) waiting time (if any) for the activity to commence, and (c) actual participation time. Given that the utility of participating in an activity is only realised if the participation actually takes place, and there exists a non-zero probability that participation will not take place, individuals were assumed to consider the expected utility of participation duration in planned activities. The authors assumed that individuals derive some disutility from time spent waiting to participate in out-of-home planned activities. Travel was assumed to offer utility only within the context of the access it provides to a desired activity. The utility of reserving flexibility in the planned activity pattern for unforeseen events was made dependent upon the likelihood that these events may arise. The utility of potential participation was assumed to be equal to the utility of the expected time spent participating in an unplanned activity at a given location.

Specific additional assumptions were made regarding the utility of the various activities and the probability of occurrence of an activity. The operational version of the model was much simpler. Typical activity-travel patterns were extracted from observations of space-time behaviour. The multinomial logit model was used to predict the choice between these alternative activity patterns. Constraints were explicitly incorporated in the model. Activity scheduling behaviour is also not addressed separately but follows from the predicted activity-travel patterns.

2.2.2 The daily activity schedule model

It was not long before the multinomial logit was replaced by the nested logit model. The various aspects of activity-travel patterns were treated as nests and a well-known methodology, albeit considerably more complex, was used to estimate the choice model. The model in this tradition that has received most attention is the daily activity schedule model, initially proposed by Ben-Akiva, *et al.* in 1994 (see Ben-Akiva, *et al.*, 1996), and later elaborated in a series of projects (Bowman, 1995; Ben-Akiva and Bowman, 1995; Bowman, *et al.*, 1998; Bowman and Ben-Akiva, 1999). It is however not the first nested logit model. Predecessors include Kawakami and Isobe (1982, 1988, 1989), who developed a model for workers only, conceptualising the generation of activity patterns as a hierarchical choice process. First, individuals have to decide whether or not other activities will be performed before or after work. Next, a pattern type is selected.

Central to Ben-Akiva and Bowman's model is a daily activity schedule, which represents the individual's demand for activity and travel as a multidimensional choice encompassing all the combinations of activity and travel an individual might choose through the course of a day. The daily activity pattern is characterised by (a) a primary activity, with one alternative being to remain at home for all the day's activities; (b) the type of tour for the day's primary activity, including the number, purpose and sequence of activity stops; and (c) the number and purpose of secondary tours. For each tour in the daily activity pattern the tour schedule includes the choices of destinations for activities in the tour as well as the mode and timing of the associated travel.

The choice of a daily activity pattern determines the number of secondary tours. The choices of secondary tour time, destination and mode were assumed conditioned upon the choice of a daily activity pattern. The model structure was simplified by removing secondary destinations from the tour schedules.

The utility of a particular alternative in a higher nest is influenced by the utility of the lower level alternatives comprising it. This decomposition of the activity schedule yields a finite set of mutually exclusive and exhaustive, discrete alternatives available to the individual. Sequential estimation techniques were used to estimate this nested choice model.

2.2.3 Wen and Koppelman

Another nested logit model of activity-travel patterns was recently suggested by Wen and Koppelman (1999, see also Wen, 1998). Their model is considerably less complicated. They identified three nests of decisions. The first nest describes household subsistence (work and work-related business) needs and mobility decisions. The second and third nest include a set of short-run decisions. The second nest consists of the generation of maintenance (grocery shopping, personal and household business) activities (stops), and the allocation of stops and autos among household members exclusively or jointly. The final nest depicts individual daily travel/activity patterns through the generation of tours, the assignment of stops to tours, and the selection of locations for each stop and travel mode(s) for tours.

Each nest is assumed to be influenced by a set of individual and household characteristics, land use patterns, and the performance of the transportation system. The long-range decisions were assumed to remain unchanged in the short run. The short-range decisions were decomposed into a two-stage structure. The first stage decisions included three linked choices: the generation of maintenance stops, the allocation of stops among household members and the allocation of autos to stops. The second stage decisions were separated into two choices: the generation of tours and the assignment of stops to tours. The first stage, stop generation and stop/auto allocation models were formulated as nested logit models. A combination of sequential and full estimation techniques was used to estimate the model (Wen and Koppelman, 1999).

2.2.4 Petra

The development of these nested logit models can be characterised as one of struggling with complexity. In order to estimate the models, researchers needed to make limiting assumptions, reducing the complexity of the model. Another good example of this practice is PETRA, another, less complicated, nested logit model, funded by the Danish Ministry of Transport, the Danish Transport Council and the Danish Energy Research Program (Fosgerau, 1998). The model is restricted to three possible travel purposes: work, errands and leisure. Non-home based tours are ignored. Activity-travel chains are conditional on car availability. At the more basic level, mode and destination choice for each tour in the chain are predicted. These choices are conditional on car availability and choice of chain.

To keep the model simple, a number of restrictions is imposed on the activity chains that are modelled. First, a chain contains at most 2 tours. Secondly, a tour has one or two destinations away from home. Thirdly, a chain contains at most three purposes, limiting the number of stop patterns to 4. There are also additional specific restrictions on the occurrences of purposes.

2.2.5 Cobra

Wang and Timmermans (2000) developed another nested logit model which differs from the previously discussed models in that it is not based on revealed preference data but rather on stated preference data. Because the experimental task is different and highly complex, new stated preference design strategies were developed (Wang, *et al*, 2000). Conceptually, they assumed that various kinds of policies influence activity engagement across the week. Four types of activities were distinguished: work, shopping, leisure and social contacts. A specific experimental design was constructed to measure how individuals adapt their pattern of activity engagement to various policies, resulting in an activity program that needs to be implemented on a particular day. Two choice facets were considered: destination and stop pattern. A stop pattern describes the sequence of activities, and is characterised by the number of home-based tours and the timing of activities. Because work is always included and differentiated between work in the morning and work in the afternoon, a particular activity can be inserted in the schedule before morning work, after afternoon work, and in between morning and afternoon work.

The choice of destination was assumed to be influenced by the travel time between pairs of destinations, opening hours, size and parking convenience of the shopping centre, and the size and parking convenience of the sport centre. A joint logit and various nested logit structures were estimated. The best results were obtained for a nested logit model, in which the choice of destination was nested under the choice of stop pattern.

2.3 Mathematical programming models

Recker (1995) formulated the household activity pattern problem (HAPP) in terms of variants of the pickup and delivery problem with time windows, developed in mathematical programming. He showed how this formulation can be used to address problems of vehicle allocation, task allocation, ridesharing and non-travelling options, including many constraints. The objective function then is to minimise some disutility function, including travel costs, travel time, delay, and risk. Simple examples were given that generated problems in finding the solution. The model has not been applied yet, and it is unclear what operational problems will arise when it is applied to specific real-world problems.

2.4 Prism-based models

The Prism-Constrained Activity Travel Simulator (PCATS) was developed by Kitamura and Fujii (1998; Fujii, *et al.*, 1997, 1998). It is a system that simulates activity-travel behaviour while considering three types of constraints: prism constraints, availability of travel modes, and recognition of potential activity locations. In addition to a stand alone model, it is used to generate alternative activity-travel patterns to form estimation choice sets that are used by PCATS-RUM.

The latter model assumes that individuals maximise the utility associated within the open periods, subject to the above constraints. Open periods are periods during the day during which an individual is free to travel and engage in activities. They contrast with blocked periods, which are characterised by commitments to conduct particular activities at particular locations. The utility associated with a particular activity-travel pattern is assumed to be the sum of the utility associated with activities and the utility associated with trips. It is assumed that the utilities are affected by the attributes of the activities and trips, and other exogenous variables. Thus, the model could also have been classified as a utility-maximising model.

2.5 Suites of linked models

Bhat (1999) developed a comprehensive framework for activity-travel generation. This framework originally considers workers only. Their activity-travel pattern is divided into several periods: before morning commute pattern, morning commute, midday patterns, evening commute and post-home arrival pattern. These patterns are described by a series of characteristics, including number of tours, number of stops, mode choice, etc. Bhat, however, also suggested a series of models to predict components of his conceptual framework. Although these have been largely published as isolated modelling efforts, when used in combination, a more comprehensive modelling approach results. One of these models predicts evening commute mode choice, the number of evening commute stops and the number of post-home-arrival stops. Other components of his system involve the modelling of duration. Bhat suggested using hazard models for this purpose. Similarly, he suggested to jointly model activity type, activity duration and travel time duration. More recently, a similar approach was suggested for non-workers (Bhat and Misra, 2001).

2.6 Computational process models

The assumption of utility-maximising behaviour, characteristic for most of the models discussed in the previous section, has been criticised by some scholars who have argued that individuals do not necessarily arrive at “optimal” choices, but rather use heuristics that may be context-dependent. A formalism to represent these heuristics is the use of IF...THEN...ELSE rules, or production system, which specify which decision will be made as a function of a set of conditions.

Computational process models conceptualise choices as outcomes of such heuristics. Thus, in its most basic form, a production system is simply a set of IF-THEN rules, which take on the following form: IF (condition = X) THEN (perform action Y). This modelling approach assumes that activity patterns may be represented in terms of a sequence of state-action (S-A) pairs in which the state S represents a possible state of both the individual and the decision making context, while the action A represents the decision taken in that state. A set of such rules makes up the model.

2.6.1 Scheduler

The first computational process is SCHEDULER, developed by Gärling, *et al.*, (1989). It is primarily a conceptual framework for understanding the process by which individuals organise their activities. According to their model, individuals and households are assumed to try and attain certain goals. Activities are defined as means, which the environment offers to attain these goals. Individuals and households hold beliefs about how instrumental activities are to attain their goals. These beliefs dictate their preferences for activities. Choice of participation in activities is determined by these preferences in conjunction with prior commitments, constraints and the like.

Scheduling is defined as the process of deciding how to implement a set of activity choices during a defined time cycle. It entails an interrelated set of decisions made by the individual, interactively with other (household) individuals, concerning who will participate in the activities, when, where, for how long, and how to travel between locations where the activities can be performed. The model assumes that feasibility of the schedule is a primary goal, minimisation of travel is a secondary goal.

Activity scheduling is based on the principle of heuristic search. That is, instead of assuming that all alternative schedules are generated, it assumes that a set of activities is chosen from what is called an individual's long-term memory. For most people the selected activities are likely to consist of a few with high priorities to be performed during the day. It involves the retrieval of memorised information about the environment and the identification of when and where each activity can be performed. The model then first partially sequences the activities on the basis of identified temporal constraints and then the activities are sequenced such that total travel distance is minimised using a variant of the 'nearest-neighbour' heuristic (Gärling *et al.*, 1986, 1988, 1989).

Starting with the activity to be executed first, a more detailed schedule is finally 'mentally executed' with the aim of evaluating its feasibility under the given circumstances. In this stage, more detailed information is also sought about activity duration, departure times, travel times, and wait times. In the 'mental execution', conflicts threatening the feasibility of the schedule, such as overlapping end and start times, are resolved, if possible, by changing the order of the activities in conflict (according to a satisficing principle rather than on the basis of a choice between all possible alternative orders), or by replacing a chosen activity with another one of lower priority.

When a schedule has been formed for the activities with the highest priority, attempts may be made to find less prioritised activities in the long-term memory, which fit into open time slots of the schedule. The model assumes that scheduling may continue as the schedule is being executed. Thus a skeletal schedule may be worked out for only a few activities, stored in the short-term memory, and other activities may be added while executing the skeletal schedule.

SCHEDULER has been operationalised as a production system, which chooses the activities that are subsequently performed at particular locations. Thus, first the first activity to perform is chosen, then the second and so on. The model describes activity choice, destination choice and the timing of activities. To choose the consecutive activities, a heuristic function is applied which incorporates activity type, travel time, time pressure due to available time slots, wait times, attractiveness of locations and activity duration. Consequently, in the operational model the consecutive activity choices are made independent of each other, apart from the history of the preceding choices.

That is to say, the effect of the current choice on the possibility to perform other activities later is not incorporated in the activity choice.

The input data for the model consist of an activity agenda, which defines a set of activity durations, available locations and available time slots. Furthermore, travel distances between locations and travel speeds of various transport modes are assumed to be known. The model has been applied to predict the activity patterns of commuters after the introduction of tele-commuting (Golledge, *et al.*, 1994). A GIS was used to generate input data in the form of available locations and travel times between various locations.

2.6.2 Gisicas

This model, developed by Kwan (1997), can be best viewed as an implementation of SCHEDULER. This GIS-based system contains various options. Given an activity agenda, it begins scheduling by fitting the activities on the agenda into the free time a person has, and orders them into a sequence. Activities with higher priority are ordered first, and the time constraints for performing certain activities are also taken into account. Various search heuristics can be specified to identify the locations where the activities can be carried out. The system then reports a preliminary schedule and also lists the activities that cannot be scheduled. The spatial search is based on a dynamic identification of feasible locations.

Both GISICAS and SCHEDULER are not truly, fully operational models. Many aspects need to be further developed and operationalised. Especially, the derivation of the mechanisms from diary data is an issue. In a series of separate papers, parts of the conceptual model were further elaborated, or were part of experimental study. The publication coming closest to some form of operationalisation of the conceptual framework is the one published in 1998 (Gärling, *et al.*, 1998). The authors acknowledge that their model overlooks some of the complexities of their theory. They focus on the scheduling part, and make the following simplifying assumptions: (1) the set of activities to be scheduled is given; (2) scheduling consists of sets of incremental choices of an activity, a location, and a start time; (3) choices are made according to a rule in which a set of hierarchically organised factors are combined linearly; (4) the variation in utilities of the activities over time is given; (5) routine activities are defined as fixed in time and space and their utilities are high when they are scheduled to be performed; (6) no learning takes place. Several rules are formulated but not tested.

The priority that an individual includes an activity in the schedule is viewed as a function of activation (the state of readiness to perform any activity), the anticipated utility of performing the activity and costs. Activation is assumed to be a negative exponential function of the number of activities already scheduled. Costs are a function of the judgement whether there is sufficient time, and the judgement of the costs to travel from the current location to locations where the activity can be conducted. It is based on how aversive the location is, travel time, wait time and time left. Normalised weights were used for these rules. The analyses were based on computer simulations for fictitious persons and schedules.

2.6.3 Amos

Another model system that bears some resemblance to computational process modelling, is AMOS, a dynamic micro-simulator of household activities and travel over time and space (Pendyala *et al.*, 1995, 1998). AMOS is an activity-based model of travel decisions that simulates the scheduling, and adaptation of schedules and resulting travel behaviour of individuals and households. Adaptation behaviour is conceptualised but not operationalised as a learning process in which individuals gain knowledge about aspects of the new travel environment as they attempt to adapt to it. Adaptation behaviour is viewed as a trial-and-error process in which the individual tries out alternative activity-travel options until a suitable option is found. The “satisficing” rule is used as a guiding principle.

Starting from an initial set of activity-travel patterns, AMOS simulates each individual's adaptation process and finally determines how individuals and households will adapt to the new environment. AMOS comprises a baseline activity-travel pattern synthesiser, a response option generator, an activity-travel adjuster, and an evaluation routine. The Baseline Activity-Travel Pattern Synthesiser evaluates the impact of a change in the travel environment by estimating, for each household or individual, changes in the activity-travel pattern. The Response Option Generator generates and prioritises a series of options that individuals are likely to consider when faced with changes in their travel environments. Response options include chain trips, change trip frequency, change departure time, change mode, or any combination of these responses, plus maintain the same activity-travel pattern. Neural networks were used to determine which response options an individual may conceive as a result of changes in their travel environment.

The application of the model system is described in a number of papers (Kitamura, *et al.*, 1995; Pendyala, *et al.*, 1997, 1998).

2.6.4 Smash

Certain components of AMOS are very similar to SMASH (Ettema, Borgers and Timmermans, 1994, 2000). This model concentrates on the process of activity scheduling. The scheduling process is assumed to be a sequential process consisting of a number of consecutive steps. In every step the schedule, which is empty at the beginning of the process, can be adjusted by one of the following basic actions: (i) adding an activity from the agenda to the schedule; (ii) deleting an activity from the schedule; (iii) substituting an activity from the schedule with an activity from the agenda; (iv) stopping the scheduling process. By repeatedly applying one of these basic actions, the schedule is constructed and adapted until a satisfactory schedule is created. In the schedule, only the locations and the sequence of the activities are stored. It is assumed that the exact start and end times are determined by the actual duration of previous activities for temporally non-fixed activities and are inherent to temporally fixed activities.

In every planning step, the production system creates all possibilities to perform the basic actions. For instance, in the case of substitution, all activities in the schedule can be replaced by all activities on the agenda, which can be inserted in every position in the sequence. Of all possible options then the action which gives the highest utility is performed. This assumption implies that SMASH incorporates notions of both production systems and utility-maximisation. The utility of the stop action is zero by definition. This implies that the process is aborted if the utilities of all options of the add, delete and substitute actions are less than zero.

To identify feasible scheduling decisions at each stage of the scheduling process, scheduling decisions are subject to three sets of constraints. First, the scheduling decisions should not lead to violation of sequence constraints. Secondly, one should be able to implement the schedule, given activity durations, available time windows, and implied travel times. Finally, the same activity cannot be conducted at the same location during consecutive episodes.

A nested logit model is used to operationalise this notion. The higher nest contains the decision to stop the scheduling process and accept the current schedule, or to add, delete or reschedule an activity. The lower nest describes the choice of the specific add, delete and reschedule options. It is assumed that the decision to stop scheduling, or to continue, is based on characteristics of the current schedule, the history of the scheduling process, and the expected maximum utility of the lower nest. The utility of alternatives at the upper nest is a function of the total time spent on activities and the total travel time. The number of preceding stages is taken as an indicator of the history of the process. The utility of the alternatives in the lower nests is considered to be a function of the frequency of the activity, the total travel time implied by the schedule, and the time spent on each of the activity types.

The estimated parameters were largely in anticipated direction, but the estimated inclusive values for the add and reschedule options violated the assumptions underlying the nested logit model. A Monte Carlo simulation suggested that the time expenditures on in-home task, in-home leisure, out-of-home task, and travel were predicted accurately. However, the model significantly underestimated the amount of time spent on out-of-home personal activities and the total amount of time spent, whereas shopping was over-predicted. The number of different activities, the number of locations, and the number of trips were also over-predicted.

2.6.5 Albatross

The only fully operational computational process model in the transportation literature to date is Albatross (Arentze and Timmermans, 2000). A prototype of the model was developed for the Dutch Ministry of Transport. The model is also the most comprehensive to date: it predicts activity choice, destination choice, timing and duration, choice of travel party, multi-mode choice, and choice of stop pattern and activity sequencing behaviour, subject to spatial, temporal, household and institutional constraints, and dynamic choice sets. The model assumes a pre-defined order of decisions, which is derived from an assumed priority ranking of choice facets of activities and a priority ranking of activities by type. Decisions are made from high to low priority for each choice facet and within each facet from high to low priority activity.

The rules that drive the various choices were estimated from activity-travel data using a Chaid-based algorithm. Later, the authors explored and compared other tree induction and data mining algorithms (Arentze, *et al*, 2000; Wets, *et al*, 2000). More relevant, however, for the present discussion is their work on more sophisticated scheduling principles. Arentze and Timmermans (2001a) developed an induction learning system in which individuals first are involved in search behaviour and then gradually switch to a more goal directed behaviour. Perhaps even more relevant is the co-evolutionary learning algorithm that they suggested (Arentze and Timmermans, 2001b). Rather than applying the derived decision rules separately and sequentially, information about other decision tables is taken into consideration. The results of their analyses indicated that this alternative algorithm increased the predictive performance of the model system.

2.6.6 Aurora

Timmermans, *et al* (2001) suggested a utility-based model of activity-travel rescheduling behaviour. Their model is called Aurora: Agent for Utility-driven Rescheduling Of Routinized Activities. A logistic equation is used to represent behaviour, which is not necessarily optimal (maximising). The authors do allow for different decision strategies, all of which are captured in the form of the utility function. Originally, they considered duration reduction and the rescheduling of activities as a result of time pressure only, but this model was elaborated and generalised to include other facets of activity-travel choice (Joh, Arentze and Timmermans, 2001). Although the model was developed as a rescheduling model, the underlying principles can also be used as a model of activity scheduling behaviour.

The utilities of activities are assumed to be time, history and context-dependent. Individuals are assumed to reschedule their activities such that it will increase the total utility, consistent with the overall decision strategy and subject to a set of (process) conditions. At the present stage of development, the model has only been illustrated using numerical simulation. The development of a procedure to estimate the model is on the research agenda.

3. INTEGRATED LAND USE – TRANSPORT MODELS

Integrated land use –transport models are more comprehensive than models of transport demand in that they attempt to establish a link between land use and transport and vice versa. Measures of accessibility, resulting from a transport model are fed back into a model predicting land use change.

An examination of the history of integrated land use – transport models suggests that after some time lag, the state of the art in modeling transport demand are incorporated into the integrated land use – transport models. Hence, since activity-based models of transport demand have become the research frontier since the mid 1990's, plans have been announced to develop activity-based, micro-simulation methods. Fully integrated models do not exist yet, but some progress has been made.

3.1 ILUTE

One ongoing research programme focused on the development of activity-based integrated land use and transport models is the Integrated Land Use, Transportation, Environment (ILUTE) modelling system which is under development by a consortium of researchers in Canada from the universities of Toronto, Calgary, Laval and McMaster (Miller and Savini, 1998). It represents an experiment in the development of a fully microsimulation modelling framework for the comprehensive, integrated modelling of urban transportation - land use interactions, and, among other outputs, the environmental impacts of these interactions. As of to date, only some of the key aspects of the envisioned system have been reported in the literature. It differs from earlier work in a number of important ways. First, it differentiates between persons and households. Secondly, the urban system state evolves over time from an assumed known base year and no particular assumptions concerning system equilibrium are required. Thirdly, it differentiates between firms, which are modelled as agents. Fourthly, in addition to zones, buildings are recognized. Finally, as indicated, activity-based models of transport demand replace the simpler trip or tour-based models. The goal here is to develop a model, which schedules individuals' activity-travel patterns within a household context, which requires some original work as most current activity-based models are fundamentally person-oriented. Moreover, the goal is to develop multi-day models as opposed to the single day models that dominate the field.

Within ILUTE a consistent conceptual structure is applied to modelling individual consumers within a given market. This involves of a three-stage process consisting of (i) the decision to become active in a market, (ii) search and (iii) bidding and search termination. The envisioned model system represents an attempt to combine such of the latest approaches in transport modelling, such as an activity-based approach. To some extent, the plans go beyond the incorporation of such a model in that some of the concepts that are discussed still need ground-breaking original research.

3.2 Ramblas

The system is developed to estimate the intended and unintended consequences of planning decisions related to land use, building programs and road construction for households and firms (Veldhuisen, *et al*, 2000). The model allows planners to assess the likely effects of their land-use and transport plans on activity patterns and traffic flows. It simulates the whole Dutch population of 16 million people.

The input of the simulation model consists of the distribution of various types of households across the different kinds of dwellings per zone, and the distribution of land uses and dwellings per zone. These variables are external to the simulation. Changes in these variables are externally monitored. Households are classified according to their size, and for each class the age and gender of household members is calculated. The spatial attributes of the area (i.e. land use, dwelling stock and road system) are treated as variables that can be manipulated by planning. The planning of the road system is also dependent on decisions of the various planning authorities. The spatial distribution of activities and trips are treated as dependent variables. Thus, the model enables us to predict the likely consequences of possible policy decisions on activity patterns and thus estimate the effectiveness of such policy decisions. In particular, these decisions concern changes in land use, dwelling stock and road construction.

The aim of the micro-simulation is to predict which activities will be conducted where, when and for how long, the transport mode involved and which route is chosen to implement the activities. National data are used for this purpose. The first step in the micro-simulation then involves for every individual in the study area to (i) identify the corresponding population segment, and (ii) draw at random from the national distribution the activity agenda and transport mode. Population segments were identified on the basis of gender, age, employment status and educational achievement. Twenty-four different segments are used. Seven activity classes are distinguished: work, child care, shopping, personal/medical care, school or study, social participation and social contacts. For each of these out-of-home activities, the distribution of chosen transport mode is derived.

Using this data, the first step of the micro-simulation results in an activity agenda for a simulated individual. The next step of the simulation addresses the problem of how this agenda is implemented in space and time. To that end, various additional operational definitions that drive the allocation of activities to particular destinations were made. In the case of the work activity, it is assumed that the travel time observed in the diary constitutes the time people are willing to travel to work, given the transport mode involved. In terms of the micro-simulation, this means that a zone of employment is drawn at random from the total number of available jobs in the region, delimited by this maximum travel time. Job locations are drawn without replacement, hence the set of job locations is reduced during the simulation.

In the case of study at school, a different principle is employed. It is assumed that children going to elementary schools invariably choose the school nearest to their residence. Although this assumption is not perfect, it reflects the planning of the school districts in the Netherlands. For students going to secondary schools, an action space of 45 minutes of bicycling time is assumed. Schools are drawn at random from this action space. The same principle is used for students of higher education, but now the distribution of employment in higher education is used as the distribution from which the school is sampled.

The latter principle is also used to determine the destination for shopping and services. The destination is drawn at random from the distribution of employment in the relevant services. As for the final activity classes, social participation and social contacts, the presence of other households rather than employment, is used as the distribution from which the destination is sampled.

Having established these origin-destination pairs, the next step of the simulation involves the micro-simulation of traffic flows. Travel time is simulated using the "speed-flow" calculation method. For every chosen interval, the traffic flows are graphically displayed on the computer screen.

3.3 The Irvine simulation models

Based on McNally (1997, 1998), Kulkari and MacNally (2000) suggested a simulation model of activity-travel patterns that closely resembles the core of the Ramblas model. One important difference however is that their model is based on a classification of representative activity-travel patterns. In common with Ramblas, however, some key aspects of such patterns are extracted from the data and used to simulate activity-travel patterns in a particular environment.

More recently, the group is exploring the use of multi-agent systems (e.g., Marca, *et al*, 200; Rhindt, *et al*, 2003). The scope is similar to ILUTE, but the methodology that is used seems different.

3.4 ILUMASS

The integrated land-use modelling and transportation system simulation project aims at a microscopic dynamic simulation of urban traffic flows into a comprehensive model system, which incorporates both changes in land use and the resulting changes in transport demand (Moeckel, *et al*, 2002). Micro-simulation is used to trace demographic development, household formation, firm lifecycles, construction of houses and buildings, and labour and household mobility. These modules are linked to models of daily activity patterns and travel and goods movements. Work on developing this model has just started.

3.5 Multi-agent models

Recently, some authors have advocated the use of multi-agent models. The concept of a multi-agent system has different meanings in the literature. Sometimes, it refers to autonomous pieces of software that communicate and jointly solve a problem. The Albatross system has been positioned like that. The word Multi-agent systems is also used to indicate that each individual traveler has certain characteristics, and behavioral rules. Object-oriented software is then used to simulate aggregate activity-travel patterns. Finally, agents can also be different stakeholders in urban development and control, again each with their own behaviour. The interaction, communication and negotiation then determine urban evolution and the resulting activity-travel patterns.

A simple, prototype, example of the latter kind is an ongoing project at the Urban Planning Group in Eindhoven. Each actor is represented by an agent. Each agent derives a certain utility from each cell in the study area, depending on its site characteristics, the distribution of other land use and accessibility. A negotiation protocol then determines the aggregate land use pattern and the distribution of facilities. Next, each individual of the population is represented as an agent, with certain socio-demographic characteristics and behavioural rules, derived from an activity-travel diary. These rules are applied to simulate activity-travel behaviour and the use of facilities in the study area. The subsequent behavioural patterns result in certain turnover at the facilities and the facility providers, also represented as agents, react or proact to changing turnover levels. All these interactions between the agents simulate the dynamics of the activity-travel patterns and the dynamics in land use patterns and distribution of facilities.

4. IMPLICATIONS FOR DATA COLLECTION

Because activity-based models of transport demand involves more facets, traditional travel surveys no longer suffice to estimate such models. Travel diaries are more appropriate as they record the timing, duration and sequence of activities, together with information about the other relevant facets of activity-travel patterns. Different types of diaries can be distinguished. An out-of-home travel diary only reports the activities that were conducted out-of-home. This type is adequate if one is only interested in travel and not in any possible substitution between in-home and out-of-home activities.

A second type is the full activity diary. It records both in and out-of-home activities and their characteristics. The principle of organising the diary is based on the activities. Finally, a day planner format can be used. This format is using time as the organising principle.

Completing an activity-travel diary can be quite demanding. Inconsistencies and missing information often happen. Moreover, the coding of such data requires a substantial amount of time. It is therefore not surprising that several computer-assisted survey instruments have been developed. The first of these is Magic (Ettema, Borgers and Timmermans, 1994): a DOS based program, developed to collect data on activity scheduling and rescheduling. Better known is the Computerised Household Activity Scheduling survey (CHASE) (Doherty and Miller, 1997) that was developed to record household multi-day activity scheduling decisions.

It is designed to track the sequence of steps taken by individuals to form weekly activity schedules. It is a much more user-friendly windows-based program. Later, a Internet-based version iChase (Lee, et al, 2000) and a GIS-based version (Kreitz and Doherty, 2003) were developed. The advantage of these computerised versions is that in principle many consistency checks can be incorporated in the software. Sylvia for example (Arentze et al, 1999) was developed for ad hoc checking, cleaning and repairing activity-travel diaries and it was embedded in Virgil, a virtual reality and Gis based system.

In addition to computer-assisted instruments, the field also started to explore the possibilities of using global positioning systems and cellular phone. Obviously, while this new technology will improve the accuracy of the travel component (routes, destinations), information about other facets of activity schedules, required for model estimation still need to be collected separately.

5. EXPECTED DIRECTIONS

This brief discussion of recent advances in transport demand forecasting illustrates that significant progress has been made. Existing nested logit models have been extended to predicting activity-travel patterns. The first prototype of a computational process model has become available. The technology for collecting activity diaries has been improved. Is the field ready for applying this new generation of transport-demanding forecasting models to practice in both developed and developing countries?

Because people and organisations have invested a tremendous amount of time and other resources in the models, data, software and procedures they use, inertia is always expected. I believe that practitioners and policy-makers will and should only try a new generation of models if these models either perform better than the models that are currently being used or allow one to address policy issues of lasting nature that cannot be addressed with the current models. Moreover, one will always have to judge whether such new or improved possibilities are worth the required new investment.

Unfortunately, to my knowledge, there is a complete lack of empirical knowledge about the relative performance of activity-based models of transport models vis-à-vis the performance of four-step models. The academic transport community has no tradition of developing and testing new models against some benchmark and common datasets. Hence, we simply do not know whether activity-based models of transport demand outperform traditional models and hence whether their application to practice can be defended in terms of improved predictive accuracy. A comparison of a nested logit model/suite of linked model, Albatross and PCATS indicated that Albatross was performing best and the nested logit model worst for that data, but this result still does not say how these models perform against four step models.

The introduction of activity-based models at the present state of knowledge should thus be defended in terms of the kind of new policies that can be evaluated with this new generation of models. As indicated in the introduction, the development of activity-based models has been advocated in terms of the need to explore activity and travel in households as opposed to individuals, the need to incorporate institutional constraints, the need to analyze the possible substitution between in-home and out-of-home activities and the need for a more detailed forecast in time and space to provide data relevant for assessing the environmental impact of transport. An examination of the relevant literature, however, suggests that the existing activity-based models have primarily focused on improving the prediction of the traditional aspects of demand forecasting such as timing and duration. Although some progress has very recently been made in developing household-level models, task allocation and the use of the car in the household are not addressed at all or only in simple terms by most existing activity-based models. Likewise, only some computational process models incorporate institutional constraints.

However, the effects of institutional constraints on shifting activity-travel patterns can only be predicted if the model has mechanisms to simulate how individual reschedule their activities and travel in time and space. The models, relying on observed patterns such as the nested logit models, therefore do not open the possibility of addressing such new policies in a straightforward, rigorous manner. This also holds true for policies such as congested pricing. Most models allow one to predict changing departure times, but except for Amos and Albatross, they do not allow one to predict the effects on the complete daily activity-travel schedules. Also, there is still a lack of work on substitution between in-home and out-of-home activities.

Most progress has been made in providing more detailed information about activity-travel patterns (timing, number of stops, etc) that can be used for a better assessment of environmental impacts of transport, although still a lot of work in this area on developing the indicators should be done.

The question then becomes whether such new, but still limited opportunities suffice to make the investment. The answer will depend on the city and country. If transport and land use policies in a country are still primarily concerned with increasing capacity, it seems that activity-based models have little more to offer than the traditional four-step approach. Their predictive performance may be better, but we don't know and the possible improvement may not be relevant for focus on proving additional transport infrastructure. If the land use and transport policies are primarily concerned with optimising the use of the existing infrastructure and the societal costs of wrong or ill-founded policies are relatively high or the process of governance requires relevant scientific support and evaluation, activity-based models are potentially relevant and the way to go. It should be realised, however, that the models should still be further developed.

To finish my presentation, let me identify some areas that require further development. I expect that the field will move into such directions. First, existing activity-based models are typically based on one or two-day travel diaries. Consequently, they will not pick up any variation over longer time horizons. There is need to further develop the dynamics of existing models. Secondly, new intelligent transportation systems and communication technology will influence people's activity and travel decisions. New or improved models that will predict how people change their activity-travel patterns in the short term as a function of intelligent information systems and new communication technology on a daily and weekly basis are thus required? Thirdly, it has been realized that transport is a demand derived from activities. However, it should also be realized that in turn the choice of activity is also made within a spatial context and it turn is linked with other lifestyle decisions related to household formation, job choice, and significant expenditure and investment decisions such as housing, vehicles, savings, and holidays. Attempts at modelling the relationships and nature of such long-term decisions are thus to be expected and required. Finally, from a policy perspective, transport cannot be viewed in isolation from land use, economic and social policies. A significant investment on integrated models is required and expected. Planning has moved from a top-down, comprehensive approach to a bottom-up, incremental approach and this shift should be reflected in the type of models that we develop. The time seems ripe to develop integrated multi-agent systems that simulate the behaviour of key stakeholders in economic and urban development, including economic development agencies, real estate companies, firms, urban planners, and transport planners and engineers.

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