Activity based travel demand modelling

- a literature study

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Preface

This note is a literature study, reviewing the state of practice in activity based travel demand modelling.

Activity based modelling of travel demand treats travel as being derived from the demand for activity participation. Travel is therefore viewed in a broader context of activity scheduling in time and space in activity based travel demand models. This is an important improvement compared to conventional demand models, which take single trips as their starting point.

Activity based travel demand modelling has been practised since the beginning of the 1980's. However, development of such models has accelerated during the last ten years, where complex policy measures such as road pricing and travel demand responses have become increasingly important in transport planning. The interest in understanding and modelling travel demand responses also motivates this study.

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1 Background

This note comprises a literature study regarding activity based travel demand modelling. The note refers to a long list of articles, reports, M.Sc. theses, Ph.D. theses and textbooks in the field of activity based travel demand models from both Denmark and abroad.

The main aim of the literature study has been to review the present knowledge regarding this type of travel demand models. Second, the study is hoped to bring forward some ideas that can inspire the future practical work with activity based models in Denmark.

The note begins with a summary of the main results of the literature study. An introduction to activity based modelling is given in chapter 3. Chapters 4 and 5 describe the main characteristics of two main groups of activity based models, i.e. discrete choice activity based models and simulation models. A comparison of the two methods is given in chapter 6.

The relevant literature is found via references in different articles, personal contacts and the Internet.

2 Summary

Activity based travel demand models predict travel behaviour as a derivative of activities. Therefore, by predicting which activities are performed at particular destinations and times, trips and their timing and locations are implicitly forecasted in activity based models. Activity based models belong to the third generation of travel demand models.

The first generation travel demand models were developed in the late 1950’s. That period was characterised by a rapid increase in car use followed by major investments in new road infrastructure. In order to assess the impact of these investments, models that could be used to predict travel demand on the long run were needed. This resulted in the development of trip based models, which predicted traffic flows between traffic zones, i.e. aggregate models. These models are also known as four-stage models because travel was assumed to be the result of four subsequent decisions, i.e. trip generation, trip distribution, mode choice and route choice. The derived nature of transport is understood and accepted in the trip based models, but that is not reflected in their structure.

Dissatisfaction with the forecasting accuracy of these models increased dramatically during the 1970’s where the transport planning turned the focus from the global infrastructure developments (i.e., regional planning) to the travel needs of a single person (i.e., disaggregate planning). In response to that the transport researchers came up with two new approaches to travel demand modelling at the Third International Conference on Travel Behaviour in Australia, in 1977:

- Disaggregate trip based demand models.

- Activity based travel demand models.

Disaggregate models won the battle at that time and they flourished during the 1980’s and 1990’s. These models are also known as the second generation travel demand models or discrete choice models. They have been applied in many projects world-wide in the last 20 years (especially in the large-scale projects) and yet they have maintained a fundamental error of the aggregate models in their structure, i.e. they analyse each trip independently of other trips made by the same individual.

Road congestion problems together with air and noise pollution problems that arose especially in the beginning of the 1990's resulted in two acts in USA, i.e. The Clean Air Act Amendments in 1991 and The International Surface Transportation Efficiency Act in 1992. These acts have defined the Travel Model Improvement Program of the US Department of Transportation from which a number of activity based travel demand models were sponsored during 1990's.

Theory behind the activity based travel demand models is based on works of Hägerstrand (1970) and Chapin (1974). Hägerstrand's time-geography theory focuses on personal and social constraints when explaining our need for activity participation. Chapin's theory, on the other hand, is more concerned with opportunities and choices than the constraints. The theory postulates that the activity demand is motivated by basic human desires, such as the desires for survival, social encounters and ego gratification.

An activity can be defined as a physical engagement of an individual in something that satisfies his or/and family needs. Activities are motivated by economical, physiological and sociological needs of an individual. Activities can be grouped into various categories, e.g. work, shop, recreation, mandatory, optional, etc. An activity does not necessarily result in a trip, i.e. many activities are completed at home. A decision to engage in an activity represents a complex interaction of:

- Household and individual roles and responsibilities.
- A particular lifestyle of an individual and his family.
- Options on activity type, location and duration.
- Time, space and budget constraints.

Activity based travel demand models rely on the following five paradigms:

- Travel is a derived demand from the activity participation.
- Focus is on sequences of activities.
- Activities are both planned and executed in the household context.
- Activities are spread along a 24-hour period in a continuous manner, rather than using a simple categorisation of 'peak' and 'off peak' events (which are usually applied in trip based models).

- Travel choices are limited in time and space, and by personal constraints.

Taking the above into consideration it is argued that the activity based approach to travel demand modelling gives a rich and accurate framework in which travel is analysed as a daily pattern of behaviour related to and derived from differences in lifestyles and activity participation among individuals. We state therefore that the travel consequences of policies such as road pricing and telecommuting can be modelled adequately only by the activity based travel demand models.

This study includes a description of 10 activity based travel demand models that are divided into two main groups, i.e. discrete choice models and rule based simulation models. An important difference between the two approaches is that the time component is modelled discretionary in discrete choice models while in simulation models the time component is modelled continuously. Simulation models are further divided into two sub-groups, i.e. activity schedule building models and switching models.

Discrete choice activity based models are based on the random utility theory. Structurally, they represent a qualitative extension of discrete choice trip based models. The extension contains improvements in the traditional generation model where now activities (trips) of different purposes are combined in what is called an 'activity pattern' model. Secondly, discrete choice activity based models chain trips into a day-overall activity pattern, taking care of the existing constraints. Discrete choice activity based models can be pictured as large nested logit models where on the higher level an individual chooses a travel pattern and below that are placed tours associated with these activities. The appropriate alternatives (activity, tour, mode, destination, time of travel) are described in the two levels by their utility functions. The model levels are connected from the bottom to the top via accessibility variables. In that way the performance of transport services (that are placed on the tour level) have also impact on the activity patterns. Prior to day travel patterns, these models usually model some aspects of the lifestyle such as the choice of work location and the choice of car ownership. Important strengths of discrete choice activity based models are the following:

- A large set of activities is defined in the travel pattern model, i.e. usually more than a hundred pattern alternatives. They are defined upon the type of the main activity, primary tour structure, secondary tour structure, pattern of intermediate stops, etc.

- Long term effects are included in the model structure, e.g. the choice of work location and the choice of car ownership.

- Attributes of the transport system performance are included in the model structure.

- Discrete choice models are based on the random utility theory, which leads further to the probability models. This is a more accurate approach to modelling choice behaviour than the approach assuming complete consistency in the way people perceive and express their preferences.

- Statistical validation of the model estimates is possible through the application of commercial software.

- Forecasting results of discrete choice models can be validated in a number of ways.

With this approach of modelling travel demand, discrete choice activity based models have often been applied when building operative traffic models that are aimed for long-term forecasts.

Simulation activity based models apply some kind of learning mechanism in order to explain how individuals build activity schedules. The idea with the learning mechanism is that we seldom consider all available alternatives when planning activity schedules. According to the theory behind simulation models, we tend to base activity decisions on some heuristic rules that are applied at some specific situations that we recognise from the past. If a new situation occurs we will again tend to consider only those activities that seem to be logical or appropriate to us. Usually, based on an externally existing activity program the patterns are built step-by-step along the day in these models taking care of the accidental circumstances that can influence the planned activities. Time is modelled continuously in simulation models. Finally, time constraints, location constraints and budget constraints are incorporated explicitly in these models.

Simulation models are often based on specific analyses such as stated preference analyses. With this approach of modelling travel demand, simulation models are mostly applicable for specific planning tasks for which short-term forecasts are needed. There are two types of simulation models, i.e. activity schedule building models and switching models. Activity schedule building models are characterised by the fact that they construct the activity schedule of an individual. Contrary to that, switching models adapt an externally existing activity schedule based on the proposed policy and the defined constraints.

3 Introduction

3.1. Motivations behind the research in activity based travel demand modelling

The two most important theoretical works, which have motivated both researchers and practitioners to model the travel demand from the activity participation point of view are the works of Hägerstrand (1970) and Chapin (1974). Hägerstrand's famous time-geography theory postulates that individuals' activities are limited by a number of personal and social constraints. He divided the constraints between 'capability constraints' (e.g., a need for sleeping and eating), 'coupling constraints' (e.g., having the family for dinner requires that the family members are present at the same place and at the same time) and 'authority constraints' (e.g., opening hours of post offices and shops). This theory postulates that individuals live in a time-space prism in which we can only function in different locations at different points in time by experiencing the time and cost of travel and by considering the above listed constraints. The theory assumes therefore that travelling to certain destinations, at certain times of day and by certain travel modes results from the demand for activity participation.

Chapin's theory is more concerned with opportunities and choices than constraints. The theory postulates that the activity demand is motivated by basic human desires, such as the desires for survival, social encounters and ego gratification. This has later on been modified by some more factors including commitments, capabilities and health.

The activity based approach to analysing and modelling travel behaviour was recognised as a new approach in demand modelling at the Third International Conference on Travel Behaviour in Australia in 1977. In the 1970's, the transport planning turned the focus from the regional planning (associated with large infrastructure investments) to policy planning, where the importance of reactions of individuals is essential. Most of the papers presented at the conference focused on the theoretical side of the new methodology. Some of them were products of a program of studies in the new development of understanding travel behaviour funded by the National Cooperative Highway Research Program in the US and the Social Science Research Council in the UK. It was recognised at the conference that the motivation for the development of activity based travel demand modelling derived mostly from rather poor forecasting results achieved in the trip based aggregate demand models. It was argued that the poor forecasting accuracy of these models occurred most likely due to the models' theoretical mis-specification, i.e. these models failed to recognise the existence of linkages among trips, and between trips and the activity participation of an individual. Most activity based models were developed only in the last ten years and there are several good reasons for that:

- The theory behind the activity based models has evolved slowly as in the first many years these models were only theoretically interesting, i.e. they could not produce forecasting results that could match those from trip based models. Besides, the trip based modelling approach continued to be developed (for instance, through the development of Stated Preference analyses) and these models were able to produce increasingly satisfactory forecasts.

- The complexities in the daily life related to road congestion, and noise and air pollution became important policy issues only in the last 5-10 years. In order to introduce a policy such as road pricing, which can effectively cope with the congestion issue (instead of continuing to enlarge the road network), it became important to develop an adequate modelling tool and that is activity based traffic models.

- We have witnessed a fast development of new technologies such as the Internet and mobile phones in the last 10 years. These technological improvements have developed new possibilities and habits for people such as flexible working hours (including telecommuting), self-employment, part-time working arrangements, teleconferencing and purchasing of items via the Internet. Such a complex activity scheduling can only be described by activity based travel demand models.

Based on the acknowledgement of the above listed points, two acts were announced in USA in the beginning of the 1990's. These are The Clean Air Act Amendments in 1991, and The International Surface Transportation Efficiency Act in 1992. These acts have led to the Travel Model Improvement Program of the US Department of Transportation. Some models described in chapters 4 and 5 have been sponsored through this program.

3.2. Trip based travel demand models

The vast majority of transport planning in urban areas in USA and throughout the rest of the world is still based on the Urban Transport Planning System (UTPS), which was originally developed in the late 1950's. The UTPS is a four-stage aggregate model system that predicts demand on car and public transport networks. The four stages consist of trip generation, trip distribution, mode choice (these three steps are also usually referred to as ‘travel demand’) and assignment (also referred to as ‘travel supply’).

The period of 1950’s and 1960’s was characterised by large motorway investments caused by a fast increase in car ownership in this period. The UTPS was built in order to perform feasibility analyses for these investments. The analysis area in a typical UTPS-project is divided into a number of sub-regional areas, zones, and all input data to the model are on the aggregate (zonal) level. The trip generation model produces estimates of trips generated by each zone. These trips are then distributed between the zone-pairs in order to produce the overall trip patterns in the analysis area. The zone-to-zone trips are then split among available travel modes (usually only car and public transport modes) in the mode choice model. The output from the demand model is trip matrices and they are assigned to the relevant networks in the assignment model. Prior to the car assignment, the car person trips are converted to the vehicle trips by applying the appropriate car occupancy rates.

The model structure of the UTPS suited very well the needs for traffic planning at the time, i.e. they were good enough to point out the basic trends in the traffic developments on the zonal level caused by infrastructure improvements. These models are, however, very robust, which, among other things, means that they produce poor forecasts in the cases where it is important to measure how individuals react to policy changes (e.g., tolls, an introduction of a metro system). Policy planning came in focus during the 1970’s and in response the trip based disaggregate models were developed. The first operative trip based disaggregate model is the San Francisco Bay Area Model from 1978 (Ruiter, E.R. and M. Ben-Akiva, 1978). In most trip based disaggregate demand models it is only the mode choice model that is estimated on disaggregate data (also referred to as discrete or individual based data). This is both revealed preference data (data describing the actual behaviour) and stated preference data (hypothetical data). It should, however, be noted that model systems have been built where some other demand models beside the mode choice models are estimated on discrete data (Jovicic, G. and C.O. Hansen, 2001).

Discrete choice models are probabilistic models where the probability of an individual choosing a given option is a function of his socio-economic characteristics and the relative attractiveness of the option (Ortuzar, J. and L.G. Willumsen, 1990).

Spear (1977) summarises some useful properties of discrete choice models in the following way:

- Discrete choice models are based on theories of individual behaviour. Based on that, it is likely that these models remain stable in time and space.

- These models are estimated using individual data and that has the following two implications:

    - The available information in discrete models is more accurate compared to aggregate models, because aggregate models apply average information for hundreds of individuals.

    - Discrete models are less likely to suffer from biases due to correlation between aggregate units. When aggregating information, the individual behaviour may be hidden by unidentified characteristics associated to the zones and this can introduce biases in aggregate models, i.e. the ecological fallacy.

- Discrete choice models are probabilistic, i.e. they yield the probability of choosing an alternative from the choice set and do not indicate which one is selected. This is a more accurate approach to modelling choice behaviour than the approach assuming complete consistency in the way people perceive and express their preferences.

- Explanatory variables that are included in discrete choice models are multiplied by their coefficients in the utility functions (see properties of random utility theory below). The number of variables can be fairly large in these models, including some very specific policy variables. The coefficients have a direct marginal utility interpretation, e.g. the value of travel time is calculated in discrete choice models as a ratio of time and cost coefficients.

The most common theoretical basis for generating discrete choice models is random utility theory (Domencich, T. and D. McFadden, 1975). In its basic form, the theory postulates that:

- Individuals are perfectly informed about the available travel alternatives.

- Individuals behave rationally, i.e. the alternative which maximises their net personal utility is always chosen.

- The individual’s choice set is predetermined in discrete choice models.

- Each alternative in the choice set is associated with its net utility function. The modeller, who is an observer of the system, does not possess complete information about all the elements considered by the individual. Therefore, the modeller assumes that the net utility consists of a measurable (deterministic) part and a random (error) part. The error component of the net utility allows that individuals with identical observations may select different options.

- The error component of the net utility is a random variable with specific properties.

The assumptions on perfect information and rationality can be relaxed by letting the error term represent a degree of random behaviour. These assumptions are thus not necessarily as restrictive as they may appear.

Discrete choice models have improved the travel demand modelling due to the following innovations:

- The importance of individual behaviour in travel demand modelling has been recognised.

- Compared to the aggregate models, the disaggregate models can capture more information from the data. Furthermore, disaggregate data is not a subject to important statistical biases, which occur in aggregate data.

- New theories for travel demand modelling, such as the theory of random utility, have been developed.

- The application of new types of data, such as Stated Preference (SP) data has been developed.

Both aggregate and disaggregate models are most often trip based, i.e. the modelling unit is a trip. There are, however, both aggregate and disaggregate models that are tour based, i.e. the modelling unit is a tour or a trip-chain. Tour based models have developed strongly since the beginning of 1990's. These models correct for some of the errors that occur in the trip based models by recognising the connection between the trips that are included in a tour. But, as well as the trip based models cannot recognise the connection between the trips, the tour based models cannot recognise the connection between the tours completed by the same person in a day. Also, non-home based tours are poorly modelled in the tour based models because it is difficult to tie them back to specific residence (generation) zones. They are therefore usually modelled as trip based models. Finally, tours with additional stops (e.g., the home-work tours with the stop in the supermarket) are usually modelled by simplifying the tour in the way that the additional stop is not modelled. This happens because a mixture of travel purposes is not possible in tour based models.

Even though the derived nature of transport is understood and accepted, this is not reflected in the four-stage models (both trip based and tour based aggregate and disaggregate demand models). The weaknesses and limitations of the four-stage models can be summarised as follows:

- They ignore the fact that the demand for travel is derived from the demand for activity participation.
- They focus on individual trips (or tours), ignoring the spatial and temporal relationship between all trips and activities completed by an individual.
- They fail to include constraints defined by Hägerstrand in their structure.
- They see an individual as a decision-maker isolated from the household context.

3.3. Introduction to activity based travel demand modelling

An activity can be defined as a physical engagement of an individual in something that satisfies his or family needs. Activities are motivated by economical, physiological and sociological needs of an individual. Activities can be grouped into various categories. Peter Jones (1979), for instance, divides activities into two broad groups according to the way the individuals satisfy their needs:

- Subsistence (sleep, food, clothing and health care) plus activities that supply income to meet basic needs (work and school).
- Culturally, socially and individually defined activities (a wide range of social and leisure activities).

An activity does not necessarily result in a trip, i.e. many activities are completed at home. A decision to engage in an activity represents a complex interaction of household and individual roles and responsibilities, a particular lifestyle of an individual and his family, options on activity type, location and duration, and time, space and budget constraints.

John Havens (1981) describes a role as a set of behavioural patterns and their associated social norms that fulfil individuals' needs at the household level. He also describes the lifestyle-term to be an ordered set of roles, the specific series of activities that fulfil them and individuals' psychological orientations (values, attitudes, satisfaction and dissatisfaction) to the activities.

Let us imagine that a person has completed the following activities in a hypothetical day (figure 1): He went to work in the morning, then he went for a meeting in the midday and later he returned back to work, then he went home and on the way he shopped in a supermarket. In the evening he went to the cinema and afterwards he went home. Four activities (work, meeting, shopping and leisure (cinema) were therefore completed with seven accompanying trips. He also completed two home-based tours (one with an additional stop to the supermarket, and the other without stops) and one work-based tour (without stops).

Trip based demand models would model the seven trips independently of each other. Tour based demand models would model tour 1 (home-work-home) and tour 2 (home-cinema-home) independently of each other, while the work based sub-tour (work-meeting-work) would be modelled as two independent trips. Activity based models would, on the other hand, model the four observed activities and the observed trips as parts of the same decision process. Therefore, all interdependencies between the completed trips are captured in this kind of model.

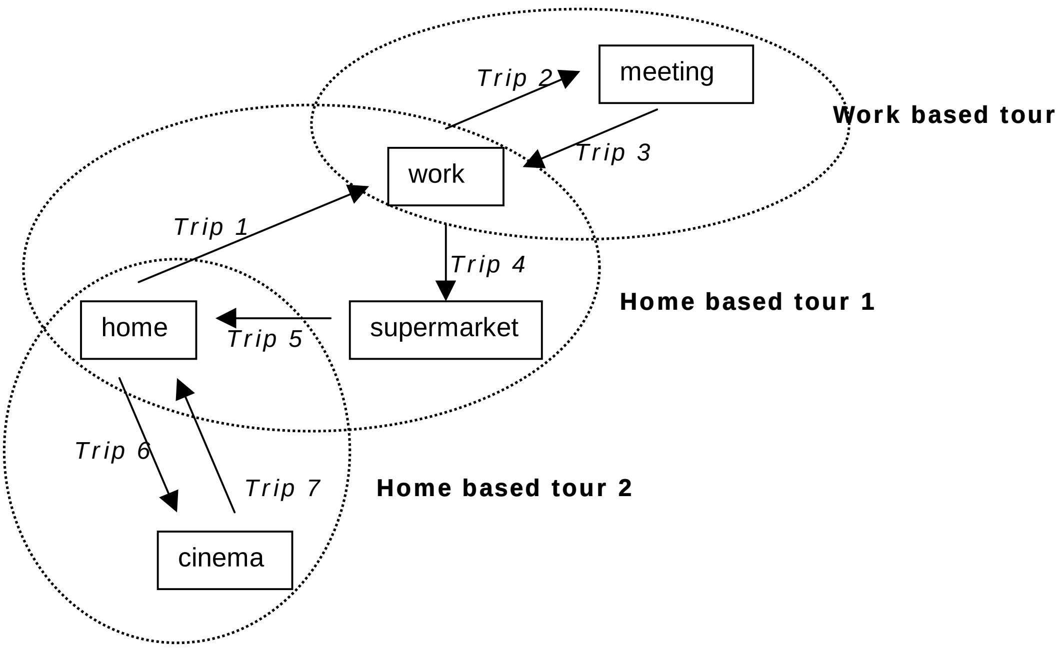

Figure 1: A graphic presentation of activities and trips completed in a hypothetical working day by an individual

If we now introduce road pricing, as a policy measure against road congestion, the person can react in a number of ways. He can, for instance, decide to stay and work at home that day, change the departure time for specific activities in order to avoid road pricing and/or choose different travel modes or destinations for some activities. Personal constraints and obligations (roles) will obviously contribute to a very complex set of changes caused by road pricing. These changes cannot be captured entirely in the trip based and tour based demand models because these models cannot recognise the complexity of the newly existing situation.

Five important features of the activity based paradigm are:

- Travel is a derived demand from the activity participation.
- The activity based approach focuses on sequences of patterns of activities.
- Individuals' activities are both planned and executed in the household (family) context.
- Activities are spread through out a 24-hour period in a continuos manner, rather than using the simple categorisation of 'peak' and 'off peak' events.
- Travel and location choices are limited in time and space, and by personal constraints. This framework is based on Hägerstand's concept of the space-time prism.

Taking the above into consideration, it is argued that the activity based approach to travel demand modelling gives a rich and accurate framework in which travel is analysed as a daily pattern of behaviour, related to and derived from differences in lifestyles and the activity participation among individuals. We state therefore that travel consequences of policies such as road pricing and telecommuting can be modelled adequately only in the activity based travel demand models.

3.3.1. A theoretical framework of activity based models

We accept here a theoretical framework of activity based models as given by Ben-Akiva, Bowman and Gopinath (1996) and Bowman (1998). They describe activity planning to be dependent on global developments, household and individual choices, and the transport supply.

Global developments. Urban developments are usually followed by appropriate infrastructure decisions such as improvements to public transport service in these areas. New areas might also be attractive for companies that can decide to establish new working places there. These global urban developments have impact on how individuals and families plan (schedule) their long-term and short-term activities. For instance, if a family that presently lives in the central area of Copenhagen decides to move in the future to the new suburb Ørestaden, one of the long–term decisions they would maybe consider is to purchase a car. In a short-term, the daily activity patterns of the family members would change in a form of number of daily (weekly) shopping tours, departure times to work/school, etc.

Household and individual choices. Household and individual choices can be divided into three groups and they fall into three time frames. These are *mobility and lifestyle choices*, *activity and travel scheduling choices,* and *implementation and rescheduling choices*.

Mobility and lifestyle choices happen at irregular and infrequent intervals. They include decisions such as housing location, place of work, car ownership, etc. The most important lifestyle attributes that influence individuals' activity planning are the household structure (size, personal capabilities and relations among household members), the individual's role in the household, activity priorities, commitments and habits, and financial and personal capabilities.

Activity and travel scheduling choices occur more frequently and at regular intervals, such as a 24-hour period. At this level individuals decide on the activities to be performed that day, the activity sequence (made according to priorities), locations, times and modes of travel.

Finally, after the one-day activities have been planned it is possible that during their execution certain *rescheduling decisions* need to be undertaken. Rescheduling can occur for instance on a certain trip (re-routing or changing mode of travel). Unexpected events can also cause cancellation of activities.

Transport supply. It is well known that the demand for, say, public transport follows its service level (i.e., supply). On the other hand, global developments and individuals' decisions together affect the performance of the transport system. For instance, an increase in commuting trips by bus will lead to an improved service capacity, bus frequency, etc. as the service providers will seek to meet the increased demand, i.e. the Mohring effect.

The supply characteristics serve as input to the activity based travel demand models.

The activity based theory of travel demand assumes that every choice has three important elements. These elements are a set of alternatives, a decision maker and a decision protocol.

Set of alternatives. The set of all feasible alternatives is referred to as the 'universal set' while the set of alternatives the individual is actually considering is referred to as the 'choice set'. Alternatives in the choice set are assumed to be mutually exclusive and exhaustive so that the individual must choose exactly one of them.

Decision maker. An individual faces a difficult task when building a choice set and when choosing one alternative in the choice set. Individuals possess limited resources and capabilities for making decisions such as activity choices. Usually, they are not fully informed of all possibilities because this requires time, energy and money. As a result, people usually act on incomplete information, especially when the choice involves large universal and choice sets. Household interactions have a large effect on individuals' activity planning. These effects differ by household type and size, the relationship between the family members, age and gender. In a similar manner, children prove also to have a significant impact on parents' activities.

Decision protocol. A decision protocol is a process that describes peoples' activity behaviour. Ben-Akiva et al. (1996) and Bowman (1998) assume that a decision protocol consists of two stages: a generation of the choice set from the universal set and a choice of one alternative from the choice set. The generation of a choice set is characterised by a particular *search style* and a *search rigor.*

The *search style* can be:

- Random, in which no systematic method for finding alternatives in the choice set is employed.

- Structured, in which alternatives in the choice set are found based on a specific rule.

The *search rigor* can be:

- Exhaustive, which searches throughout the universal set before finalising the choice set.

- Non-exhaustive, which stops building the choice set before all alternatives have been identified in the universal set based on a pre-specified rule.

The choice of one activity from the choice set is based on a certain decision rule. Decision rules are based on one of the following three types of criteria:

- *Multiple criteria*. The multiple criteria include:
  - A dominance rule, i.e. a rule that selects alternatives that are superior to other alternatives in every aspect.

  - A satisfaction rule, i.e. a rule that sets a minimum standard for every aspect and selects alternatives that satisfy every minimum standard.

- *Ranked criteria.* The ranked criteria include:
  - A lexicographic rule, i.e. if two alternatives are equal in most important aspect they are compared on less important aspects until only one alternative remains.

  - An elimination-by-aspect rule, i.e. a rule that sets a minimum standard for every aspect and selects alternatives that satisfy every minimum standard. If two or more alternatives still exist they are compared on less important aspects until only one alternative remains).

- *Composite criteria.* In the composite criteria the alternatives in the choice set are described by their utility functions. The alternative with the most positive utility value is chosen.

Depending on the allowed interaction between the two phases, a decision protocol process can be *deliberative* or *reactive*. In a *deliberative process,* the phase 1 (definition of the choice set) and the phase 2 (the choice of one alternative in the choice set) are conducted sequentially in a non-iterative fashion. In this process all the alternatives are identified before one of them is chosen. The resulting type of activity based models are, so called, discrete choice activity based models. They are also known as econometric activity based travel demand models. These models are described in more detail in chapter 4 paying attention to the data input, model structure and the model outputs. The fact that time is modelled discretionary is important to these models.

In a *reactive process* the choice of some alternatives can lead to the identification of additional alternatives. In this process phases 1 and 2 are conducted simultaneously in an iterative fashion where time is modelled continuously. The resulting activity based models are called rule based simulation activity based models. The simulation models are based on a kind of learning mechanism of defining the decision protocol, where its simulation is essential. There are two types of simulation models, i.e. activity schedule building models and switching models. These models are described in chapter 5.

4 Method 1: Discrete choice activity based travel demand models

Trip based discrete choice demand models assume independence between different travel purposes in the generation model. In discrete choice activity based models combinations of activity purposes are modelled explicitly in what is called ‘activity pattern models’. The available alternatives in the activity pattern define the choice set (see chapter 3.3.1). An activity pattern can be defined as a sequence of activities planned by an individual. In an activity schedule to each of the activities from the activity pattern we attach the time of execution and duration, destination and the travel mode.

Discrete choice activity based travel demand models are based on the theoretical and practical assumptions as given in 3.2. These models define a large set of available alternatives in the choice set by applying an exhaustive search style. Each alternative is then described through its utility function. The choice of the alternative is probabilistic and it is based on the composite criteria of the decision rule.

Individuals use a priority-based decision process (also called a ‘deliberative process’) when building the decision protocol process in discrete choice activity based models (Ben-Akiva, M. et. al, 1996). This means that individuals make day activity schedules by deciding on the activity patterns (and trips) before they begin executing the schedule. In that way the incidental circumstances, such as circumstantial changes in the bus time schedule, have no impacts on the execution of the planned activities. In these models an individual goes through the decision protocol process sequentially where no interaction between the stages is allowed. Regarding this, Peter Stopher (1996) postulates that most travel is habitual and hence travel patterns do not commonly change from day to day. According to that, we seldom deviate from the planned activity schedule.

Discrete choice activity based demand models represent the behaviour of a single individual. To our knowledge all presently existing discrete activity based models are person based and do not explicitly include household interactions. The latest version of the Portland model (version 4) is intended to be household based where interactions between the family members are taken into consideration. The SMART model (see chapter 4.5 for more detail) is planned to be household based but that model has never been finalised.

Discrete choice activity based models are large nested multinomial logit (NMNL) models where a long-term model (e.g., a model for the choice of the work location) is placed at the top of the hierarchy, below that a model for day travel patterns is placed and finally at the bottom of the hierarchy are placed tour and trip models associated with the chosen activities from the pattern model. As stated by Bowman (1998), this structure matches the natural hierarchy of the decision process of an individual. The models placed lower in the hierarchy are conditioned to the outcomes of the higher-placed models. In the opposite direction, the calculated accessibility measure (i.e., logsum variables) of the lower-level models is included in the utilities of alternatives placed higher in the hierarchy. Discrete activity based models predict probabilities of the decision outcomes, just as the discrete choice trip models do. Accordingly, it is possible to generate trip matrices from these models.

On the other hand by applying, say, Monte Carlo simulations these probabilities can be used to produce activity and trip patterns for a single person. Furthermore, these patterns can be aggregated on a zonal level (OD matrices) or based on some socio-economic classes, e.g. according to income groups.

Discrete choice activity based models are based on the discrete choice theory that has been in a broader use since the mid 1980's. These models have therefore a shorter evolution than the rule based simulation models. The main theoretical strengths of discrete choice activity based models are the following:

- A large set of activity patterns is defined in the choice set. These patterns are defined upon the type of the main activity (e.g., home-work activity), primary tour structure (e.g., home-work-supermarket-home), secondary tour structure (e.g., home-work activity), pattern of intermediate stops, etc. The demand for travel is therefore derived from the demand for activity participation in discrete choice activity based models.

- Long term effects can be incorporated into discrete choice models. Prior to day travel patterns, these models usually include some aspects of the lifestyle such as the choice of work location and the choice of car ownership.

- Attributes of the transport system performance are included in the model structure.

Discrete choice activity based modes are most applicable for operational models, especially if the time scale is long (i.e., for long term forecasts).

4.1. The Portland model

'The Day Activity Schedule Approach to Travel Demand Analysis'
Ph.D. Thesis at the Massachusetts Institute of Technology, USA, 1998
Author: John L. Bowman

The Portland model is the first large-scale operational activity based travel demand model in the world. We describe here the first version of the model as given in the Ph.D. thesis of John Bowman. The model is currently being built in its fourth version.

The Portland model belongs to the group of discrete choice models, which was preferred in the project to the rule based simulation models because:

- Discrete models rely on random utility theory, which has been proven to give the most accurate forecasts.

- The estimation results in discrete choice models can be statistically checked.

- Existing statistical software, such as ALOGIT, can be applied straightforward, while considerably more programming is needed when working with rule based models.

The model is based on a 1994 household survey with some 5.000 households where two-day activity diaries are completed by all household members. The activity pattern estimation is based on 6.475 observed patterns. Stated Preference (SP) experiments were also completed at the time concerning travel frequency, mode choice, time-of-day choice and route choice. The analysis area of Portland is split among 1.244 zones in the model.

The model operates with the following terms:

- A primary activity: If a person completes a number of activities a day, one of them is chosen to be the primary activity of the day. A primary tour always starts and ends at home.

- A secondary activity: Every extra tour beside the primary tour is described as a secondary tour. A secondary tour can happen prior to the primary tour or after the primary tour. A secondary tour always starts and ends at home.

- A sub-tour: If a person goes for a meeting or lunch away from his working place such a tour is described as a work based tour, or sub-tour.

- Intermediate stop: On both the primary tour, secondary tour and sub-tour it is possible to make one (or more) stop, e.g. a stop at the grocery store on the way from work to home. These stops are called intermediate stops.

The model-part we focus on here is the activity schedule model. Prior to the activity schedule model is a mobility and lifestyle model, which forecasts the choice of the work location and the car ownership. The choice of work location and the car ownership is a matter of long-term planning and will not be considered here.

Data input

Data input to the model estimation are threefold. These are data on households, zonal data and network data. The household data origins from the household survey and it contains information about the household type and size, income and individual's socio-economic background such as age, gender, education and the job-type, the roles of the household members, and the individual's activity (trip) participation. Zonal data describes population distribution, job and educational opportunities, location and size of shops, etc. Finally, network data origins from assignment models for car and public transport modes and it describes travel conditions between the zones, e.g. travel distance, travel time, travel costs, departure frequency for public transport modes.

Model structure - Day activity schedule model

The day activity schedule model is a nested multinomial logit (NMNL) model consisting of two models, i.e. the day activity pattern model on the higher level, and the tour model on the lower level. The tour model is conditional on the activity pattern outcome. In the opposite direction, the calculated accessibility of the tour model is included in the activity pattern model. Therefore, a probability of certain day schedule is calculated in the Portland model as a product of the pattern probability and the tour probability that is conditional to the pattern probability.

<u>Day activity pattern model</u>

In its application, the Portland activity pattern model is a multinomial logit (MNL) model with 114 alternatives. (The latest version of the model, which is under construction, includes more than 1.500 alternatives in the activity pattern model.) These alternatives are defined by a) the primary activity of the day, b) whether the primary activity occurs at home or on the tour, c) the type of tour for the primary activity, including the participation and purpose of any intermediate stops before or after the primary stop and, for work patterns, the participation and purpose of a work based sub-tour, d) the number and purpose of secondary tours, and e) whether at-home maintenance activities are conducted.

The primary day activities in the Portland model are:

- Subsistence (work/school) at home.
- Maintenance (personal business) at home.
- Discretionary at home.
- Subsistence (work/school) on tour.
- Maintenance (shopping, personal business) on tour.
- Discretionary (social, recreational) on tour.

If the primary activity is completed on tour, the tour configuration is defined in the activity pattern model. There are four types of tour patterns in the model:

- A simple pattern, i.e. that is without stops between home and the destination.
- One or more intermediate activities on the way from home to the primary destination.
- One or more intermediate activities on the way from the primary destination to home.
- One or more intermediate activities in both directions.

The activity pattern model defines the following characteristics of the individual's daily activities:

- The primary activity of the day.
- The tour type for activities that occur away from home.
- The tour type for work-based sub-tour (as part of home-work primary tour).

- The number and purpose of secondary tours. (A secondary tour can be a tour to the cinema in the evening, after the work tour has been completed earlier in the day).

The model allows individuals to make an extra activity (tour) when they are at work. This is defined to be a work-based sub-tour. The same four tour types as above are allowed in the model for the work-based sub-tours.

Once when the primary tour is finished an individual can make a secondary activity (tour). The model defines six types of secondary tours based on the number and purpose of these tours:

- No secondary tour.

- One secondary tour for work or maintenance.

- Two or more secondary tours for work or maintenance.

- One secondary tour for work or discretionary.

- Two or more secondary tours for work or discretionary.

- Two or more secondary tours when at least one tour is for work or maintenance and at least one tour is for discretionary.

Since not all defined tour types apply to all of the primary activity types, there are 19 possible combinations of primary activity and tour types in the Portland model. Each of the six above defined secondary tours are allowed for all 19 primary activity and tour types, which results in 19x6=114 alternatives in the pattern model (i.e., the choice set).

An activity pattern is defined for a working day for persons older than 16 years from the sample.

<u>Tour model</u>

The tour model consists of 1) the home-based tour time-of-day model, 2) the home-based tour mode and destination model, 3) the work-based sub-tour mode and destination model, and 4) intermediate stop location model for car-driver tours. The Portland tour model is a NMNL model for itself.

Home-based tour time-of-day model

For the chosen activity pattern the time-of-day model determines the time sequencing and duration of tours that results from the activity of a schedule. The model distinguishes between five time periods, i.e. early (3 a.m. till 7 a.m.), AM peak (7 a.m. till 9.30 a.m.), midday (9.30 a.m. till 4 p.m.), PM peak (4 p.m. till 7 p.m.) and late (7 p.m. till 3 a.m.). There are three segments in the time-of-day model, based on activity purposes: work/school, maintenance and leisure.

The variables that are included in the time-of-day models are:

- The person's socio-economic variables (age, gender, job type).
- The household variables (children, household income).
- The trip type variables (e.g., intermediate stop on the way from/to home).
- The logsum variable, which originates in the home-based tour mode and destination model, which is placed below time-of-day model in the model hierarchy.

Home-based tour mode and destination model
When the activity pattern is known as well as the time-of-day for each tour that is included in the activity pattern, the home-based tour mode and destination model predicts the primary mode and destination for each tour. Applying the alternative sampling procedure (Ben-Akiva, M. and S.R. Lerman, 1985) 21 destination zones are chosen for each tour (sampled alternatives are weighted according to the sampling probability to achieve consistent estimates).

The main modes of transport in the Portland model are: car drive alone, car drive with passenger, car passenger, metro with car access, metro with walk access, bus with car access, bus with walk access, bike and walk. Values of travel time (VOT) are estimated in a separate SP model for two purpose-defined segments: home-work and home-other trips. For each of the purpose segments three income-based sub-segments are defined. In conclusion, the SP VOT model consists of six models (segments). The SP-based VOT are used to calculate generalised-time variable for the car and public transport modes (the total time and cost utility divided by the 'car drive alone' time coefficient), which is included in the model structure.

The home-based tour mode and destination model consists of three segments (just as the time-of-day model) based on activity purposes, i.e. work/school, maintenance and leisure. Each segment consists of nine mode-defined alternatives, which utilities include:

- The generalised-time variable (for car and public transport modes).
- The person's socio-economic variables (age, gender, job type, income).

- The household variables (household type).

- The trip type variables (e.g., intermediate stop on the way from/to home).

- The destination-zone variables (job distribution, distance, intra-zonal trips).

The logsum variable was originally defined in the model structure but the estimate fall outside the 0-1 interval.

Work-based sub-tour mode and destination model
Cross tabulation of data from the Portland household survey has showed that a large number of home-work tours include an extra tour (work based sub-tour), which can include activities such as lunch, meetings, etc. A separate mode and destination choice model is defined for this type of tours. The model has basically the same structure as the previous one. Again, this model has only one segment based on work, as the trip purpose.

Intermediate stop location model for car-driver tours
Going to/from work, or to/from other activities individuals sometimes stops for an extra activity (e.g., stop for shopping in the supermarket on the way home from work). In order to take this into account in the tour model, a separate model is defined in order to determinate the locations for these intermediate activities. The model has two segments for home-work tours and home-other tours. The structure of these models is similar to the structure of the 'home-based tour mode and destination model'. The Portland model allows intermediate stops only if 'car drive-alone' is applied.

Model output
The Portland model predicts activity schedules for each individual in the population applying the methodology of a synthetic population. The methodology is different from the sample enumeration procedure and it is described below.

An input to the methodology of a synthetic population is data describing a representative sample of the population. In the Portland model the representative sample is derived from census data. Each record in the census data has the following characteristics: the household size and structure, the relationship between the household members, the household income, the number of cars in the household, location of the residence, the employment status of each member, age and gender. The activity behaviour in this sample is not important.

Both the population and the sample (the census data) are divided in a number of groups (cells) according to some individual and household characteristics in the base year. In the Portland model the cells are defined according to four income levels (classes), four age-classes of the head of the household and four household sizes. The Portland model operates therefore with 64 cells.

For the forecasting year, the sizes of the 64 cells in the sample are calculated based on the exogenous indicators. The population sizes of the 64 cells in the forecasting year are then calculated based on the base year population cell-sizes and the cell-sizes in the forecasting sample.

If, say, cell number 5 of zone 10 has 13 individuals in the forecasting year then 13 respondents will be drawn from the corresponding cell in the forecasting sample applying Monte Carlo simulation. For each of the 13 drawn individuals the activity schedule is calculated in the model in the form of the calculated probabilities based on the known characteristics of these individuals. For each modelled outcome a random number between 0 and 1 is then drawn in order to simulate a particular outcome according to the modelled probabilities. For instance, let us imagine that in the destination choice model zone 1 has a probability of 0.7 to be chosen while zone 2 has a probability of 0.3 to be chosen for the drawn individual. If 0.8 is drawn then zone 2 is chosen for the destination of that particular trip.

There are basically three types of results derived from the application of the Portland model:

1. The basic output of the model is an activity pattern for each individual in the population. The individual patterns can therefore be visualised in GIS.

2. Predicting activity patterns for each individual in the population allows a flexible aggregation of results for policy analysis. That is, the results can be aggregated according to any socio-economic classification for which reliable variables are available at the individual level.

3. The individual activity (trip) patterns can be aggregated on the zonal level, which produces origin-destination trip matrices. The trip matrices are split by mode, trip purpose, time-of-day and income classes, and they can be assigned on the road and public transport networks.

4.2. The Boston model

'Activity Based Travel Demand Model System with Daily Activity Schedules'
M.Sc. Thesis at the Massachusetts Institute of Technology, USA, 1995
Author: John L. Bowman

The Boston model is a discrete choice activity based model that was developed in 1995 for research purposes and it has not been operationalised. Many results achieved in this model are applied in the Portland model.

Data input

The Boston model is an activity schedule model based on the data from a 24-hour household travel survey from 1991. Besides, the model input is zonal and network data.

Model structure

The structure of the Boston model is a simplified version of the Portland model. The model assumes that individuals make their day activity schedules by deciding on the activity patterns and subsequently the tour configuration. The probability of a particular activity schedule is therefore equal to the product of the marginal pattern probability and the conditional tour probability. The analysis area is divided among 786 zones.

<u>Day activity pattern model</u>

The activity pattern is characterised by:

- The primary activity of the day.
- The type of tour for the day's primary activity, including number, purpose and sequence of activity stops.
- The number and purpose of secondary tours.

The pattern model consists of 54 alternatives:

- 1 home alternative (i.e., the individual spends the whole day at home).
- 30 work-based alternatives (i.e., work is a primary activity of the day).
- 12 school-based alternatives.
- 12 leisure-based alternatives.

30 work based choice alternatives consist of 5 primary tour types x 6 number and purpose of secondary activities (tours). 12 school based choice alternatives consist of 2 primary tour types x 6 number and purpose of secondary activities (tours). 12 other based choice alternatives consist of 2 primary tour types x 6 number and purpose of secondary activities (tours).

In the application two pattern model-segments are built, i.e. workers and non-workers, by classifying the above 54 alternatives. The variables included in the pattern utilities are socio-economic variables and logsum variables that originate from the lower level tour model.

Tour model

The tour configuration model includes the models for the choice of time-of-day and the destination/mode choice model. These two model types exist in the model structure for the primary tours and secondary tours.

The Boston tour model is defined to be a NMNL model where on the higher level is placed the time-of-day choice model and on the lower level is placed the destination/mode choice model. The NMNL structure allows the accessibility measure to be included in the higher-level models.

Tour time-of-day models

Two similar MNL models of the choice of tour time-of-day are estimated, one for the primary tour and one for secondary tours. The models consists of 16 alternatives, defined by the combination of 4 departure time-intervals from home to the primary destination and 4 departure time-intervals from the primary destination to home. Time periods are AM, PM, midday and the rest of the day. The biggest drawback of the time-of-day model is that level of service (LOS) variables are not included in its structure, i.e. the logsum variable from the destination and mode choice model is not included in the structure of this model.

Tour destination and mode choice models

Two similar MNL models of the choice of destination/mode choice are estimated, one for primary tour and one for secondary tours. The models consist of 48 alternatives, defined by the combination of 6 modes and 8 departure zones.

The available modes in the model are car drive alone, car shared, public transport with car as access mode, public transport with walk as access mode, walk and bike. For each tour 8 zones are assigned as the possible destinations out of 786 possible zones applying the alternative sampling procedure, as described in the Portland model (see chapter 4.1).

Variables included in the utilities are time and cost of travel, where cost is income dependent, socio-economic variables and the logsum variable. Unrealistically high values of travel time (VOT) have been estimated here. This indicates model specification errors and data difficulties that have not been solved under the model estimation.

Model output

The Boston model predicts activity schedules for each individual in the population applying the methodology of synthetic population (see chapter 4.1 for details). The prototype of the Boston model has demonstrated practical solutions for modelling travel demand from the activity scheduling point of view. The problems with VOT and data would require further empirical tests and model refinements if the model needed to be operationalised.

4.3. A model by Wen and Koppelman

‘A conceptual and methodological framework for the generation of activity-travel patterns’
Transportation, Vol. 27, 2000
Authors: Chieh-Hua Wen and Frank Koppelman

Chieh-Hua Wen and Frank Koppelman have proposed a concept of activity based travel demand modelling at the Eighth Meeting of the International Association for Travel Behaviour Research in Austin, Texas, in 1997. The model has not been operationalised yet. The model is described below through the data input, model structure and the model output.

Data input
The model is based on the Portland data from 1994. The data originates from an activity based survey where a two-day activity diary is completed. Zonal and network data are also applied in the model estimations.

Model structure
The authors recognise that activities are motivated by the economical, physiological and sociological needs of individuals. Activities within a household that satisfy these needs are split between subsistence (work, school), maintenance and leisure. Subsistence and maintenance are classified to be household needs while leisure needs are classified to be needs of an individual.

Household subsistence needs include employment participation of household members, and residential and work locations. They are determined by the individual’s/household’s characteristics and by the transport supply as the accessibility measure. The individual’s/household’s characteristics are determined by a lifestyle and a lifecycle. A lifestyle is described by the authors to be an orientation of an individual or a set of preferences towards his life. A lifecycle is further described to be a progress of the household size and ageing. Household substitution needs are long-term needs.

Maintenance needs are also household needs but they are short-term decisions. They include shopping, personal and household business, child care, etc. These needs are conditional on subsidence needs. Gender plays an important role when completing maintenance activities. For instance, women are traditionally more used to take care of household maintenance activities than men.

The model focuses on modelling the household activity and travel patterns, which are conditional to household’s subsistence needs and maintenance needs. Because the subsistence needs are long-term needs they are not modelled here. Therefore, the model starts by modelling the maintenance activities (e.g., shopping). The second stage of the modelling system includes the choice of number of tours and the assignment of stops to tours for each individual. In both stages the models are in the form of nested logit models.

The model consists of two sub-models placed one below the other.

The model placed at the top
The highest placed model is a NMNL model that calculates the number of maintenance stops made in the household. These stops are then allocated between the husband and wife and finally for each maintenance stop the available car(s) is/are allocated.

The lower placed model
In this model the number of tours are calculated for each household adult and the pattern of stops for each tour. The model distinguishes between husband and wife in the model structure. This model is also in the form of a nested logit model.

Model output

The proposed model framework predicts day activity schedules separately for wife and husband in a family. The model shows that the number of children has a big impact on the parents' activity scheduling. The patterns include the choice of number of tours, choice of destination, travel modes and the choice of time of day travel.

4.4. PETRA

'PETRA – An activity based approach to travel demand analysis'
Chapter 11 of the book 'National Transport Models – Recent Developments and Prospects', 2001
Author: Mogens Fosgerau

PETRA is the only Danish activity based travel demand model so far. The model covers the whole country and it belongs to the group of discrete choice models.

Data input

PETRA is based on disaggregate data originating from the Danish home-based travel behaviour survey (so called TU data) from 1995. The data set consists of 13.000 travel diaries that describe the completed activities and the related trips for the day before the interview is completed. In addition to travel information, the data set contains socio-demographic characteristics for the household members.

The network and zonal data are also available in PETRA.

Model structure

PETRA is defined to be a NMNL activity based model, where on the higher level is placed the model for the population forecasts and on the lower level is placed the travel demand (TDM) model, as shown on figure 2.

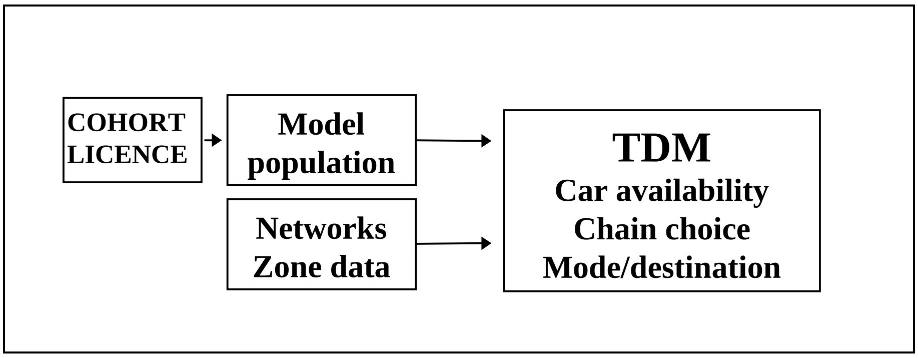

Figure 2: PETRA's structure

<u>Model for population forecasts</u>

Cohort or diffusion effects of car ownership result in increased car ownership as the generations change, independently of income growth. These effects are modelled through two satellite models, i.e. COHORT model and LICENCE model. COHORT projects the licence holding rates for groups defined by age and gender and projects these rates from the base year to the forecast year. LICENCE is used to distribute licences on individuals such that the licence holding rates for the model population in the forecast year match those predicted by COHORT. The licence holding data generated by COHORT and LICENCE are taken as exogenous by the Travel Demand Module (TDM) as part of the characteristics of the model population.

The zonal data and the network data are also found at this level but they are calculated outside PETRA.

Travel demand model (TDM)

The TDM is applied for the model population using sample enumeration. Using the model population and network and zonal data, the TDM predicts travel demand and the demand for cars.

At the most general level the TDM predicts car availability for each household in the model population. For the interviewed person in each household, the TDM predicts probabilities for choosing different travel chains conditional on car availability. At the most basic level, the TDM predicts mode and destination choice for each tour in the trip chain conditional on car availability and choice of trip chain.

The travel demand model in PETRA is a NMNL model, which has three levels. At the top of the hierarchy is a car-availability model, which predicts probabilities for car ownership for two social groups, i.e. single people (0 and 1+ cars) and couples (0, 1 and 2+ cars). Input variables in the model are income and licence holding for the respondent, and the accessibility measures which originate from the activity pattern model and destination/mode choice model (these two models are placed below the car availability model in the tree structure).

Conditional to car availability, the travel demand model predicts activity pattern choices for each individual in the sample. Respondents choose between staying at home the whole day and completing one (or more) of 12 defined types of activity patterns. Three main tour purposes are work, errand and leisure. Each tour starts and ends at home. Tours can be simple (e.g., home-work-home) or complicated (e.g., home-work-leisure-leisure-home). Variables in this model are respondent's socio-economic variables, logsums from the destination/mode choice model and constants for the day of the week.

The destination/mode choice model is estimated for each of 12 tour-types that are defined in the activity pattern model. Each of the sub-models has 54 alternatives consisting of nine alternative destinations and six travel modes. Variables included in the model structure are travel cost and time, different socio-economic variables, and population and employment sizes (as attraction variables).

Model output

The travel demand model results in a table containing information on the expected travel demand for each respondent in the sample. The table contains:

- Respondents ID, which is connected to his socio-economic characteristics.
- Probabilities of car availability.
- Predicted km by mode.
- Activity pattern probabilities.

This table is further linked to a table with ‘weights’ that expand the sample to the population size.

4.5. SMART

'SMART – Simulation Model for Activities, Resources and Travel'
Transportation, Vol. 23, page 293-312, 1996
Authors: Peter Stopher, David Hartgen and Yuanjun Li

SMART stands for the Simulation Model for Activities, Resources and Travel. SMART is originally thought to be developed in order to replace the Urban Transport Planning System. However, the model has never been finalised. SMART is an activity based travel demand model that integrates land use, traffic, and household activities and resources. The model was planned to work in a GIS platform where some zonal aggregation can be achieved.

SMART is based on the following assumptions:

1. A household is the choice unit. Individuals who are engaged in these activities carry out the decisions made on the household level according to their roles. The household resources are assigned to these activities. After the household needs are met, the individuals' needs are met to extend to the actual time and money resources.

2. Travel demand is a derived demand from the desire to participate in certain activities.

3. Most activity engagements are habitual because of what the household travel patterns do not change frequently.

4. Time and cost constraints limit the choices of activities and locations available to the households.

5. Over time, land owners and companies adapt activity sites and transportation systems to meet the demand.

Input data
The input data in SMART are personal and household characteristics, activity patterns for the household, zonal data and LOS (level of service) files.

Model output
The proposed structure of the model works in a GIS platform. It is therefore possible to follow each individual with his day activity pattern in the model output. Aggregation on the zonal level (building of OD matrices) is also possible.

5 Method 2: Rule based simulation activity based models

Simulation activity based models construct activity schedules by considering Hägerstrand's constraints explicitly in their structure in a continuos time. There are two main groups of these models, i.e. activity schedule building models and switching models. The difference between the two approaches is that the building models construct an activity schedule from scratch while the switching models alter (or adapt) the pre-defined schedule as a result of proposed changes (e.g., policy changes or infrastructure changes).

The first simulation activity based models were developed approximately at the same time as the discrete choice theory and the first discrete choice trip based models, i.e. in the end of 1970's and the beginning of 1980's. That is to say, that simulation models have a longer history than discrete choice activity based models.

The most important characteristics of simulation activity based models are the following:

- They place most attention to explain how individuals think when building schedules. To do that they imply some kind of learning mechanism in their structure. The idea of this mechanism is that behaviour leading to positive experiences will be reinforced in the future behaviour. Gradually these experiences are transformed into finished heuristics (rules) that we apply in specific choice situations. In entirely new situations we do not re-examine all possible alternatives. Instead, we consider only a selected set of alternatives again based on some heuristics. This leads us to one of the important characteristics of simulation activity based models, i.e. the choice set in these models is considerably smaller than in discrete choice activity based models.

- Along the day each new activity relies on the previous activities (time of day, mode and destination) and this activity might also result in making some changes in the previous planned activities. The definition of the choice set and the choice of one alternative in the choice set therefore work in an iterative procedure in these models.

- Simulation activity based models predict decisions (realisations) in the outcome (i.e., they are not probabilistic). A drawback of this is that the simulation models cannot be checked for the statistical properties.

Some important theoretical strengths of rule based simulation models are the following:

- Demand for travel is derived from the demand for activity participation in these models. (Most researchers working with simulation activity based models believe that these are the truly activity based models while discrete choice activity based models are considered to be a qualitative extension of trip based models into tour based models.)

- Time, location and budget constraints are incorporated explicitly in the model structure.

- The time component is modelled continuously allowing therefore for interaction between the two phases in the decision protocol.

- Many simulation models are family based.

Simulation activity based models are often applied on very specific subjects because of what detailed analyses are often undertaken (e.g., SP analyses) in order to build these models. The individual or family activity schedule, which is the output of simulation models, is very rich in details especially taking into consideration different types of constraints. Simulation models are therefore best applied for short-term forecasts and on very specific subjects.

5.1. SAMS and AMOS

SAMS

'The sequenced activity mobility simulator (SAMS): an integrated approach to modelling transportation, land use and air quality'
Transportation, Vol. 23, page 267-291, 1996
Authors: Ryuichi Kitamura, Eric Pas, Clarisse Lula, T. Keith Lawton and Paul Benson

SAMS stands for the Sequenced Activity Mobility Simulator, which is a dynamic and integrated simulation forecasting system for transport and land use. SAMS is essentially a new approach to travel demand modelling that takes into consideration some more dimensions to traffic modelling such as land use and air quality measurement.

The mostly criticised shortcomings of the traditional four-stage traffic models, i.e. trip modelling (instead of activity modelling), lack of time dimension and static nature of these models are attempted to be modernised in SAMS. SAMS models therefore the evolution of households and firms, car ownership changes and socio-economic changes besides the modelling of travel demand. SAMS operates with point based geographical representation of respondents (and not with zones). The respondents are in that way coupled with the correct distances and times.

SAMS includes:

1. A socio-economic and demographic stochastic (micro)simulator.

2. An urban simulator (urban evolution of households and companies where land prices and rents are endogenously forecasted).

3. A car ownership simulator.

4. A dynamic network simulator that provides LOS files based on time based public transport service.

5. AMOS – the activity-mobility simulator (see below). Simulation is applied in SAMS in order to produce activity schedules because activity travel behaviour is understood to be a multi-dimensional process that has time and spatial constraints and that is influenced by many factors where some of them are stochastic in nature.

Data input

Activity Mobility Simulator, AMOS, requires a detailed external activity program. An activity program in AMOS contents activity purposes, their frequencies, a priority list, the available times for such activities, the activity duration and location. AMOS is designed to be a switching model, which means that the existed activity schedule is adjusted in the model in response to policy changes. AMOS is also supplied with LOS data and socio-economic characteristics of the respondents.

Model structure

Adaptation is a central concept in AMOS. In AMOS, the person first recognises the changes in the travel environment. These changes cause AMOS to find a set of possible changes in the person's travel behaviour. These options are 'tried out' in the model (i.e., the individual's adaptation behaviour is characterised as a trial-and-error experimentation process), one at the time, until a satisfactory pattern of activities is achieved. AMOS contains four modules that operate in an iterative procedure, i.e. 1. a base line activity travel pattern synthesiser, 2. a response option generator, 3. an activity travel adjuster and 4. an evaluation routine.

1. The base line activity travel pattern synthesiser identifies the types of out-of-home activities and their duration based on the person's activity diary. The synthesiser identifies also the constraints associated with each trip based on a set of rules. The basic response is modelled as a MNL model with eight alternatives: no change, change departure time to work, switch to public transport, switch to carpool, switch to bike, switch to walk, work at home and other.

2. The response option generator generates and prioritises series of options that the person might consider as a result of changes in his travel environment. These options are simulated.

3. The activity travel adjuster serves to experiment with the options (activity patterns) generated in the previous step. The activity patterns and the corresponding trips are assigned on the road and public transport network, the latest based on the time tables for the actual time of day and mode. AMOS applies a GIS based dynamic network assignment. The assignment model provides the actual travel times and the arrivals at each destination, i.e. it is simulated what the person would experience by adopting a particular option (an activity pattern).

4. The evaluation routine serves the person in order to decide if an option is:

   - Satisfactory and therefore acceptable.
   - To be modified.
   - Inadequate and therefore rejected.

   This module evaluates the newly built activity pattern based on a set of rules. SP data is completed in SAMS for evaluating the person's preferences towards alternative activity and travel options. Panel RP data are also important here because SAMS is a dynamic model system. A simple choice model finally accepts or rejects the proposed adjustment. If the proposed adjustment is rejected by the choice model, the structured search is repeated until an acceptable adjustment is found. If all proposed adjustments for one basic response are rejected by the choice model AMOS will search for another basic response.

Model output

AMOS is a simulation model system of individuals' adaptation behaviour (AMOS is a switching model), which predicts changes in the travel behaviour as a result of changes in the travel environment.

5.2. SMASH

'Activity based Travel Demand Modelling'
Ph.D. Thesis at the Eindhoven Technical University, Holland, 1996
Author: Dick Ettema

SMASH, Simulation Model of Activity Scheduling Heuristics, aims in describing individuals' activity scheduling behaviour. SMASH belongs to the group of activity schedule building models.

SMASH assumes that activity scheduling is a stepwise decision-making process. Each decision in this respect involves the choice of how to proceed the heuristic search process, based on the current schedule and the attributes of the available alternatives. An individual can therefore at each step adopt the existing schedule by adding, deleting or rescheduling an activity or he can reject the existing schedule.

Data input

Input to SMASH is a detailed external activity program, which consists of long-term factors and specific circumstances for that day (i.e. incidental factors). Long-term factors consist of:

- Long-term calendar, e.g. activity frequency, purpose, duration, destination and time window.

- Cognitive map, e.g. geographical location of the activities and travel distances between the locations.

- Resources, e.g. availability of travel modes.

Incidental factors are grouped in two groups:

- Activity agenda, e.g. priorities, incidental duration, opening times and destinations.

- Incidental circumstances, e.g. changes in transport network.

The available information for each activity are therefore the activity's frequency, average duration, available destinations and the available time window per destination. Further on, it is known from LOS files what travel times and destinations per modes per activity are. Finally, data regarding personal characteristics are also known in SMASH.

Model structure

Decision (i.e., dependent) variables in SMASH are the choice of activities, destination choice, sequencing, timing of activities, mode and route choice, and choice of company whom the activity is performed with.

SMASH builds an activity schedule through an iterative procedure using activities from the existing activity program (the schedule is empty in the first iteration). The choice set is built by a generic (heuristic) non-exhaustive search rigor (see chapter 3.3.1 for details) with possibilities to add, delete or reschedule one activity from the activity schedule. In this phase (phase 1 of building the choice set out of the universal set) a number of adjustments are proposed.

In phase 2, SMASH chooses one of the potential adjustments from the choice set and continues the search, or accepts the previous schedule and ends the search. The choice between schedule adjustment and schedule acceptance is implemented in a nested logit structure. Schedule acceptance occurs when the utility of the schedule acceptance alternative is greater than the utility values of all available schedule adjustment alternatives under consideration.

A schedule is more likely to be accepted if:

- The activity time is maximised relative to the travel time.

- One or more highly prioritised activities are included in the schedule.

Model output

SMASH builds individuals' activity schedules. For each activity SMASH predicts the destination, time of travel, mode of travel, route and the accompanied person(s) at the activity.

5.3. STARCHILD

'A model of complex travel behaviour: part I – theoretical development'
Transportation Research A, 20A(4), page 307-318, 1986a
'A model of complex travel behaviour: part II – an operational model'
Transportation Research A, 20A(4), page 319-330, 1986b
Authors: W.W. Recker, M.G. McNally and G.S. Root

STARCHILD stands for Simulation of Travel/Activity Responses to Complex Household Interactive Logistic Decisions. With changes in, say, LOS files STARCHILD models the scheduling decisions of an individual in the family context resulting in timing and sequence of the activities. STARCHILD belongs to the group of activity schedule building models.

Input data

A detailed activity program for family members must be supplied from outside STARCHILD. An activity program includes details about the individual's schedule including activity purpose, duration and location. Constraints on tour-sequences such as timing, location and coupling of activities are also included in the external activity program. LOS files and zonal data are also available in STARCHILD.

Model structure

Generation of the choice set in STARCHILD is done in three steps:

- First, the feasible alternatives are exhaustively enumerated with careful attention to constraints.

- Then, statistically similar alternatives are grouped in 3 to 10 classes.

- Finally, only one alternative is chosen to represent each class, resulting in the fact that the choice set in STARCHILD consists of 10 alternatives at the most.

When the choice set is built the choice of an alternative (activity) is done in the following way:

- A kind of decision rule is applied in order to eliminate some of the alternatives in the choice set.

- A multinomial logit model then represents a utility maximising choice among the remaining alternatives in the choice set.

Model output

The output of STARCHILD is activity schedules of the individuals that are included in the sample. Individuals are seen in the family context in STARCHILD.

STARCHILD's strong side is the first step in the generation of the choice set where feasible alternatives are enumerated with a careful attention to different types of constraints. Weak sides of the model are that:

- It relies on external data set describing the activity program.
- The second step in the process of building the choice set can result in a wrong choice set.
- The choice set is considered to be small in order to represent truly available opportunities to the individual.

5.4. CARLA

Chapter 11 of the book 'Understanding Travel Behaviour', 1983
Authors: Peter Jones, M.C. Dix, M.I. Clarke and I.G. Heggie

CARLA stands for Combinatorial Algorithm for Rescheduling Lists of Activities. It origins from the beginning of 1980's and it is therefore one of the first activity based travel demand models. The decision unit in CARLA is a household. CARLA takes into account individuals' spatial and temporal constraints when planning and executing activities. Finally, CARLA views activities over a continuous period of time, rather than considering discrete events, such as AM and PM peak periods. CARLA belongs to the group of activity schedule building models.

Input data

As in previously described rule based models, CARLA reads an external data base with a list of activities to be scheduled, i.e. an activity program. Activities' duration and the time of day are also known.

Model structure

CARLA builds the activity schedule based on the externally existed activity program and the proposed policy in the model forecasts. The new schedule is feasible if it is in agreement with a number of pre-defined rules. These rules are either tested in the algorithm itself or they are explicitly stated in the model input.

The list of observed reactions to the external changes are numerous, as listed below, but CARLA deals only with the first type of these reactions, (i.e., re-timing of a fixed set of activities, at fixed locations):

- Re-timing of activities, i.e. the same set of activities is undertaken but their duration is altered and/or their sequence is re-arranged.
- Changes in the set of alternatives undertaken.
- Changes in location of some activities.
- Changes of mode of transport.
- Re-location of activities among family members.

The planned activities for one day can be arranged in a large number of ways. The particular arrangement adopted by a person/household in CARLA is based on a set of behavioural rules:

- Logical rules underline that a person can perform only one activity at a time at one location. Logical rules ensure also that changing locations involve some travel time.

- Environmental rules describe the travel network (i.e., travel times between locations) as well as opening hours of different places.

- Inter-personal rules specify the linkages between household members.

- Personal rules describe personal preferences.

The problem of scheduling activities in CARLA is defined in the following way: *Choose such an arrangement of the given set of activities, which obeys logical, environmental, and interpersonal rules and which represents the personal preferences of the individual who is being modelled by the optimisation of some objective function.* Stated in this way, CARLA arranges peoples' activities by solving the Travelling Salesman Problem. This is done by combing combinatorial methods (i.e., enumerate all possible arrangements of activities and then choose the optimum one) and heuristics (i.e., use a set of 'common sense' rules to limit the number of alternatives to be further examined by combinatorial method).

Model output

CARLA was tested in the Burford School study, which involves completion of 'before' and 'after' activity diaries of 62 pupils. Heuristic and combinatorial rules are examined in the activities from the 'before' study. CARLA is then applied to re-schedule pupils' activities in the 'after' situation where the observed change relates to setting the school hours 30 min forward relative to the 'before' situation. For each pupil CARLA produced a set of feasible activities in the new situation in the model output. These schedules are then compared to the pupils' activity diaries from the after-study. In 65% cases the schedule from the after-study was identical to one of CARLA's proposed schedules. In further 29% of cases the schedule from the after-study was identical to one of the model's schedules except that a new activity was generated by pupils in the after-study, something that CARLA cannot handle (a problem related to the external activity patterns, which are applied when defining the heuristic rules). Finally, in 6% of cases CARLA did not find feasible schedules, applying that some of the heuristic rules had to be broken in order for the pupil to adjust to the school hour change.

5.5. ALBATROSS

'Rule based versus utility maximising models of activity travel patterns',
9th International Association for Travel Behaviour Research Conference, Australia, 2000
Authors: T. Artenze et al.

ALBATROSS is a household activity based model system for predicting travel demand. Travel demand is modelled via predicting the choice of the individual activity schedule. The probability of a certain individual activity schedule is in ALBATROSS in function of:

- An activity agenda, i.e. a set of activities that an individual need or wish to carry out.
- A cognitive environment, i.e. locations available to individuals for specific activities.
- The available modes and the land use pattern.

ALBATROSS is driven by choice heuristics, which means that an exhaustive set of mutually exclusive 'if-then' expressions drive the system. ALBATROSS belongs to the group of activity schedule building models.

ALBATROSS is developed by the Urban Planning Group of the Eindhoven University of Technology in Holland.

Data input

The main input to the model is the activity diary, which describes individuals' activity sequencing, purpose, timing and duration. Apart from that the input to ALBATROSS are a list of different types of constraints, data describing individual and household characteristics, zonal data, and the characteristics of the transport system (files of level of service).

Model structure

ALBATROSS's core is a so-called scheduling engine, which is a system of models connected by conditional rules. The scheduling engine controls the scheduling process in terms of a sequence and steps. In the scheduling engine the process of activity scheduling starts with a schedule skeleton that contains the fixed activities that need to be conducted that day, e.g. work. The fixed activities are known from the input data in the activity diary. The start time and the location of the fixed activities are also known. The scheduling process involves adding flexible activities, such as shopping, to the skeleton. If by heuristic rules it is decided to add a flexible activity to the existing activity schedule then the system chooses with whom the activity is conducted and what duration the activity will have. At that point ALBATROSS knows what activities (both fixed and flexible activities) are to be performed by the person that day, i.e. the individual activity pattern.

In phase 2 the scheduling engine decides on the activity's starting time and trip chaining, i.e. the individual activity schedule. The final steps involve the mode choice and destination choice. At each step the scheduling engine takes into consideration all possible constraints given by the available information. Every time a new flexible activity is added, the scheduling engine may re-position the activities, adjust the start and end times, update travel times, and so on.

Model output

ALBATROSS is a model for forecasting household activity scheduling and travel demand. This is done in the way that activity scheduling is produced for two adults in the household (i.e., parents) where possible interactions between these people are taken into account.

6 Comparison of the two approaches

6.1. Basic requirements

There are two important approaches when modelling travel demand from the activity participation point of view, i.e. discrete choice models and simulation models. Under the simulation activity based models we include two sub-groups of models, i.e. activity schedule building models and switching models.

From the beginning of 1990's there has been an ongoing discussion about which of the two main approaches is 'more correct' or 'more truly' the activity based approach to modelling the travel demand. We do not intend to contribute to this discussion in the note basically due to the opinion that both model types have improved considerably the state-of-practice in travel demand modelling. The two model types have many strong properties and some less attractive properties. The application of one of the model types depends therefore upon the requirements for the specific project.

Let us start here by describing these tasks that stand in front of the activity based models. Table 1 lists the theoretical requirements of the activity based travel demand models while table 2 concerns a basic set of practical requirements.

1. Demand for travel is a derived demand from activity participation.
2. Individuals experience time, location and budget constraints when planning activities and travel.
3. Individuals plan activities in the context of their role in the family. Children are, for instance, proved to have a large impact on parents' activity scheduling.
4. Life style, as a long term parameter, plays an important part in the daily activity scheduling.
5. Scheduling decisions are part of a process governed by commitments and priorities.
6. Schedule choices must be interacted with the transport system performance attributes.

Table 1 – Theoretical requirements for activity based travel demand models

1. Activity based models must be theoretically sound, that is both behaviourally and mathematically. If this is not ensured we cannot rely on the obtained model forecasts.
2. A sufficient resolution of these models is needed in order to explain policy impacts. For instance, in order to explain all potential effects of road pricing a period of 24 hours must be divided in many more time intervals than peak and out-of-peak periods. Ideally, the time component should be modelled continuously.
3. Important practical resource requirements for the activity based models are:
   - The model needs to be technically and financially feasible to develop, operate and maintain. This requirement includes a maintainable software, relatively short running time and easy operating procedures.
   - Where possible, the available data should be split in two parts, i.e. one for estimating model parameters and the other for the model validation.
4. A statistical check of the model estimates is needed.
5. Model results need to be validated. For instance, the trip matrices that are produced in activity based models need to be assigned on the road and public transport networks and compared with the observed traffic counts.

Table 2 – Practical requirements of the activity based travel demand models

6.2. Strengths of the two model types

Taking care of the full list of theoretical and practical requirements from the activity based models we now present the important strengths of the two model types. Important strengths of discrete choice activity based models are the following:

- (Theoretical requirement) A large set of alternatives is defined in the travel pattern model (i.e., the choice set). (There are more than 1.500 alternatives in the activity pattern model in the latest version of the Portland model.) They are defined upon the type of the main activity, primary tour structure, secondary tour structure, pattern of intermediate stops, etc. Tours and trips are then defined to be dependent on the activity pattern model. In short, demand for travel is derived from the demand for activity participation in discrete choice activity based models.

- (Theoretical requirement) Some constraints are included in their model structure, i.e., car availability, choice of location and time of travelling.

- (Theoretical requirement) Long term effects are included in these models. Prior to day travel patterns, these models usually model some aspects of the lifestyle such as the choice of work location and the choice of car ownership.

- (Theoretical requirement) Attributes of the transport system performance are included in the model structure.

- (Practical requirement) Discrete choice activity based models are based on random utility theory, which has been proved in a large number of projects in the last three decades.

- (Practical requirement) Statistical validation of the model estimates is possible.

- (Practical requirement) Forecasting results of discrete choice models can be validated in a number of ways.

- (Practical requirement) These models are based on available software (e.g., ALOGIT), hence extensive programming knowledge is not necessary.

Important strengths of simulation activity based models are the following:

- (Theoretical requirement) These models put most attention in explaining the way we think when planning activities. Demand for travel is derived from the demand for activity participation in these models.

- (Theoretical requirement) Time, location and budget constraints are incorporated explicitly in their model structure according to the Hägerstrand's time-geography theory.

- (Theoretical requirement) ALBATROSS is presently the only operational model that is family based, including both discrete choice models and simulation models.

- (Practical requirement) Time is a continuos variable in the simulation models.

6.3. Weaknesses of the two model types

Major weaknesses of discrete choice activity based models are the following:

- (Theoretical requirement) Time is modelled discretionary in discrete choice models, i.e. a 24-hour period is divided in a number of time segments (AM peak, PM peak, etc.). Assuming that time is a discretionary variable means that:

  - Accidental disruptions of the planned schedule do not occur in discrete activity based models.

  - Activities that begin and end in two time segments must be re-allocated to only one segment.

- (Theoretical requirement) There are no family based discrete choice activity based models. These models are person based where family obligations are taken into consideration through the individual's roles in the family.

- (Theoretical requirement) In some earlier models (e.g., the Boston model) logsum parameters are not always successfully estimated (the 0-1 range). This problem seems to be solved in some newer models of this type.

- (Practical requirement) Choice of time-of-day models are usually based on the split of the day into 3 to 5 time periods (e.g., period before AM peak, AM peak, between the peaks, PM peak and evening). It is suggested in some projects that these periods need to be further divided into smaller periods (e.g., peak periods division between 'peak' and 'shoulder peak' periods).

Most important weaknesses of simulation activity based models are:

- (Theoretical requirement) Long term decisions (lifestyle) such as car ownership and the choice of working location are usually omitted in the structure of these models.

- (Theoretical requirement) The transport system performance is usually not incorporated in the structure of the simulation models.

- (Practical requirement) Simulation models are dependent of the external activity program. The set of proposed rules (heuristics) that suits the sample does not necessarily cover all cases that might occur in the forecasts considering the population or another sample of respondents.

- (Practical requirement) Generation of the choice set (applying a non-exhaustive method) results in a small number of alternatives and that cannot properly describe the realistic choice set.

- (Practical requirement) Simulation models produce realisations (and not probabilities as discrete choice models). Based on that a statistical validation of model results is not possible.

- (Practical requirement) Programming skills are needed when working with these models.

- (Practical requirement) Simulation models go through a very detailed structure of rules when building activity schedules by adding, deleting or rescheduling activities. That can sometimes cause a long running time of these models.

6.4. Some conclusions and recommendations

Table 3 summarises the main strengths (denoted by '+') and weaknesses (denoted by '-') of the two model types. Sign '(+)' means that a specific characteristics is only partially covered in the model type.

Characteristics	Discrete choice models	Simulation Models
Travel is a function of activities	+	+
Explicit inclusion of constraints	(+)	+
Explicit inclusion of family members' interactions in the model structure	-	+
Inclusion of long term effects in the model structure	+	-
Inclusion of transport system attributes in the model structure	+	-
Time is treated as a continuous variable	-	+
Special need for programming skills is not demanded	+	-
Statistical check of the model estimates is possible	+	-
Model validation is possible	+	(+)

Table 3 – Comparison of the two model types

Recommendation 1
The most important conclusion based on the discussion in chapters 6.1 to 6.3 is that one needs first to determine the purpose of the project where the activity based approach can be applied before deciding which one of the main methods should be applied.

Recommendation 2
It seems that if an operational model is needed, especially if the time scale is long (i.e., long term forecasting model) then discrete choice activity based models are proposed. Contrary to that, if a very specific task needs to be tackled and in a rather limited time period then simulation activity based models are preferred.

Recommendation 3
If a statistical check of the obtained results is demanded then discrete choice models are preferred to simulation models.

Recommendation 4
If the imperative of the model is that time is modelled continuously then simulation activity based models should be applied.

Recommendation 5
If the time, location and budget constraints need to be modelled explicitly then simulation activity based models should be applied.

Recommendation 6
If one wishes to include the impact of lifestyle parameters and the transport system performance upon the choice of the activity schedule then discrete choice models are preferred.

The activity based approach to modelling travel demand offers an improved understanding of travel behaviour. As this area of travel planning is very complex more research is needed. This may or may not result in better travel demand forecasting models in the future.

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How does a travel demand model work? Traditionally, an approach known as the â€œfour-step processâ€ has been used for regional transportation planning analysis. As its name implies, this process has four basic phasesÂ A complex sub-model has been created for determining the modal choice, and is based both on certain assumptions about transit capacity, schedules, and fare levels and on real-world observations of how, when, and where people use transit. What routes will people take? Trip assignment determines the routes people will take from start (origin) to finish (destination). Activity-based travel demand models predict travel sequences on a day for each individual in a study region. These sequences serve as important input for travel demand estimate and forecast in the area. However, a reliable method to evaluate the generated sequences has been lacking, hampering further development and application of the models. In this chapter, we use travel behavioral information inferred from mobile phone data for such validation purposes. Our method is composed of three major steps. 7. Activity-Based Travel Demand Model? A few principles Sum of all small behavior types is the majority of behavior ïƒ we are all unique, and that is important. 0.18 0.16 0.14 Income $0-30kP robability Dens ity Income $30-60k 0.12 Income $60-100k 0.1 Income $100k+ 0.08 0.06 0.04 0.02 0 $- $5 $10 $15 $20 $25 $30 Value of T ime ($/Hour) SAN FRANCISCO COUNTY TRANSPORTATION AUTHORITY 7. 8. Activity-Based Travel Demand Model?What it comes down to:â€¢ A less-cool-looking version of sim-city.Â â€œActivity based travel demand models as a tool for evaluating sustainable transportation policiesâ€ Research in Transportation Economics Volume 38/Issue 1. Feb 2013. San francisco county transportation authority 31. Recommended.