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ACTIVITY-BASED APPROACHES TO TRAVEL ANALYSIS: CONCEPTUAL FRAMEWORKS, MODELS, AND RESEARCH PROBLEMS

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ABSTRACT

The recent policy discussions about information technology in transport and traffic demand management have increased the interest in activity-based approaches to the analysis of travel behaviour, in particular in the modelling of household activity scheduling which is at the core of many of the required changes in travel behaviour. The paper is a state-of-the-art review of conceptualizations and models of activity scheduling with special regard to issues raised by the new policy instruments. In the course of the review, the validity of behavioral assumptions are critically examined and several needs for future research identified.

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1 INTRODUCTION

The growth of car ownership outdistances the growth of road capacity in most urban areas around the world forcing planners to consider a new mix of policy instruments to maintain minimum service standards in the face of further increasing congestion. An important part of such a policy mix are measures to manage traffic demand. Two main instruments have been identified for traffic demand management. The first is the restraint of traffic through increasing the generalised costs of travel brought about by policies such as road pricing, the active management of parking facilities or regulatory measures (e.g. reduced speed limits, woonerfs, etc.). The second instrument, currently under intense development around the world, is the use of information technology to provide travellers with more and improved information about the travelling conditions before and during their trips. Examples are information systems which guide route choices or parking location choices. Although there are other policy instruments, those mentioned are of particular interest because their evaluation highlights a number of issues which traditional transport research has tended to neglect. The most important of these is the question to which extent travellers are willing to substitute out-of-home with in-home activities, or, at least, to reschedule out-of-home activities and in this process possibly switching the originally intended location and/or travel mode. As a consequence, it becomes central to the assessment of these policies and technologies to understand the factors which affect the substitution or rescheduling of out-of-home activities. Questions need, for instance, to be raised about what role within and between-household coordination plays, what kind of travel information is needed and used, and the importance of the reliability of the transport system.

In what has become known as activity-based approaches (Heidemann, 1988; Hensher and Stopher, 1979), a basic aim is to account for decisions concerning activities which affect the demand for travel. Such decisions consist of an interrelated set including decisions for each activity of whether, where, when, for how long, and with whom to participate. Clearly, not all of these decisions are always made. Furthermore, depending on which time horizon the decision maker has, the number and type of activities which are scheduled may differ. It nevertheless seems essential to draw on this kind of broader conceptualisation when developing models of activity decisions evaluating the new mix of policy measures.

Activity scheduling has not been of primary interest in empirical transport research. See for instance the relative absence of this topic in the comprehensive reviews of Damm (1983), Kitamura (1988), or Jones, Koppelman, and Orfeuil (1990). Yet, a number of conceptual frameworks and mathematical-statistical models have been proposed and used to study this issue. An inevitable consequence of the relative lack of substantial empirical work on activity scheduling are the strong behavioral assumptions which need to be made in its modelling. The task of the present paper is to review and critically assess the validity of such assumptions, with special regard to the aim of defining problems in need of being investigated in future research.

Existing conceptual frameworks are presented in the next section. There are several attempts at modelling activity participation, timing and duration with econometric tools developed for the modelling of single trip decisions. These are discussed in the third section. Directions for further research are identified in the final section.

3CONCEPTUALIZATIONS OF ACTIVITY SCHEDULING

4.1A Utility-Maximization Conceptual Framework

A widely used and adapted conceptual framework for activity analysis is based on the economic theory of consumer choice (Lancaster, 1966), as extended in a theory of households' time allocation first advocated by Becker (Becker, 1965; Ghez and Becker, 1975) and later by Winston (1982). Even though this framework primarily addresses the question of why people spend a certain amount of time in various activities, it also has bearing on the issue of how they schedule these activities. The framework is similar to the motivational theory proposed in psychology by Atkinson and Birch (1970, 1986). However, following from the economic theory of choice, a basic assumption is that the observed time allocation entails decisions made according to the principle of utility maximization. Since this is an assumption whose validity frequently has been questioned (e.g. Prelec, 1982), or, at least, been identified to require substantial modification (Kahneman and Tversky, 1979), it is not clear whether the conceptual framework should be considered as prescriptive for, or as actually descriptive of, how decisions are made.

In this conceptual framework it is assumed that an individual's utility derives from the consumption of a vector of goods x, times spent in various non-work activities t, and time spent working t_w. (The presentation follows the study into the *Value of Travel Time Savings*, MVA *et al.*, 1987). The individual maximizes utility subject to constraints, such as the full income constraint which requires that the sum of the income earned in t_w at wage rate w plus the unearned income y must cover the costs of the goods x at their current prices p in time period T. The sum of times spent on working and on other activities must be smaller than time period T. Both work and other activities have a minimum time period t* proportional to the goods consumed in that activity. Thus the utility maximization problem can formally be stated as follows:

$$\text{Max} \quad U(x_1, x_2, ..., x_n, t_1, t_2, ..., t_n, t_w)$$

$$s.t.$$

$$w \ t_w + y \geq \sum_{i=1}^{n} p_i \quad x_i$$
$$T \geq t_w + \sum_{i=1}^{n} t_i$$
$$t_w \geq t_w^*$$
$$t_i \geq t_i^* \quad \forall i \qquad [1]$$

Winston (1982) develops the framework further by addressing its failure to take into account effects of the timing of activities. Winston assumes the existence of a production function for each activity type $z_i(t)$, which describe the relation between the labour and goods inputs and the resulting intensity of activity (production). This functions assume underlying technologies of consumption for specific commodities and for the performance of certain activities. Assuming a single person household, i.e. time independent labour inputs, and time invariant prices for the goods inputs, the functions are assumed to have the following form:

$$z_i(t) = z_i(x_i(t);t)$$

$$z_{i'}(t) = \frac{\partial z_i(t)}{\partial x_i(t)}$$

$$z_{i''}(t) = \frac{\partial^2 z_i(t)}{\partial x_i(t)^2} < 0 \qquad [2]$$

$$\frac{\partial z_i(t)}{\partial x(t)} = \frac{dE_i(t)}{dt}$$

with

$x_i(t)$: Goods inputs to activity i
$E_i(t)$: Production environment of the household for activity i

$E_i(t)$ is defined as the measured quality of the `production' environment of the household (e.g. the weather, the opening hours of shops, the presence of friends). The utility of activity i at time t is thus a function of the satisfaction from performing the activity itself and the intensity with which it is performed. Both the satisfaction and the intensity depend on time, t, which result in a time-of-day dependent utility for each activity. The utility functions $u_i(t)$ is assumed to have the following form:

$$u_i(t) = u_i(z_i(t);\ t)$$

$$u_{i'}(t) = \frac{\partial u_i(t)}{\partial z_i(t)} \qquad [3]$$

$$u_{i''}(t) = \frac{\partial^2 u_i(t)}{\partial z_i(t)^2} < 0$$

This definition excluded an effect of the duration of an activity. To take such an effect into account, Winston expanded the formulation of the utility functions to the following form (the production functions are similarly transformed):

$$u_i(t) = u_i(z_i(t), t - t_{i-1}) \quad , for\ t_{i-1} < t < t_i$$

$$u_i(t) = u_i(z_i(t), t - t_i) \quad , for\ t_i < t < t_{i-1} \qquad [4]$$

Winston is also able to provide a potentially useful classification of activities, based on the derivatives of ui(t) and zi(t) with respect to duration and frequency, as follows:

$$\frac{\partial u_i(t)}{\partial (t - t_{i-1})} = \begin{cases} > 0,\ Excitement \\ < 0,\ Boredom \end{cases} \quad , for\ t_{i-1} < t < t_i$$

$$\frac{\partial u_i(t)}{\partial (t - t_i)} = \begin{cases} > 0,\ Hunger\ or\ appealing\ novelty \\ < 0,\ Forgotten\ pleasures \end{cases} \quad , for\ t_i < t < t_{i-1}$$

$$\frac{\partial z_i(t)}{\partial (t - t_{i-1})} = \begin{cases} > 0,\ Warming\ up \\ < 0,\ Fatigue \end{cases} \quad , for\ t_{i-1} < t < t_i \qquad [5]$$

$$\frac{\partial z_i(t)}{\partial (t - t_i)} = \begin{cases} > 0,\ Rest\ and\ rejuvenation \\ < 0,\ Athrophy\ of\ skills\ from\ disuse \end{cases} \quad , for\ t_i < t < t_{i-1}$$

At present this classification lacks empirical support. Nevertheless, to the extent that the hypothesized states and their determinants implied by it are verified by empirical observations, the utility functions including duration has to be adopted in any utility-maximizing framework addressing activity scheduling. Even in the absence of empirical support the intuitive appeal of the classification may make it advisable to employ it as a working hypothesis.

Winston assumes that the utility derived from an activity has two components; the satisfaction from doing something, and the satisfaction of having done something. These components may be termed process and goal-achievement utility, respectively. A similar distinction has occasionally been made in motivational theories in psychology (e.g. Triandis, 1977). Goal-achievement utility should be conceived of as being obtained in a, perhaps limited time interval following the completion of an activity, whereas process utility should be conceived of as being `spread out' over its whole duration. However, for simplicity Winston assumes that the latter is true of both types of utility. (For an alternative set of assumptions see Kawakami and Isobe, 1986).

To summarise, the conceptual framework discussed in this subsection thus basically assumes that, within the time and cost constraints imposed by their budgets, people choose to spend time in activities which is proportional to their (process and/or goal-achievement) utilities. To account for the fact that people change activities over time, utilities are assumed to be dependent on duration, frequency and time of day. In contrast to the conceptual frameworks discussed in the next section, no descriptive model is provided of how people actually manage (or do not manage) to schedule activities so that utility is maximized. Such a model needs to explicitly account for the different decisions entailed by activity scheduling and how they are organized in time.

4.3 Eclectic Conceptual Frameworks

Three conceptual frameworks which do not rely as exclusively on the assumption of utility maximization have also been proposed. The frameworks vary in how explicitly they try to build on knowledge about how people actually make decisions (e.g. Abelson and Levy, 1985), and in how realistic they are in their assumptions about people's capacity to process information (Simon, 1990). Another difference is that the frameworks are primarily confined to conceptualizations of how a given set of activities are scheduled. Thus choices of participation in a set of activities are assumed to have been carried out already. Furthermore, in the tradition of much modelling of cognitive processes in psychology based on the pioneering work of Newell and Simon (1972), these conceptualisations envisage computer simulation as a viable modelling tool. (See also Smith, Pellegrino, and Golledge (1982) for a discussion of some of the virtues and problems with computer modelling in the present context).

4.4.1CARLA: Enumerating the feasible alternatives

One way of conceptualising scheduling is to assume that the decision maker first generates all possible activity schedules for a given time horizon (a day, a week, etc.), then chooses one of these to execute on the basis of their evaluation. Because of people's well known limitations to process information (Simon, 1990), such an assumption is unrealistic as soon as the number of possible alternatives are more than a few. However, as argued by proponents for the Swedish school of time geography (Hägerstrand, 1970), different spatiotemporal constraints may reduce the number of alternatives to only one or a few. Fundamental constraints of this sort are various capability limits circumscribing activities such as, for instance, people's physiological limits, or a certain transport technology limiting access to space; the fact that people, as well as people and objects, are coupled in space and time through work and other joint activities; and, finally, limits on use of space through authorisation, that is through rules, laws, and power relationships. CARLA (Jones, Dix, Clarke and Heggie, 1983) is a combinatorial algorithm which was developed as a means of identifying the feasible alternative schedules. It is comparable to Lenntorp's PESASP model (1976) in this respect. It does that through the implementation of a branch-and-bound algorithm, which reorganizes the given activity program. Whether CARLA identifies the same constraints as people identify, and whether it does that in the same way as people do is not known. These are clearly important questions since few constraints are absolute, nor are constraints always accurately perceived.

The availability of the complete set of feasible schedules allows the use of alternative criteria to establish the best schedule. In a study of rural bus services cuts, Clarke, van Knippenberg and Splinter (1984) proposed a simple metric, the `Disruption index', to measure the difference between the existing activity schedule and a possible new one. However, this is still one step from a method explicitly including in its conceptualisation the process of choice between activity schedules.

4.4.3STARCHILD: Identifying and choosing between representative activity schedules

A more comprehensive conceptual framework has been proposed by Root and Recker (1983). As Figure 1 illustrates, in this framework the daily scheduling process is divided into two stages. In the pre-travel stage, the individuals schedule activities which satisfy their needs and desires. The execution of the schedule is continuously monitored during the travel stage. Revisions, additions, and deletions are accomplished in response to unforeseen consequences of the schedule, new demands, or unexpected incidents such as, for instance, road accidents. Recker and Root assume that individuals attempt to select an optimal sequence of activities, in terms of their durations, locations, and modes, in order to maximize the total utility of the activities, while maximising the flexibility of the schedule, minimising the time spent away from home, and minimising the coordination effort involved in the scheduling.

Figure 1

In connection with work on the computer program STARCHILD (Recker, McNally, and Root, 1986a, 1986b), the conceptualisation of the pretravel-stage activity scheduling was further specified. Basically, in the refined conceptual framework it is assumed that individuals first filter out a subset of all feasible activity schedules, then choose the alternative schedule in this subset with the highest utility. The assumption is also made that the utilities of the activity schedules are computed as the sums of the utilities assigned to the different time components making them up, that is participation in activities, wait times, and travel times. In the operationalisation of the conceptual framework in STARCHILD, different assumptions are made for the assignment of utilities to activities and their associated wait and travel times depending on whether the activities are planned out-of-home activities (e.g. work), unplanned out-of-home activities (e.g. grocery shopping), or discretionary in-home activities (e.g. watching TV). The utilities of planned out-of-home activities are in STARCHILD assumed to be proportional to their perceived importance multiplied by an objective index of probability of performance. Unlike the assumption made by Winston (1982), utilities are assumed to be independent of duration. However, the utilities of wait and travel times are assumed to be inversely proportional to the actual wait and travel times with a slope which decreases with the importance of the activity. A similar formulation is used to assign utilities to the individuals' potentials for the participation in unplanned out-of-home activities, in this case by multiplying perceived importance with an index of the probability of performing the unplanned activities at available locations. The utility is also made dependent on the duration since the activity was performed last time. Furthermore, the expected disutilities of the additional travel times are taken into account. In the calibration of STARCHILD, in-home activities presented a problem because no information was available from the obtained travel diary data. Such activities are therefore all considered discretionary. Their utilities are assumed to depend on duration at home and the number of other household members being at home. Further information needs to be obtained to ascertain whether in-home activities should be treated differently from out-of-home activities.

To briefly summarise, in addition to using a different means of generating alternative activity schedules than CARLA, STARCHILD also provides an estimated model for the choice between these alternatives. In doing so, a utility maximization framework is employed in which utilities of alternative schedules are computed by summing utilities assigned to the activities, wait times, and travel times according to rules which differ depending on whether the activities are planned out-of-home, unplanned out-of-home, or discretionary in-home activities. The expected utility formulation entailed by STARCHILD is similar to subjective expected utility (SEU) theory (Edwards, 1954) which has been proposed as an account of how people make decisions under uncertainty, although it is unclear whether the probability index captures (or is supposed to capture) subjective probability. A recent, closely related example of an application of

SEU theory is the theory of planned behaviour proposed by Ajzen (1985). In this theory the assumption is made that preference for an activity is proportional to perceived importance of its consequences multiplied by the perceived probability of successful performance. Nevertheless, a number of assumptions entailed by STARCHILD are unlikely to be true of how people actually schedule activities. Recker *et al.* (1986a) themselves note that it is implausible that people consider many different alternative activity schedules. However, the critical issue is how the number is reduced. In STARCHILD an attempt is made to identify and retain alternatives which dominate others. The reasoning is that people may use a noncompensatory (not utility-maximizing) decision rule to screen out alternatives. There is some supporting evidence for this, suggesting that the lexicographic or elimination-by-aspects decision rules are used to select a subset of decision alternatives when the number is large (Montgomery, 1990; Svenson, 1979; Tversky, 1972). However, the process of reducing the number of alternatives in STARCHILD still seems to require that all feasible alternatives are generated. Furthermore, it does not in general guarantee that a realistically small number of alternatives remain in the final choice set. In a similar vein, even though it may seem plausible that flexibility in the sense of providing for unplanned activities contributes to the utility of the schedule, the actual calculation of this utility appears too much demanding to realistically represent what people do.

In both CARLA and STARCHILD it is tacitly assumed that the time horizon is a day or shorter, whereas this may differ for different activities or activity types. Other relevant time horizons are conceivable, such as, for instance, the weekly commitments, the time until the next major holiday, and the time until the next vacation. Because these time horizons may be similar for a large part of the population, it becomes essential to include them in any conceptual framework and empirical analysis. The individual will, in addition, respond to claims made by significant others. It is not clear to what extent and in what way such moral obligations, e.g. to escort a family member to the doctor, to attend a funeral, to go to a wedding, are subject to a narrow cost-benefit calculation. In the theory of planned behaviour (Ajzen, 1985) mentioned above, as well as in its predecessor (Fishbein and Ajzen, 1975), intentions to perform an activity are assumed to be influenced by whether one believes that other significant people would endorse its performance. Ample evidence shows that this factor sometimes is as important as, or more important than how much the activity is preferred. A related conclusion is reached by Heap (1989) who proposes that a narrow cost-benefit calculation often may be dominated by societal rules governing choice of activities (See also Harré, Clarke and De Carlo, 1985).

4.4.5SCHEDULER: Generating the activity schedule

A conceptual framework which addresses several of the shortcomings noted above has recently been proposed by Gärling, Brännäs, Garvill, Golledge, Gopal, Holm and Lindberg (1989). In this framework which is partly based on the cognitive model of planning proposed by Hayes-Roth and Hayes-Roth (1979), activities are defined as means which the environment offers individuals or households to attain their goals. Individuals have preferences for these means based on their beliefs about how instrumental they are and how important the goals are which the activities are believed to lead to. Choice of participation in activities is determined by these preferences in conjunction with prior commitments.

Scheduling is defined as the process of deciding how to implement a set of activity choices during a defined time cycle. It entails an interrelated set of decisions made by the individual, interactively with other individuals, concerning who would participate in which activities, when, where, and for how long they would participate, and how they would travel between locations where the activities can be performed. Feasibility of the schedule is a primary goal, minimization of travel a secondary goal.

As may be noted, the framework thus provides a definition of the utility of activities based on contemporary attitude theory (Ajzen, 1985; Fishbein and Ajzen, 1975). Furthermore, in line with this theory, commitments (appointments, obligations) are another factor determining activity choices. Preferences are assumed to be rather enduring but to change depending on changes in saliency of different goals. Similarly, there is no time horizon specified for commitments. However, scheduling is assumed to have a limited time horizon of a day or shorter. The reason is that different processes of scheduling, perhaps varying in degree of elaboration, are assumed depending on time horizon. At present only the short-term scheduling process has been worked out in any detail.

The specific assumptions about the activity scheduling can be described with reference to Figure 2. Because it is neither assumed that all feasible schedules are generated nor that any tedious calculations are made, these assumptions are more compatible with the psychologically plausible process of `heuristic search' (Newell and Simon, 1972; Simon, 1990). Thus, instead of assuming that all alternative schedules are generated, it is assumed that a set of activities is chosen from the part of the individual's memory, called the long-term calendar, which stores information about the activities. The selection is made in order of priority with a cut off point dependent on how priority changes and a crude judgment of number of activities possible to perform in the time slot. For most people the selected activities are likely to consist of a few with high priorities to be performed during the day. What in Figure 2 is called the SCHEDULER then retrieves memorised information about the environment and identifies when and where each activity can be performed. In passing it may be noted that this identification is not trivial because of the many possible biases in how an individual remembers the environment (Gärling and Golledge, 1989).

On the basis of the identified temporal constraints (e.g. opening hours) the activities are first partially sequenced, then they are sequenced so that total travel distance is minimized using a variant of the `nearest-neighbour' heuristic (Gärling, 1989; Gärling, Säisä, Böök, and Lindberg, 1986). Starting with the activity to be executed first, a more detailed schedule is finally `mentally executed' with the aim of evaluating its feasibility under the given circumstances. In this stage decisions about travel modes are made. More detailed information is also sought about activity durations, departure times, travel times, and wait times. Only to the extent this information is accessible will the `mental execution' proceed. There is also an upper limit on how many activities are `mentally executed'. In the `mental execution' identified conflicts threatening the feasibility of the schedule, such as overlapping end and start times, are if possible resolved by changing the order between the activities in conflict (according to a satisficing principle rather than on the basis of a choice between all possible alternative orders), or by replacing a chosen activity with another of lower priority. When a schedule has been formed for the activities with the highest priority, attempts may be made to find less prioritised activities in the long-term calendar which fit into open time slots in the schedule.

Figure 2

In the SCHEDULER framework it is not assumed that all scheduling is accomplished at a certain point in time but may continue as the schedule is being executed. Thus a skeletal or detailed schedule may be worked out for only a few activities, stored in what in Figure 2 is called the short-term calendar, then while those activities are being executed others are added. Thus an individual may in this way retain a degree of preferred flexibility or opportunism (Hayes-Roth and Hayes-Roth, 1979), or may simply be unable to form a schedule because information is lacking. Allowance is also given for revisions of the schedule if it cannot be performed as expected. The execution of the schedule must thus be modelled so that appropriate feedback to the scheduler is provided.

A conceptualisation of scheduling as both simultaneous and sequential appears realistic. However, in the SCHEDULER framework, further assumptions are needed to specify when one or the other will take place. In particular, assumptions about the role of metadecisions (Hayes-Roth and Hayes-Roth, 1979), for instance concerning how to schedule, may need to be incorporated.

The interaction within a household, or a wider social group of which the individual is a member, is likely to strongly influence the daily scheduling of activities. In the scheduler framework some activities are assumed to require the participation of at least two household members (e.g. a family outing), some can be performed by either household member (e.g. grocery shopping), whereas still others must be performed by the individual (e.g. work). Scheduling of the first two types of activities is assumed to be made so that another person's schedule is taken into account. At any time when scheduling takes place, the individual scheduling of such activities will receive as additional input the other person's schedule regarding these activities (time, location) (see Figure 2). If these constraints cannot be responded to, the activities are rescheduled or replaced so that the other person needs to change his or her schedule. Thus, the SCHEDULER framework includes a rudimentary representation of social interactions between household members while scheduling their daily activities.

Even though such work is now in progress[1], unlike CARLA and STARCHILD the SCHEDULER has not been developed into a computer simulation. Therefore, it has not been possible to calibrate an operational model. Related to this basic shortcoming is that several assumptions lack precision. For instance, the criteria of feasibility and minimization of travel which the scheduler is assumed to employ are not precisely stated. No specific assumptions are made about how information is biased in memory, or how information may be biased in the social interaction process. Furthermore, the assumptions made about how choices of departure times, of destinations, and of travel modes are made appear to be oversimplifications.

4.4.7Summary

The approaches presented in this section provide frameworks, in which to address the scheduling process explicitly in contrast to the time allocation approach. Their behavioural base needs to be strenghtend, but that reflects our lack of knowledge in many areas which these frameworks address.
Two particular issues are important: the handling of change and the handling of routines:
A common shortcoming of CARLA and STARCHILD is that no assumptions are made about changes. To the extent this means that nothing is assumed to change, it is certainly questionable as recently pointed out by Goodwin, Kitamura, and Meurs (1990) in a discussion of dynamic approaches to travel analysis. However, in the SCHEDULER the individuals are, in principle, assumed to learn about the environment and the transport system, and to base their decisions on the information they acquire.

Furthermore, in line with much current theorizing in cognitive psychology and cognitive science (Abelson, 1981; Schank, 1982), deliberate decisions are over time assumed be replaced by the execution of scripts or routines. These assumptions are in need of a more detailed specification. For instance, the implication may not be tenable that the automation of activity scheduling is identical to the automation of many motoric activities, such as cycling or car driving. The repetition observed could be the result of the avoidance of the work involved in scheduling itself, of the repeated execution of a script superior to others, of the lack of knowledge about alternatives, or of the lack of alternatives.

5EMPIRICAL MODELS OF ACTIVITY SCHEDULING

[1] Gärling and Golledge, personal communication

Becker-Winston's allocation-of-time framework, CARLA, STARCHILD, and the SCHEDULER, described in last section, seem to capture several important aspects of how people schedule their daily activities. They also represent a progression from less to more encompassing and realistic conceptualizations. At the same time, to develop and to empirically calibrate models become increasingly more difficult. This section addresses the question of to what extent models have been developed with a bearing on the validity of the different conceptual frameworks. It reviews the most promising attempts at calibrating models of different choices entailed by activity scheduling. These include choices of activity schedule, choices of activity participation, and choices of activity duration (Table 1).

6.1Choices of Activity Schedule

In CARLA and STARCHILD alternative activity schedules are generated, and in STARCHILD choices between these alternatives are an essential part of scheduling. Similarly, maximization of the utility of set of activities is important in the Becker-Winston allocation-of-time framework. Only a few models of activity-schedule choice have however been calibrated.

Adler and Ben-Akiva (1979) developed for a sample of full-time employed persons a model of the choice between complete activity schedules described by their travel-related (e.g. number of trips, total travel time, travel costs) and activity-related characteristics (e.g. retail or service employment density at the destinations, leisure facilities). The description of travellers included household income and number of non-working household members. The choice set consisted of the activity pattern realised by the traveller and a small random sample of activity patterns of travellers living in the same home zone. The estimation results (multinominal logit analysis) indicated a preference for home-based single-purpose journeys to high-activity non-CBD destination near home. There was furthermore an influence of the number of non-working household members on the probability of travelling.

Another model of activity-schedule choice was estimated by Recker, McNally and Root (1986a, 1986b) as part of STARCHILD (See above for the model structure). The estimation results (multinominal logit) showed that the subjects weighted travel times independently of the importance of trip purposes (activities), but that they allowed for extra slack times to ensure the performance of important activities. The subjects furthermore valued positively the potential to engage in unplanned activities. They also more strongly preferred to spend time at home when all other household members were present.

6.3Choices of Activity Participation and Duration

All frameworks reviewed make assumptions about factors which affect choices to participate in activities. Time of day, degree of previous participation, other household members' activity choices are such factors. However, only in the Becker-Winston framework are choices of duration assumed to be made. Below, two models of activity-type choice are first reviewed, then several models of choice of activity participation and duration or of only duration are reviewed.

On the basis of the assumption that choices to participate in activities during a specified time period are made sequentially, Kitamura and Kermanshah (1983, 1984) proposed a logit model of how choices of activity type (personal business, social and recreational, shopping, escorting passengers and return home (on non-home-based trips only)) depend on socio-economic characteristics, number of cars, time of day, and degree of previous participation in the activities. The model was estimated separately for home and non-home-based trips. For the home-based trips, the choices of activity type were influenced by time of day and degree of previous engagement in the same activity. For the non-home-based trips, it was likewise found that choices were influenced by time of day and, to a more limited extent, by degree of previous participation in the activity. The results also showed that the duration of out-of-home activities and the number of journeys had a strong influence on the timing of the return home, suggesting either a long and intensive or a very restrained and short participation.

The work of Mentz (1984) likewise adopted a sequential analysis of the decisions to participate in different activities. A separate multinominal logit model was estimated for every choice of a new activity during the day. The models include the socio-economic characteristics of the household, degree of previous participation in the same types of activities by the individual and other household members. The model was estimated separately for both working and non-working subjects. The results showed in almost every case an influence of previous participation in the activity by the same subject, whereas the influence of the degree of participation by other household members were less. Furthermore, the weights associated with degree of previous participation increased during the day, indicating a non-linear effect and a time-of-day dependent influence of this factor.

Damm and Lerman (1981) proposed a model of choice of participation in and duration of non-work activities in predefined time periods. The time periods were defined in relation to work (before, on the way to, during, coming from, and after). The exact timings varied between subjects depending on their working hours. The model included temporal constraints, spatial constraints, and the socio- economic situation of the household. The model was estimated with a two-stage procedure combining a binary probit formulation for the discrete choice of participation and a regression formulation for the continuous choice of duration. The results showed a clear influence of day as well as of time of day. Furthermore, the results demonstrated effects of household factors (number of children, number of non-working adults, presence of a working spouse, and drivers per car) on both the timing and duration of non-work activities. The results of Kitamura (1984a) verified these results, although obtained from the estimation of a more limited model. Kitamura proposed a two-stage tobit formulation for modelling the choice of participation in and duration of leisure activities. Two variables included in the model were the subjects' socio-demographic and work characteristics. Type or quality of the leisure activities were however not included. Choice of activity participation was almost exclusively determined by work duration. Choice of activity duration was again shown to be influenced by time of day factors (start time, work duration) as well as day. The importance of household factors are apparent in the influence on duration choice of the number of driver per car and the age, gender, employment structure of the remaining household members.

Hirsh, Prashker, and Ben-Akiva (1986) developed a theoretically complex nested-logit model of shopping participation with the whole week as planning horizon. They estimated a simpler model of participation in shopping activities for each day with indicators for the shopping activities in preceding days. The other variables in the model included subjects' socio-economic characteristics, household composition, and available time for shopping before and after midday. There were obvious differences in the estimation results for the various days of the week. The results for the normal days, Sunday, Monday, Wednesday, and Thursday, differed substantially from those for the special days, Friday (weekend shopping) and Tuesday (afternoon closure). The interaction of the shopping activity across the week is captured by budget variables (frequency of shopping and number of earlier shopping trips) and by the logsum term of a nested scheduling model focusing on the timing of shopping.

Kitamura's (Recker and Kitamura, 1985) activity-duration model points in a different way to the importance of the flexibility of the activity schedule. The author estimated log-linear regression models of choice of duration of four different activity types (personal business, shopping, social and recreational, escorting passengers). The models included descriptions of socio-economic characteristics, start time, total out-of-home time, number of journeys, participation in other activities, and accessibility of locations. The results again showed the importance of time of day and of previous activities during the day, especially for shopping and social and recreational activities. In addition the model captures the importance of the accessibility to the locations of other activity purposes through statistically significant accessibility indices for these activity purposes.

6.5Summary and Conclusions

The review of the different models gives a scattered picture. This is understandable because the research has not been guided by any overall framework. One common feature of the models is, however, their reliance on the utility maximisation principle which was criticized above for possibly not being descriptive of how people actually make decisions. Furthermore, a shortcoming is that all model estimation is made on the basis of observations of actual choices (revealed preferences). It is difficult then to infer causal relationships, as it is not clear that the assumptions used hold. Furthermore, most of the variables included in the models are at best approximations of those key variables of interest, e.g. number of children instead of children's activity programmes and timing constraints. To eliminate or reduce these problems, in future research revealed preference results need to be verified by subsequent experimental studies. A good example of such a mix of strategies is the research by Jones *et al.* (1983).

Despite these weaknesses, some results may still be reliable when they are found repeatedly. There seems to be clear indications that choices of activity participation and duration are dependent on the position of the day in the week and time of day, that such choices are influenced by previous and planned activity participation and thus not made independently, and that social interaction within households is an important factor. Of course, these findings point to the need for a broader conceptualisation such as proposed in the SCHEDULER described above. In addition, some evidence seems to suggest that people schedule their activities with a longer time horizon than a day, indeed that a number of time horizons are planned for simultaneously.

7RESEARCH PROBLEMS

The aim of this section is to highlight the problems within the activity-based approach which are most urgently in need of further investigation. Several basic problems are related to the process of activity scheduling. In fact the details of this process, how information of the environment and the transport system is acquired and used, how utilities or priorities are assigned to activities, and which heuristics and decision rules are used, are largely unknown (Axhausen, 1991).

Methods need to be developed which make it possible the study of this process in more depth than in the past. What is needed is a combination of naturalistic observations of scheduling through diaries or similar techniques known as experience sampling (Hormuth, 1986) which in the past have been used to study the performance of activities, observations under simulated but fairly realistic conditions (Jones, 1979, 1985; Jones, Bradley, and Ampt, 1989), and observations under experimental conditions using many of the techniques developed in psychology, such as analysis of performance errors, chronometry, and, possibly, computer modelling of `think-aloud' protocols (Lachman, Lachman and Butterfield, 1979).

More specific questions include in which ways, how fast, and to what degree of accuracy people acquire or update knowledge about destinations, travel times, and travel costs. Furthermore, the precise role this knowledge plays in activity scheduling needs to be studied. For instance, do people routinise their scheduling decisions relatively quickly with the consequence that very little new information is actively sought? Related questions concern the actual organisation over time of the scheduling decisions themselves. To what degree are such decisions made simultaneously, and what time horizon is used? Why, when, and how are scheduling decisions later revised? What degree of realism is aspired to, and how are different spatiotemporal constraints identified and taken into account to achieve the aspired to degree of realism? What costs are minimised and how?

Even though most research to date has obtained data on activities rather than on their scheduling, many problems are nevertheless unresolved. In particular, one such important and unresolved problem concerns how utilities are assigned to activities. Empirical evidence furthermore needs to be sought concerning the possible distinction made above between process and goal-achievement utility. Finally, how utilities or priorities change over time deserves further investigation.

A related, neglected question is for instance, to what extent are activities performed in response to demand by other people within or outside the household. The expression `living on borrowed time' has been used to refer to the fact that many people's agendas are to a large degree determined by demands of other people. The repeated exchange of `time' through help, support, participation in joint activities, or services, such as taking on shopping, escorting persons, creates a web of obligations, which can only be repaid with `time' and cannot, or only with great difficulty be replaced by any other good (Grieco and Pearson, 1991). The expression `living on borrowed time' applies especially to crisis situation, but the inevitability of such crises makes prudent preparation a necessity.

The importance of household interaction has so far only been captured in model estimation by the inclusion of some crude index. On the basis of more elaborate theoretical assumptions being imported from social psychology and related areas of research, improvements may be possible to achieve. Nevertheless, further progress is very much dependent on the development of a methodology which makes it possible to observe within and between-household interactions. Because there are so many obstacles, this is not easy, or even feasible. It will be possible to obtain some limited information from diaries about when different people interact in scheduling, and how the schedule is determined by such interactions.

9 SUMMARY AND CONCLUSIONS

The present paper has reviewed several conceptual frameworks and models within the activity-based approach to the analysis of travel behaviour. Even though the progress to date is impressive, it is also the case that the problems posed within this approach are indeed difficult to come to grip with. Therefore, more questions have in this review been raised than have been possible to answer. Nevertheless, it is believed that answering these questions through research is not a matter of scientific curiosity but responds to the need to provide policy makers with models of how households schedule activities.

Such models, based on scientific sound conceptualizations, are indispensable to guide the formulation and implementation of the policies needed to cope with the problems of managing traffic demand in the face of the serious threats of traffic congestion and environmental pollution in metropolitan areas and regions.

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13REFERENCES

ABELSON, R.P., 1981, Psychological status of the script concept. *American Psychologist*, **36**, 715-729.

ABELSON, R.P. and LEVY, A., 1985, Decision making and decision theory. In: *Handbook of Social Psychology*, **2**, edited by G. LINDSEY and E. ARONSON, pp. 231-309 (New York: Random House).

ADLER, T.J. and BEN-AKIVA, M.E., 1979, A theoretical and empirical model of trip chaining behaviour. *Transportation Research*, **13B**, 243-257.

AJZEN, I., 1985, From intentions to actions: A theory of planned behaviour. In: *Action control: From cognition to behaviour*, edited by J. KUHL and J. BECKMAN, pp. 11-39 (Berlin: Springer).

ATKINSON, J.W. and BIRCH, D., 1970, *The Dynamics of Action* (New York: Wiley).

ATKINSON, J. W. and BIRCH, D., 1986, The fundamentals of the dynamics of action. In: *Motivation, Thought, and Action*, edited by J. KUHL and J.W. ATKINSON, pp. 16-48 (New York: Praeger).

AXHAUSEN, K.W., 1991, The role of computer-generated role playing in travel behaviour analysis. Paper presented at the 70. Annual Meeting of the Transportation Research Board, Washington, D.C..

BECKER, G.S., 1965, A theory of the allocation of time. *Economic Journal*, **75,** 493-517.

CLARKE, M, VAN KNIPPENBERG, C. and SPLINTER, J., 1984, Analysing the effects of rural bus service reductions. Paper presented at the 63. Annual Meeting of the Transportation Research Board, Washington, D.C..

DAMM, D., 1983, Theory and empirical results a comparison of recent activity-based research. In: *Recent Advances in Travel Demand Analysis*, edited S. CARPENTER and P.M. JONES, pp. 3-33 (Aldershot: Gower).

DAMM, D. and LERMAN, S.R., 1981, A theory of activity scheduling behaviour. *Environment and Planning*, **13A**, 703-718.

EDWARDS, W., 1954, The theory of decision making. *Psychological Bulletin*, **51**, 380-417.

FISHBEIN, M. and AJZEN, I., 1975, *Belief, Attitude, Intention and Behaviour: An Introduction to Theory and Research* (Reading: Addison-Wesley).

GÄRLING, T., 1989, The role of cognitive maps in spatial decisions. *Journal of Environmental Psychology*, **9**, 269-278.

GÄRLING, T., BRÄNNÄS, K., GARVILL, J., GOLLEDGE, R.G., GOPAL, S., HOLM, E. and LINDBERG, E., 1989, Household activity scheduling. Paper presented at the Fifth World Conference on Transport Research, Yokohama.

GÄRLING, T. and GOLLEDGE, R.G., 1989, Environmental perception and cognition. In: *Advances in Environment, Behaviour, and Design*, **2**, edited by E.H. ZUBE and G.T. MOORE, pp. 203-236 (New York: Plenum).

GÄRLING, T., SÄISÄ, J., BÖÖK, A. and LINDBERG, E., 1986, The spatiotemporal sequencing of everyday activities in the large-scale environment. *Journal of Environmental Psychology*, **6**, 261-280.

GHEZ, R.G. and BECKER, G.S., 1975, *The Allocation of Time and Goods over the Life Cycle* (New York: Columbia University Press).

GOODWIN, P.B., KITAMURA, R. and MEURS, H., 1990, Some principles of dynamic analysis of travel behaviour. In: *Developments in Dynamic and Activity-Based Approaches to Travel Analysis*, edited by P.M. JONES, pp. 56-72 (Aldershot: Gower).

GRIECO, M. and PEARSON, M., 1991, Spatial mobility begins at home? Re-thinking inter-household organisation. Paper presented at the Annual Conference of the Institute of British Geographers, Sheffield.

HÄGERSTRAND, T., 1970, What about people in Regional Science?. *Papers of the Regional Science Association*, **24**, 7-21.

HARRÉ, R., CLARKE, D. and DE CARLO, N., 1985, *Motives and Mechanisms* (London: Methuen).

HAYES-ROTH B. and HAYES-ROTH, F., 1979, A cognitive model of planning. *Cognitive Science*, **3**, 275-310.

HEAP, S.H., 1989, *Rationality in Economics* (Oxford: Blackwell).

HEIDEMANN, C., 1988, Regional planning methodology: The first and only annotated picture primer on regional planning. *Discussion paper*, **16**, Institut für Regionalwissenschaft, Universität Karlsruhe, Karlsruhe.

HENSHER, D.A. and P.R. STOPHER, eds., 1979, *Behavioral Travel Demand Modelling* (London: Croom Helm).

HIRSH, M., PRASHKER, J.N. and BEN-AKIVA, M.E., 1986, Dynamic model of weekly activity pattern. *Transportation Science*, **20**, 24-36.

HORMUTH, S., 1986, The random sampling of experiences in situ. *Journal of Personality*, **54**, 262-293.

JONES, P.M., 1979, `HATS': A technique for investigating household decisions. *Environment and Planning*, **11A**, 59-70.

JONES, P.M., 1985, Interactive travel survey methods. In: *New Survey Methods in Transport*, edited by E.S. AMPT, A.J. RICHARDSON and W. BRÖG, pp. 99-127 (Utrecht: VNU Science Press).

JONES P.M., BRADLEY, M. and AMPT, E.S., 1989, Forecasting household response to policy measures using computerized, activity-based stated preference techniques. In: *Travel Behaviour Research*, edited by the INTERNATIONAL ASSOCIATION FOR TRAVEL BEHAVIOUR, pp. 41-63 (Aldershot: Avebury).

JONES, P.M., DIX, M.C., CLARKE, M.I. and HEGGIE, I.G., 1983, *Understanding Travel Behaviour* (Aldershot: Gower).

JONES, P.M., KOPPELMAN, F. and ORFEUIL, J.-P., 1990, Activity analysis: State-of-the-art and future directions. In: *Developments in Dynamic and Activity-Based Approaches to Travel Analysis*, edited by P.M. JONES, pp. 34-55 (Aldershot: Gower).

KAHNEMAN, D. and TVERSKY, A., 1979, Prospect theory: An analysis of decisions under risk. *Econometrica*, **47**, 263-291.

KAWAKAMI, S. and ISOBE, T., 1986, A method of activity estimation for travel demand analysis. Paper presented at the 4th World Conference on Transport Research, Vancouver.

KITAMURA, R., 1984, A model of daily time allocation to discretionary out-of-home activities and trips. *Transportation Research*, **18B**, 255-266.

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

KITAMURA, R. and KERMANSHAH, M., 1983, Identifying time and history dependencies of activity choice. *Transportation Research Record*, **944**, 22-29.

LACHMAN, R., LACHMAN, J.L. and BUTTERFIELD, E.C., 1979, *Cognitive Psychology and Information Processing: An Introduction* (Hillsdale: Erlbaum).

LANCASTER, K.J., 1966, A new approach to consumer theory. *Journal of Political Economy*, **74**, 132-157.

LENNTORP, B., 1976, *Paths in Space-Time Environments* (Lund: Liber).

MENTZ, H.-J., 1984, Analyse von Verkehrsverhalten im Haushaltskontext. *Schriftenreihe des Instituts für Verkehrsplanung und Verkehrswegebau*, **11**, Technische Universität Berlin, Berlin.

MONTGOMERY, H., 1989, From cognition to action: The search for dominance in decision making. In: *Process and Structure in Human Decision Making*, edited by H. MONTGOMERY and O. SVENSON, pp. 23-49 (New York: Wiley).

MVA CONSULTANCY, INSTITUTE OF TRANSPORT STUDIES (UNIVERSITY OF LEEDS) and TRANSPORT STUDIES UNIT (UNIVERSITY OF OXFORD), 1987, *The Value of Travel Time Savings* (Newbury: Policy Journals).

NEWELL, A. and SIMON, H.A., 1972, *Human Problem Solving* (Englewood Cliffs: Prentice-Hall).

PRELEC, D., 1982, Matching, maximizing, and the hyperbolic reinforcement feedback function. *Psychological Review*, **89**, 189-230.

RECKER, W.W. and KITAMURA, R., 1985, Activity-based travel analysis. In: *Transportation and Mobility in an Era of Transition*, edited by G.R.M. JANSEN, P. NIJKAMP and C.J. RUIJKGROK, pp. 157-183 (Amsterdam: Elsevier).

RECKER, W.W., McNALLY, M.G. and ROOT, G.S., 1986a, A model of complex travel behaviour: Theoretical development. *Transportation Research*, **20A**, 307-318.

RECKER, W.W., McNALLY, M.G. and ROOT, G.S., 1986b, A model of complex travel behaviour: An operational model. *Transportation Research*, **20A**, 319-330.

ROOT, G.S. and RECKER, W.W., 1983, Towards a dynamic model of individual activity pattern formulation. In: *Recent Advances in Travel Demand Analysis*, edited by S. CARPENTER and P.M. JONES, pp. 371-382 (Aldershot: Gower).

SCHANK, R.C., 1982, *Dynamic Memory*. (Cambridge: Cambridge University Press).

SIMON, H.A., 1990, Invariants of human behaviour. *Annual Review of Psychology*, **41**, 1-19.

SMITH, T.R., PELLEGRINO, J.W. and GOLLEDGE, R.G., 1982, Computational process modelling of spatial cognition and behaviour. *Geographical Analysis*, **14**, 305-325.

SVENSON, O., 1979, Process descriptions of decision making. *Organizational Behaviour and Human Performance*, **23**, 86-112.

TRIANDIS, H.C., 1977, *Interpersonal Behaviour* (Monterey: Brooks/Cole).

TVERSKY, A., 1972, Elimination by aspects: A theory of choice. *Psychological Review*, **79**, 281-299.

WINSTON, G.C., 1982, *The Timing of Economic Activities* (Cambridge: Cambridge University Press).

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Table 1
Models reviewed and their scope

Authors, Year	Scope	Data base
Adler & Ben-Akiva, 1979	Activity pattern	Washington, 1968
Damm & Lerman, 1981	Activity participation (Yes/No) in exogenously determined time periods and duration	Twin Cities, 1970
Kitamura & Kermanshah, 1983	Activity type	Baltimore, 1977
Mentz, 1984	Activity type	München, 1977
Kitamura, 1985	Activity duration	Baltimore, 1977
Kitamura, 1984	Activity participation (Work/ Leisure) and duration	Baltimore, 1977
Recker, McNally & Root, 1986	Activity pattern	Windham, 1979
Hirsh, Prashker & Ben-Akiva, 1986	Participation in shopping activities over a week	Israel, 1983

Figure 1
Root and Recker: Dynamic utility maximisation framework

Figure 2
Gärling *et al.*: Components of a household scheduling model