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**THE HOUSEHOLD ACTIVITY-TRAVEL SCHEDULING PROCESS:
COMPUTERIZED SURVEY DATA COLLECTION AND THE
DEVELOPMENT OF A UNIFIED MODELLING FRAMEWORK**

by

Sean T. Doherty

A thesis submitted in conformity with the requirements
for the degree of Doctor of Philosophy
Graduate Department of Civil Engineering
University of Toronto

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PhD Thesis by Sean T. Doherty

Graduate Department of Civil Engineering, University of Toronto, 1998

**The Household Activity-Travel Scheduling Process: Computerized Survey Data
Collection and the Development of a Unified Modelling Framework**

ABSTRACT

In the field of transportation, a strong argument has been made for the use of an activity-based approach to improve the behavioural foundations of travel forecasting models.

Activity patterns are a complex spatial-temporal phenomenon and recent models have attempted to replicate entire activity patterns or “schedules”. Through a review of the literature, it was found that existing activity schedule models lacked a strong behavioural basis that has limited their potential and contributed to the lack of development of a “unifying” modelling framework. In response, many researchers have been calling for more in-depth research into the underlying activity scheduling decision processes.

This thesis proposes that insights into the scheduling process will significantly increase our understanding of complex travel patterns and our ability to model/forecast travel demand.

This thesis has contributed both a data collection tool for observing activity scheduling as it occurs in reality, over time, within a household (the Computerized Household Activity SchEduling survey, or CHASE), and a conceptual model that attempts to provide a unifying framework for activity scheduling modelling.

A sample of 42 households from the Hamilton, Ontario area completed the CHASE survey. Performance results showed that the CHASE survey was highly efficient, with a low respondent burden and minimal fatigue effects. This approach goes a long way towards solving the data collection problem associated with sequential decisions process models. Future applications of the CHASE program are discussed. Further empirical analysis showed that activity scheduling occurs on various time horizons, that a significant amount rescheduling occurs during execution, and that scheduling can be opportunistic and impulsive. Based on these findings, a conceptual model of the weekly household activity scheduling process is proposed. The model attempts to deal with the complexities of activity scheduling by segmenting the problem into distinct components - agenda formation, routine "skeleton" schedule, and the weekly decision process. These components have clear interactions and behavioural interpretations that allow for the unification of past econometric and "rule-based" approaches. Long term development will require the operationalization of various components of the conceptual model using the new types of data and variables provided by the CHASE survey.

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CHAPTER 1 INTRODUCTION

This thesis dissertation addresses and attempts to solve one of the most complex behavioural problems in the field of urban analysis, yet it is one that billions of people solve everyday with relative ease. The results of this solution serve to define the urban areas that we live in and is of vital importance to the environment. The problem seems straightforward: *How do people plan their daily lives?* Travel behaviour researchers are interested, because they have come to realize that travel is a direct result of the need to participate in activities outside the home, which are arguably the result of this planning or “scheduling” process. Increasingly, they are recognizing the need to investigate this underlying process in order to improve the behavioural foundations of travel forecasting models that are used to assess the impacts of emerging policies. Simply observing the outcome of this process, in the form of observed activity-travel patterns, does little to provide insights into the behavioural processes that underlie it.

Perhaps it is because everyone solves this problem on a daily basis that, as researchers, we have avoided the issue. Intuition (i.e. a sample of size one) abounds in the literature concerning how scheduling is performed and why it is important. Virtually no empirical efforts have been devoted to observing the process as it occurs in reality. Yet many activity “scheduling” models have been developed despite a lack of understanding of the underlying behavioural process. As commented by Heggie (1978) twenty years ago, there still appears to be precious little behaviour in behavioural models.

This thesis dissertation attempts to fill this gap. The central thesis is this:

That the scheduling process underlies and determines activity and travel patterns and that insights into this process will significantly increase our understanding of complex travel patterns and our ability to model/forecast travel demand.

Many researchers have been calling for more in-depth research into the underlying activity scheduling decision processes, recognizing that existing data sources are wholly inadequate (i.e. they focus on observed activity-travel patterns which are the outcome of the scheduling process). Despite this, few have made definitive suggestions on just how to go about data collection. This has hampered the development of operational models of activity scheduling capable of providing travel demand forecasts that meet current needs.

How does this thesis dissertation remedy the situation? The first problem that needs to be addressed is a measurement one. How do we observe activity scheduling in such a way as to gain valid insights into its behavioural constructs? The second problem relates to how we then replicate the scheduling process in the form of a model. This dissertation presents a solution to the first problem via a computerized survey, and takes a large step towards the solution to the second problem via the design of a conceptual model. Additionally, the survey design addresses important issues that go beyond its application to activity scheduling, and the conceptual model serves as a unifying framework for past modelling approaches. The implications of this dissertation are widespread, and serve to define a long term research agenda for the author.

1.1. Research Objectives

In their review of activity-based modelling included in the latest edited book on "Activity-based Approaches to Travel Analysis", Ettema and Timmermans (1997) highlight the various types of research directed at understanding activity-travel patterns, including theory development and testing, descriptive empirical studies, data collection methods, model development and application. They go on to state that a considerable body of knowledge exists but that "research in this area has been fragmented and that a unifying framework which links research in different areas is still missing" and that "this is probably due to the complexity of the phenomenon and the applied nature of most activity-based research." (Ettema and Timmermans 1997, 33)

The research presented in this dissertation attempts to address these concerns as unbiased as possible, unconstrained by the direct and/or urgent need for an applied model (although its contribution to applied models is discussed). The overall goal is as follows:

To overcome both the complexities of data collection and model development concerning activity scheduling and travel patterns, and at the same time provide a unifying modelling framework that links past research in different areas.

Specifically, the objectives of this dissertation are to:

1. To develop a data collection tool that allows new understandings into the decision process that underlies observed activity-travel patterns. At a minimum, this will require a multi-day, within-household, activity scheduling approach.
2. To assess the data collection methodology and its applicability to the field of travel behaviour as a whole.
3. To provide fundamental empirical analysis of the underlying activity scheduling process.
4. To propose a “unifying” framework for the study of activity-travel patterns, in the form of a conceptual model of the household activity-travel scheduling process.

The long term objective of this research is to develop an operational model of the household activity scheduling process capable of outputting travel demands in an urban area by time of day and day of week.

1.2. Research Relevance

This research is relevant for both theoretical and applied reasons. Theoretically, it represents a first attempt to gain an understanding of a complex phenomenon as it occurs in reality, over multi-days, within a multi-person household. Even the most fundamental results of the work may have resounding consequences for past and future theoretical model developments, particularly in terms of the assumptions on which they are based.

From an applied sense, this research will contribute to an operational model that could be used in isolation, or within a larger urban integrated model of land-use, transportation and environmental emissions to assess the impact of emerging policies that past models were simply incapable of providing. These include Transportation Demand Management Policies (car pooling, road pricing, flex hours, telecommunication, etc.) and Intelligent Transportation Systems, that inherently invoke a rescheduling response that can effect multiple time periods, people, and places, as opposed to singular trip-based responses. Placing this analysis within context of a large integrated urban model also allows examination of long term impacts on land-use, employment, residential location, economic markets, and environmental emissions that are linked to transportation.

1.3. General Research Approach

The research in this dissertation represents a fundamental “inductive” approach. The intent was to collect empirical evidence with as few pre-defined assumptions as possible, allowing an understanding of the phenomena to be garnished from the analysis of the data. The development of conceptual/operational models would then be based on these findings. This differs from past approaches in the field of activity scheduling that have first defined a theoretical model, then sought data to validate or operationalize it. This approach was adopted for three main reasons:

1. The complexity of the research phenomena
2. The lack of existing empirical evidence
3. The few institutional constraints or requirements for applied models in the short term.

Despite this inductive approach, it is not completely free from bias inherent in the multi-disciplinary approach taken and the literature. Existing studies and comments of other researchers in the literature obviously influenced the current work. However, a concerted effort was made to ignore the literature following the submittal of the original proposal in order to allow more independent thought on the design of the data collection

methodology and conceptual model to follow. This literature was later revisited in an effort to place the current approach in context of previous work.

The approach adopted for this research is also highly multi-disciplinary. Urban/transportation planners recognize the multi-disciplinary need for behavioural as well mathematical integrity in the modelling tools developed to support long term planning. This pluralization is not always captured by sole contributors in the field of analysis, and collaborative research efforts are the norm. The social-scientific, spatial-temporal, and highly behavioural approach of the author within a traditional engineering discipline represents a clear attempt to address this pluralization, and reflects a growing open-mindedness in the field and in civil engineering as a whole.

1.4. Chapter Outline

This dissertation consists of six chapters. Chapter 2 is a literature review that includes a introduction to the basic concepts of activity-based analysis and a review of activity-based travel demand models and integrated models. Specific reference is made to the differences between econometric and “rule-based” approaches to model development. Chapter 3 places the research presented in context of larger integrated urban models. Chapter 4 presents the survey methodology used to investigate activity scheduling, a description of the sample data collected, along with empirical results that serve to assess the survey design. Chapter 5 contains empirical results on the scheduling process along with the design of a conceptual model supported by the findings. Chapters 4 and 5 are based on two papers written and presented at conferences as a result of this research. Chapter 6 contains a discussion on the findings, particularly as they relate to the provision of a unifying framework for future model development.

CHAPTER 2 LITERATURE REVIEW, CRITIQUE AND COMMENTARY

2.1. Basic Concepts of an Activity-based Approach

Over the past several decades a strong argument has been made for the use of an activity-based approach to further our understanding of travel behaviour, to improve travel demand forecasting, and to better assess the impacts of emerging transportation policies. The basis of this approach is the recognition that travel is a demand derived from individuals' desires to participate in activities outside of the home. Over the past two decades, the field of *activity analysis* has gained acceptance as an emerging paradigm in the understanding and prediction of peoples' travel behaviour. Compared to the traditional trip-based approach, activity analysis provides a more holistic understanding of the processes which lead to trips and the spatial/temporal sequencing of trips throughout the day. It is particularly useful for understanding the mechanisms of trip chaining and for providing insights into how people modify their behaviour when travel constraints are introduced. The traditional trip-based approach is limited to the analysis of discrete trips, which hampers our ability to evaluate policies which have wider travel, activity, and social costs and benefits.

The most comprehensive summaries of what constitutes the core of activity analysis are provided by Peter Jones and his associates in the Travel Studies Unit at Oxford. Their 1983 textbook, "Understanding Travel Behaviour" (Jones et al. 1983) is perhaps the most frequently cited reference for activity analysis. Other reviews and assessments include articles by Jones (1983) and Clarke (1986), who focus on the practical application of activity-based approaches, and Damm (1983), who focuses on empirical results and provides a good summary of the terminology used by activity researchers. Equally important to the work of Jones is an evaluation of activity-based travel analysis provided

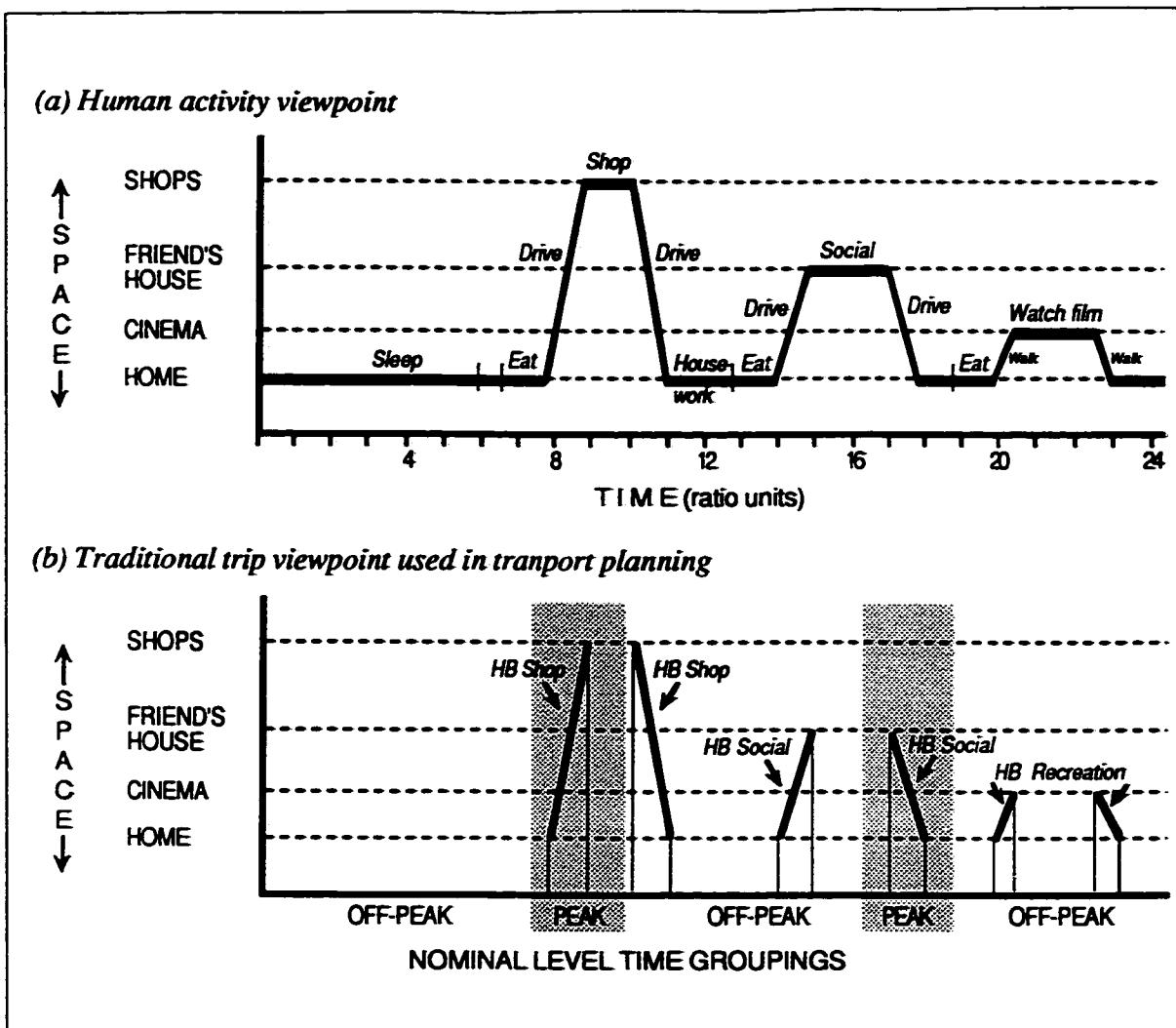
by Ryuichi Kitamura (1988), and more recent reviews available in the proceedings of a recent conferences (e.g. Bowman and Ben-Akiva 1997) and in Ettema and Timmermans' (1997) edited book. The array of multi-disciplinary contributions has made an activity approach a varied set of concepts and methods that cannot be neatly labelled. One way to understand what activity analysis entails is first to trace the conceptual routes of the approach, then compare it to the more traditional trip-based approach to travel analysis.

The conceptual framework for the activity-based approach is rooted in the integration of time-geographic concepts and traditional human activity analysis. The objective of activity-based approach to travel analysis is to account for the travel behaviour of households over a given time period. The starting point is the set of activities which each member of the household attempts to schedule over the day. These activities are related to specific economic, physiological, psychological, and social needs, and can be classed as either obligatory (e.g. work) or discretionary (e.g. recreation). Many of these activities must be performed outside of the home. Thus daily behaviour can be categorized as the outcome of a process in which people match activity *demands* against the *supply* of facilities outside of the home in both space and time. This process is also subject to a number of constraints including those intrinsically related to the activity (some activities have fixed durations, periodicity, or must be carried out in a particular order); those related to the facilities (shop/school, opening hours, and locations); those related to the household and resources available (money, cars, etc.); and those related to individuals (habits or perceptions). These constraints limit the kinds of activities that can be performed as well as their timing and location. In addition to these constraints, the interactions and relationships between household members creates a series of scheduling constraints which further restrict daily behaviour. The competition between activities for limited time and space requires household members to assign priorities and make trade-offs between activities. Implicit in these trade-offs are limits imposed by the nature of the space-time environment, since it takes time to travel over space and there is a limit to the destinations which can be reached. Jones et al. (1983) refer to the concept of space-time prisms as formalized by Hägerstrand (1970) to capture this phenomenon accurately.

Many of the conceptual elements of an activity-based framework are similar to the more traditional trip-based framework; however, there are important differences in the way the resulting travel behaviour is viewed. The best way to contrast the differences is through a graphical representation of a trip versus an activity pattern in time and space, as provided in Figure 2.1. The example represents a person who takes his/her car to go shopping, visit a friend, then walks to the cinema.

The conventional trip-based representation of the travel patterns ('b' in Figure 2.1) shows an individual making six home-based trips, two for shopping and four for social/recreational purposes. Each trip is measured as a discrete event of precise duration, which is undertaken for one main trip purpose, by a specific mode. Because trips are often grouped by type and aggregated, the direction of travel and the continuity between successive trips are lost during modelling and analysis. The time of day of travel is largely ignored, except for the distinction between peak and off-peak periods, making it difficult to identify the sequence of travel or constraints on timing. In the human activity representation of travel behaviour ('a' in Figure 2.1), travel forms part of a continuous pattern of daily behaviour, depicted as a sequence of activities in time and space. This allows more complex temporal, spatial, and interpersonal constraints to be identified as a context in which travel choices are made. It also illustrates the true role and importance of travel in daily life - travel consumes relatively little time compared to other activities, yet it has the unique property of acting as a 'glue' that bonds successive activities at different locations. From this perspective, travel is treated as a *derived demand*. This approach also allows the direction and sequencing of trips to be measured and analyzed.

Figure 2.1 Alternative representations of travel behavior



Adopted from Jones et al. (1983, 36)

The significance of the differences in approach rests in the way the choice to travel is made. Instead of dealing with an *all or nothing* phenomenon in the trip decision, the choice to travel is based on the choice to participate in an activity at a different site. This in turn depends upon several different factors, including the characteristics of the transport network, the characteristics of activity facilities at destinations, the set of activities which can satisfy a perceived need, interpersonal and resource constraints affecting the individual, and the amount of time available to the individuals at a particular point in the day. This places emphasis on activity *choice* and activity *scheduling*. These

two major themes have emerged in the more practical efforts of activity researchers, particularly those interested in modelling activities.

In general, the conventional approach to the study of travel behaviour based on single trips is replaced by a "richer, more holistic" framework in which travel is analyzed as daily patterns of behaviour related to and *derived* from differences in lifestyle and activity participation in the population. Over the past decade, the field has progressed to the status of an "emerging paradigm". The features of this paradigm which have prevailed in the literature can be summarized as follows (modified from Jones 1990):

- Explicit treatment of travel as a derived demand - from the 'need' to take part in a set of activities which depend upon an individual's circumstances, preferences and obligations.
- Focus on sequences or patterns of behaviour rather than an analysis of discrete trips (i.e. trip based approach).
- Emphasis on decision-making in a household context, taking explicit account of linkages among household members.
- Emphasis on the detailed timing as well as the duration of activity and travel, rather than using the simple categorization of 'peak' and 'off peak' events.
- Explicit consideration of spatial, temporal and inter-personal constraints on travel and location choices (as outlined above).
- Recognition of the interdependencies among events which occur at different times, involve different people, and occur in different places.
- Use of household and person classification schemes (e.g. stage in family life cycle), based on differences in activity needs, commitments and constraints.
- Development of models of activity scheduling behaviour subject to the various constraints which limit behaviour. In general these models reflect that a number of alternative activity schedules are feasible, each having advantages and

disadvantages for the individual which will be used to make the choice to adopt a particular schedule.

The motivation for a shift in the way travel analysis is performed was derived mainly from a dissatisfaction with established procedures, both on theoretical and operational grounds. Many forecasts of trip-based models have proven to be inaccurate, mostly due to the lack of a behavioural relationships in the models used for prediction. The biggest shortfall most often cited in the literature is the failure to recognize the existence of linkages among trips and multiple activities which may be performed during a single trip. These "trip chaining" behaviours have been poorly understood, and have been held responsible for the shortcomings of many travel demand related policies, such as transportation demand management strategies. An activity-based analyst approaches these and other problems through a deeper understanding of travel and the characteristics of households and activities which relate to travel.

While this approach has much promise and appears on the verge of changing the way travel behaviour research is performed, there are several drawbacks. Foremost is the added complexity in the treatment of travel, which is necessary in order to gather a more complete understanding of travel provided by activity analysis. While many important insights have been gained, particularly those related to trip chaining and the impact of household life cycles, an activity-based approach has yet to be adopted in practice because of the added complexities in developing travel forecasts and the lack of large scale activity data bases. The shift from aggregate to disaggregate models was complex enough for transport planners, so the move towards even further complexity in travel analysis through an activity approach may be a long time in the making. There have been some important exceptions to this pattern, however, and it appears that recent activity-based travel modelling efforts are beginning to emerge from the methodological and theoretical roots which they are based.

2.2. Understanding the Evolution of the Activity-based Approach: Historical Highlights

Human activities in urban settings have been the focus of much research over the last century. They have been extensively observed, quantified, and analyzed, mostly from a social perspective. These studies share a common interest in how people allocated time around different activities and what factors impinge upon the patterns observed (e.g. Brail and Chapin 1973; Chapin 1974; Cullen and Godson 1975). Most studies were descriptive in nature, although several attempts to model the allocation of time to activities has been made. The types of models developed focused mainly at time budgets and the aggregate way in which time is spent. Geographers, such as Hägerstrand (1970) and others, have contributed a spatial-temporal perspective on activities. Perhaps most influential was the concept of space-time prisms, which helped to define a potential range of activity choices based on overcoming the constraints of travel time to participate in activities in space. Much of this work made only passing reference to travel as one form of activity and subsequently made only descriptive comments about travel in conjunction with other factors, such as day of the week. More extensive reviews of the pre-1980's temporal and spatial studies of human activity can be found in Chapin (1974), Cullen and Godson (1975), Jones (1979), Jones et al. (1983) and Pickup and Stephen (1983).

Applying an activity approach to gain insights into travel is a relatively recent phenomenon. Not until the late seventies was serious interest shown in applying activity-related concepts to transport research, mostly in response to the disenchantment with aggregate procedures and the lack of behavioural predictability of models used in the past. The major impetus behind the recognition of activity-based approaches as a new development in the study of travel behaviour was a paper by Peter Jones in "Behavioural Travel Modelling" (see Jones 1979). Much of the content of this paper, and further work carried out by Jones and his associates at the Travel Studies Unit (TSU) at Oxford, is summarized in the seminal text "Understanding Travel Behaviour" (Jones et al. 1983). The book provided the theoretical and methodological underpinnings of a "new"

approach to understanding complex travel behaviour phenomena. The approach promised to provide the ability to predict the effects of emerging policies of car restraint and public transport improvements which existing models were struggling with. The book also included detailed discussion on activity data collection and activity modelling. The CARLA activity scheduling model still stands as one of the major achievements in modelling. The success of the book is partially attributable to the multi-disciplinary backgrounds of the authors, particularly Jones' background in geography which formed the backbone of the development of the time/space activity framework.

In 1981, the first of two conferences on "Travel Demand Analysis: Activity-based and Other New Approaches" was held at Oxford, sponsored by the TSU (see Carpenter and Jones 1983). In the first article, Damm (1983) provides a thorough review of the types of hypotheses which have been generated in research related to activity patterns. These are broadly categorized as relating to individual characteristics, household characteristics, and environmental constraints. Damm also provides the earliest (if not only) attempt to summarize the terminology used by activity researchers. Other articles in the proceedings document applications of activity-based approaches, especially to aspects of trip chaining behaviour and the incorporation of lifestyle and lifecycle variables in analysis of activities and subsequent travel. A later section in the proceedings dealt entirely with activity-based modelling, laying the roots for the more applied research to follow on activity schedule modelling.

In 1982, the Transportation Research Board produced a special report on "New Approaches to Understanding Travel Behavior" (Allaman et al. 1982). This document clearly established the practical importance of incorporating fundamental social science concepts into trip generation models which formed the first component of the standard urban transportation demand forecasting system (trip generation, trip distribution, modal choice, and route assignment). Lifestyle, lifecycle, and household structure were identified as relevant variables which influenced trip generation rates. The effects of these same variables on the allocation of time to specific activities was also examined.

These variables were of particular long term importance given the expected changes in population structure, and female labour force changes expected to occur in the future. The document was instrumental in introducing the practical applications of the activity-based approach by bringing a new set of variables to the attention of transportation planners, and provided a practical comparison of the value of incorporating this new set of variables into standard trip generation models. At this early stage, there was little mention of the development of new models which would account for travel directly through the modelling of activities.

By 1986, activity analysis had gained momentum and appeared in the first section of "Behavioural Research For Transport Policy" which constituted the proceedings of "The 1985 International Conference on Travel Behaviour" (see Clarke 1986). The first article by Clarke (1986) was devoted entirely to the practical application of activity analysis, however, little reference was made directly to travel demand modelling and how activity models may improve upon them. Clarke does acknowledge that further development is needed, especially for activity schedule simulation models. Outside of articles devoted explicitly to activity analysis, the remaining literature on traditional travel demand models exhibited scant reference to activity-based modelling possibilities, indicating that they had yet to be accepted in mainstream transport planning as a possible avenue for model development. This is partially due to conflicting disciplinary structures - engineers typically develop travel demand, while social scientists have introduced activity analysis.

In 1989, the presentation of activity-based travel research retained its prominence as the first section in "Travel Behaviour Research" which was based on the proceedings "The Fifth International Conference on Travel Behaviour" held in 1987. The array of articles focusing on practical application of activity-based analysis marked a significant departure from previous proceedings concerned more with methodological and theoretical issues. Of particular note was the emphasis on applying activity analysis to understand the dynamics of travel behaviour (Chang and Mahmassani 1989), the use of computerized techniques for forecasting household activity response to policy measures (Jones et al.

1989), and the reaction of households to future changes in energy use in Canada (Lee-Gosselin 1989).

In 1988, the second conference on "Travel Demand Analysis: Activity-based and Other New Approaches" was held at Oxford. The proceedings were published under the heading "Developments in Dynamic and Activity-based Approaches to Travel Analysis" (Jones 1990). These proceedings clearly established the links between activity and dynamic approaches and included contributions from all major authors in the field. A dynamic approach to activity analysis involves the analysis of changes in activities which occur over time. Acknowledged throughout the proceedings was a sense that activity-based approaches have gained acceptance as an emerging paradigm. The development of activity-based models was also identified as one of the more important applications of the approach, and several authors summarized existing models. Much of the work to follow would reference these proceedings as the most comprehensive collection of work to date.

In addition to these major collections of works are several articles which mark the coming of age of activity-based travel analysis. Perhaps the first indication that activity-based travel analysis was becoming more acceptable in mainstream literature was the devotion of an entire issue of *Transportation* to the field (issue 15, 1988), based on papers presented during a session of the 1987 Annual Transportation Research Board Meeting. By far, this set of articles and responses constituted the most comprehensive review and evaluation of the progress in the field up until that time in terms of the developments which have been fundamental to activity-based travel analysis. Kitamura (1988) and Mahmassani (1988) review several aspects of activity analysis including data collection, analysis, and modelling. These reviews were followed by commentaries by Hanson, Hartgen, Jones, Koppelman, and Kostyniuk (1988). Data collection issues focused on the improved ability of the activity framework to assist in an individual's recall of their travel movements and application of computer-based survey techniques to improve the collection of activity diary information. Travel pattern analysis was said to benefit from the theoretical and empirical research results of activity-based studies through the

improved understanding of complex travel patterns, such as trip chaining and day-to-day variability in travel behaviour. The activity-based travel research has also played a significant role in improving the specification of existing trip-based models of travel behaviour. This has mainly been accomplished through the addition of new types of independent variables, and explicit treatment of the interdependencies of trip making (e.g. competing use for a car within a household or the interdependence involved in ride-sharing and lift giving). Also included is the development of new types of dependent variables, such as the number of tours and stops as opposed to using single trips. Noted as much less developed and not fully operational at the time, was the development of activity-based models capable of handling the restructuring of travel and activity patterns based on combinatorial programming and simulation techniques.

Also in 1991, conference proceedings on "Long Term Issues in Transport" contained several travel demand articles which addressed activity-based approaches, although no single article was devoted to the field. This is of particular importance because it marked the voluntary progression of activity-based techniques into the realm of travel planners and engineers traditionally responsible for modelling travel demand for practical purposes. Although subtle at times, authors in the proceedings such as Banister et al. (1991) and Dusgupta (1991) note what activity-travel researchers have emphasized for some time - that travel demand is a derived demand from the needs of people to participate in activities outside the home and that changes are needed for future models of travel demand. Banister et al. (1991, 109) acknowledge that "long term travel demand changes should be analyzed as derivatives" but are still reluctant to suggest concrete changes to activity-based travel demand modelling. In fact, in a summary of urban travel demand modelling, Dusgupta (1991) makes only passing note of one potential application of activity-based approach to understanding the factors contributing to trip suppressions (or the related concept of latent demand) and makes no further mention of its potential contribution. Although this text does not represent the views of all transport demand planners and researchers, the statement made is a crucial acknowledgement coming from

the somewhat "hard-core" traditional travel demand modeller. It appears they are still a long way off from accepting these approaches into main stream planing applications.

Since 1990, several reviews of the field have been published, focusing mainly on model developments. Axhausen's (1990) review of complex activity pattern models first makes a distinction between static and dynamic theoretical frameworks, then argues for a shift from exclusive econometric approaches to one emphasizing decision rules and heuristics that focus on human problem solving. Bowman and Ben-Akiva (1997) contrast utility-based econometric modelling systems with "hybrid simulation" that use sequential decision rules to predict decision process outcomes. They highlight the challenging data required of the latter approach as a major stumbling block. Kurani and Kitamura (1996) make a distinction between econometric and cognitive psychological approaches, and proceed to review recent activity scheduling models. They conclude that a choice exists to continue making incremental adjustments to existing travel demand forecasting tools, or to make a wholesale reformulation towards integrated activity-travel approaches. Most recently, Ettema and Timmermans (1997) review activity-based models developed over the last decade in fields such as geography, urban planning, economics, time use research, psychology and transportation. Theoretical and modelling approaches are merged in the review within each discipline. In summary, they conclude that no unifying framework exists that could bring together the various approaches and/or modelling techniques that have been proposed to solve this complex problem.

In general, it appears that the field of activity analysis is beginning to progress beyond description, theory, and potential uses, towards the development of activity-based models, especially scheduling models, capable of forecasting travel demand across the entire day. This is in keeping with Kitamura's (1988, 10) observations that "the ultimate mission of travel behavior research is to develop the capability to predict how individuals respond to changes in their travel environments and how the responses are temporally correlated." Jones (1990) also notes that model development would mark a real advance in the state-of-the-art in activity analysis. Since 1990, many activity-based travel models have made

it to mainstream journals, marking this type of progression in the field. Development of the models is however, far from complete, and the review presented in the following section is intended not as a thorough source of modelling efforts, but as a platform for commentary on model development in the future.

2.3. Activity-Travel Modelling Foundations

"Activity models are based on an attempt to go beyond the notion that if we simply observe the trips made by a sample of individuals we are in a position both to explain their behaviour and to predict how they would react to changes to their personal or external circumstances. In an attempt to get a more basic motivation for travel behaviour we look at the activities which a person undertakes, and how these are organized into a schedule describing the way in which that person spends his/her time. Travel is relegated to a supporting role - as a mechanism whereby the individual can move through space to complete a desired sequence of activities." (Clarke 1986, 3-4)

Transport modelling attempts to replicate the relationships of observed behaviour in the transport system by identifying parallel mathematical relationships. The model input parameters are then changed in accordance with observed or expected trends to produce estimates of future patterns of travel. Under the traditional four-stage model (generation, distribution, modal split, assignment) the transport world is treated as a closed system in which all relevant influences are derived from observed travel behaviour or from readily available statistical sources such as economic growth, population and land-use changes (Pickup and Stephen 1983). Assumptions about human behaviour usually reflect a view of the rational economic person.

The traditional model came under considerable criticisms in the early 1970s and 80s mainly because of the poor predictive power of many of the models and the lack of a behavioural basis (Burnett and Thrift 1979; Jones 1979; Jones et al. 1990). For a number of forecasting applications the models are successful, as long as the predicted responses to changes are not too far away from the base situation from which the models were estimated. However, they have not proven very successful at forecasting changes in demand as a result of changing demographic, lifecycle and lifestyle changes which are

likely to occur over the next few decades. The full impact of other policy initiatives, such as those aimed at curbing peak-period travel, have also remained rather difficult to examine under this traditional modelling approach. This is because household responses to changes in the transportation and land-use system are varied and complex, often involving reorganization of trips into trip chains and complex rescheduling of activities and travel. Traditional trip-based models of travel demand consider only simple adjustments in the daily travel pattern in the form of deletions/additions of trips, changes in mode or destination, or change in trip time.

Activity-based models attempt to “fill the gap” between existing modelling capabilities and a realistic representation of actual travel changes. This is accomplished through models which can handle the restructuring of travel and activity patterns. Considerable work during the 1980's established the ground work for operational models which are emerging in the 1990's. Model structures have also begun to break away from traditional utility maximization and discrete choice roots towards alternative methodologies for modelling activities. Several distinct new classes of activity models have emerged, relying either on econometric modelling techniques, alternative psychological “rule-based” and computational techniques, and hybrid approaches that mix the two. The following review examines the development of these new types of models, starting first with a brief review of the basic underlying decision rules used.

2.3.1. Decision rules

Travel behaviour analysis involves the understanding of choices, with growing emphasis on complex choices such as activity scheduling. In all cases, a rule or series of rules are needed to mimic the choices made among a set of perceived alternatives that have perceived attributes. The most widespread approach is to use econometric “rules” of choice which assume that people are utility maximizers. However, despite their proliferation, they represent but one possible rule that people use in reality. Recent models have attempted to adopt more boundedly rational or satisfying type rules that

reflect more accurately the way people solve complex problems. The following section outlines the basic constructs of both these types of approaches.

2.3.2. Utility maximization, discrete choice

The specification of random utility models for transportation planning has benefited from the publication of several textbooks that outline the theoretical foundation and main assumptions. The following description draws mostly from Ortuzar and Willumsen's (1990) "Modeling Transport" textbook and Train's (1986) "Qualitative Choice Analysis" textbook.

The theoretical foundation of utility maximization is in microeconomic theory, which provides a way of looking at the actions of individual decision making units. Basically, random utility maximization theory postulates that:

- Individuals belonging to a given homogeneous population act *rationally* and possess *perfect information*. They will always select the option which *maximizes* their net personal *utility* subject to a set of constraints including social, physical, institutional, and/or budgetary constraints.
- There exists a set of available alternatives for individuals in a given group. This set, termed the "choice set", is normally defined for each population group or individual in the group, reflecting the fact that different decision-makers might face different sets of alternatives in similar choice situations.
- There exists a vector of measured or observed attributes of each alternative faced by individuals in the given group.
- There is an equivalent vector describing the attributes/characteristics of individuals in a given group.

Each alternative j is said to have an associated net *utility* for a given individual q , represented by U_{jq} . It is assumed that this utility has two components:

- i. a measurable, systematic or representative part, V_{jq} , which is a function of the measured/observed attributes of the alternatives and the decision-maker.
- ii. a *random* part, E_{jq} , that reflect the fact that the modeller does not have complete information about all the elements considered by the individual making a choice. The random part reflects the idiosyncrasies and particular tastes of each individual, together with any measurement or observation errors made by the modeller.

Thus, the modeller postulates that:

$$U_{jq} = V_{jq} + E_{jq} \quad (1)$$

This allows the possibility of two individuals, of the same measured characteristic facing the same choice set, to select different options.

Two essential elements of this formulation are that the individuals are assumed to weigh all the elements of interest (with no randomness) and select the most convenient option, and that secondly, the modeller who observes only some of the observed elements needs the residuals E to explain what otherwise would amount to non-rational behaviour. The residuals in turn are dictated to follow stringent distributional rules.

The alternative j with the maximum utility associates with it is chosen by the individual q . That is, the individual chooses alternative j if and only if:

$$U_{jq} \geq U_{iq}, \text{ for all } i \text{ alternatives in the choice set of individual } q \text{ not equal to } j.$$

Substituting (1), we have:

$$V_{jq} - V_{iq} \leq E_{iq} - E_{jq} \quad (2)$$

The probability of choosing alternative j , after rearranging some terms, is given by:

$$P_{jq} = \text{Prob}\{(E_{jq} - E_{iq}) \leq (V_{iq} - V_{jq})\}$$

for all i alternatives in the choice set of individual q not equal to j . (3)

P_{jq} is the probability that relation (2) holds (it is not possible to determine with certainty of it does), that is, that the utility of alternate j is higher than that of any other alternative, given the measured/observed components of the utility for each alternative.

Examining (3), reveals that the right hand side is observable, and the difference can be calculated, while the left hand side is unobserved, varying randomly across decision-makers with the same observed components of utility. Since the E's are both random variables, their difference $E_{jq} - E_{iq}$ is also a random variable. By knowing the distribution of the random components, but not their values, the modeller can derive the distribution of the difference, and by using (3), can calculate the probability that the individual will choose alternative j as a function of the observed difference $V_{iq} - V_{jq}$. Different choice models are derived by specifying different distributions for the E's, giving rise to different functional forms of the choice probabilities.

For example, if we assume the random component is distributed independently and identically in accordance with the extreme value distribution (also called the Weibull distribution), the probability that the individual will choose alternative j is:

$$P_{jq} = \frac{\exp(V_{jq})}{\sum_i \exp(V_{iq})} \text{ for all } i \text{ alternatives in the choice set of individual } q \text{ not equal to } j$$

Which is the familiar *logit* model.

In short, utility maximization assumes that the attractiveness of an alternative (activity) can be expressed by a vector of attribute values that is reducible to a scalar (Ben Akiva and Lerman 1985). This conveniently defines a single objective function expressing that attractiveness of an alternative in terms of its attributes - termed the *utility* index or function. The decision-maker is said to attempt to *maximize* utility through his/her choice. A utility maximization approach is more amenable to mathematical analysis associated with model development than other approaches. The application of this

approach to activities can rely on existing travel data in the short term (using trip purpose to define activities), although large scale activity data sets are beginning to be collected in the United States (e.g. Portland Area Activity Survey).

2.3.3. Alternative “rules-based” decision structures

More recent models of activity schedules have tended to used a more boundedly rational or satisfying context as opposed to a strict utility maximization framework (which in itself can be classified as one type of decision “rule”). Alternative “rules” for decisions have long been the focus of research in the field of cognitive psychology. The brief summary provided herein is based mostly on the seminal textbook by Newell and Simon (1972) on “Human Problem Solving”, and papers by Svenson (1979) and Payne et al. (1992).

Rule-based approaches basically assume that decision-makers are not utility maximizers but simply “satisficers”. The search for a “solution” (such as an activity scheduling problem) is often stopped once an acceptable solution is found, and this may involve a combination of searching, learning and decision making. The underlying decision theory is based on the assumption that people act as information processing systems when solving problems. The set of processes or mechanisms that underlay decisions presumably exist in the central nervous system and are general to all humans.

Basically, human decision-makers are assumed to:

- have a limited capacity information processing ability.
- use various decision strategies in response to the demands of complex task environments (e.g. choices with many alternatives and attributes).
- use multiple decision strategies to balance the goals of achieving an accurate decision and limiting the cognitive effort required to reach a goal.

- adopt complex decision rules when faced with complex multi-attribute choices or when new situations arise. If similar decision problems have been faced earlier it is possible that a decision-maker has developed simplifying strategies or heuristics to reach a decision more easily.

A long list of decision rules have been identified based on “think aloud” data collection techniques. These included elimination-by-aspect, lexicographic choice, satisficing, majority of confirming dimensions, and equal-weight rules. These rules/heuristics may be grouped together into a “production system” or “computational processes” which are basically a set of rules in the form of condition-action pairs that specify how a task is to be solved (such as activity scheduling). The condition-action pairs are specified according to a set and sequence of Elementary Information Processes (EIP), including the following (from Payne et al. 1992):

READ an alternative’s value on a particular attribute into short term memory
COMPARE two alternatives on an attribute
DIFFERENCE calculation between two attributes for an alternate
ADD the values of an attribute in short term memory
PRODUCT, weight on value by another
ELIMINATE an alternative or attribute from consideration
MOVE to the next element of the external environment
CHOOSE the preferred alternative and stop the process

For instance, the Lexicographic choice strategy involves a number of reading and comparison EIPs but no adding or multiplying EIPs, whereas the Weighted additive strategy involves reading EIPs, a number of adding and multiplying EIPs, and some comparisons.

Operationalization of these rules normally takes the form of a collection of “if-then” rules that represent human cognitive processes. Vause (1997) provides an example pertaining

to a commuter's mode choice between the alternatives car, bus and walking. If we suppose that the commuter first considers the attributes travel time, then travel cost, then comfort, then a lexicographic rule could be implemented by:

- Rule 1: Sort by travel time
- Rule 2: Sort by travel cost
- Rule 3: Sort by comfort

This could be combined with a satisfaction strategy, whereby certain alternatives are excluded using the following rules:

- Rule 1: If travel time $> x$ minutes, then exclude this alternative
- Rule 2: If travel costs is greater than y dollars, then exclude this alternative
- Rule 3: If comfort is less than z (rated on a scale) then exclude this alternative.

The final choice is the alternative at the top of the sorted list. Vause notes that the utility-based approach (as presented in the previous section) can be viewed as a "trivial case of the rule-based approach" where the rules boil down to "Rule 1: sort by utility".

One of the endearing challenges of this approach is the fact that people do not always use the same choice strategy, particularly when in different choice environments or when faced with more complex situations and alternatives (Payne et al. 1992). In order to operationalize such an approach, the modeller must be able to simulate the various choice strategies.

2.4. Models of Activity-Travel Schedules

Activity-based models have sought to replicate one or more of the four basic dimensions of activities: i) choice; ii) duration (over what time periods); iii) location; and iv) sequencing (i.e. when they take place, in what order, and with what frequency). Many of

the first models sought only to replicate certain dimensions, such as time allocation to activities. Later models incorporate all dimensions within their model in an attempt to replicate the way individuals and households arrive at a total activity pattern in time and space. These are often grouped under the heading of activity "schedule" models, since a schedule of activities embodies all four of these dimensions. Models of this latter type are the focus of this review as they are of primary significance to this thesis.

Given all the dimensions, a wide range of techniques have been considered to capture the behavioural components of activity scheduling. Creators of these models most often cite developments in time geography by Hägerstrand (1970) as the basis for their models. Their initial and continued development draws heavily upon the prevailing econometric modelling techniques, which are reviewed in some depth in the next section and compared to more recent "rule-based" and "hybrid" activity scheduling modelling approaches. The review focus on those models, which seek to replicate activity patterns directly and are applicable to travel analysis. Theoretical, conceptual, and operational model developments are presented together.

2.4.1. Econometric-based models

The first models to emerge under the econometric framework sought to replicate the first two dimensions of activities - choice and duration. Damn and Lerman (1981) can be attributed with outlining the first of these models in which the probability of participating in an activity over a certain period was formulated as a binary probit problem. The utility functions in their model depended upon a range of temporal, spatial and socio-economic variables. This basic model was taken up by several other researchers over the past decade and developed further. For instance, Supernak (1992) added detailed temporal dimensions to activity choices while Solomon and Ben-Akiva (1983) developed new types of lifestyle variables to be used in the models.

Of particular interest are models of this type that incorporated explanatory variables that seek to capture the history and future dependencies of activity and location choice. Two basic approaches have been adopted. The first is to model the sequential choice of activities and locations to add to a sequence/pattern of activities and travel. Conventional logit type models are used to predict the choice(s) conditional on the characteristics of activities/locations that proceed and follow the given choice. Two models that adopt this approach are presented here for illustration: the first stresses the activity history dependence (Kitamura and Kermanshah 1983), while the second stresses the location dependence (van der Hoorn 1983). A second approach focuses on the simultaneous choice among pre-defined activity-travel sequences/patterns, rather than on their sequential construction. An illustration of this latter approach is given by the work of Kawakami and Isobe (1990). A third approach that represents a mix of the sequential choice of pre-defined patterns is the tour based model developed by Bowman and Ben-Akiva (1995).

2.4.1.1 Sequential models

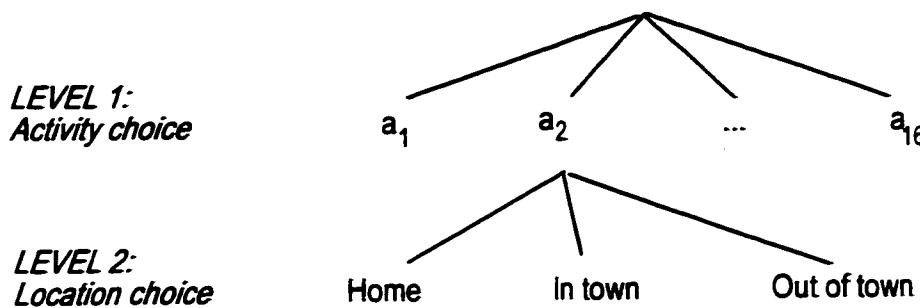
Kitamura and Kermanshah (1983) stress the time of day and activity *history* dependence in the formation of an activity choice model. They propose that the probability of choosing the next activity in a sequence is conditioned upon attributes of previous activities in the sequence (in terms of their types and timing) and current time of day. The resulting model is formulated as a function of time, history, and other factors using the multinomial logit structure. The information on the history of the behaviour, the socio-economic variables, and the time of day, are used to define the explanatory variables used in the utility functions V_i . In the example estimation presented in the article, activity history is represented by a series of binary variables for each activity type, set to 1 if the activity has already been pursued in the previous sequence. This approach allows considerable flexibility to investigate alternative history dependent variables, as well as combining other types of dependencies, such as future activity dependence or locational dependencies. Two different sets of models were presented in the article:

home-based activity choice and non-home based activity choice models. In terms of history dependent variables, the results of the models show that binary indicators of activity engagement explained the choice better than any of the other variables. For example, the coefficient of the binary variables for personal business in the home-based shopping activity model was negative, indicating that past engagement in personal business has a negative influence on the choice of shopping later. Alternatively, the coefficient for shopping in the non-home-based shopping activity model was positive, indicating that previous shopping activity tends to encourage more shopping activity later. These findings are particularly valuable since they imply that history dependence can be expressed in a very simple manner with binary indicators.

One of the major limitations of the model is that it does not yet include spatial explanatory variables related to land-use and the transportation network, making it inappropriate for most practical applications. To this extent, the authors suggest that any model predicting activity *location* choice should incorporate variables that indicate attractiveness of a particular location for the performance of current and future activities. This approach is adopted by van der Hoorn (1983).

Van der Hoorn (1983) expands upon the earlier work of Tomlinson et al. (1971; 1973) in their development of a disaggregate level activity and location choice model for each 15 minute time period in a day. Their model appears to build upon the work of Kitamura and Kermanshah by merging location choice with activity choice and incorporating past and future dependencies in the model. The set of logit-based activity models that are developed are actually used in a simulation model that describes the distribution of a population across activities and locations throughout each 15 minute time period of the day. The combining of activity choice and location is what makes this model of practical relevance for simulation, as activity choice alone is not enough for practical transportation planning purposes. The variables used in the model reveal similar types of activity history dependent variables as adopted in the previous model but with an emphasis on spatially dependent aspects of activities.

The joint probability of choice of activity and location is equal to the probability that an activity will be chosen by an individual, given that his/her previous location, times the probability that location n will be chosen by an individual, given his/her *previous* location and the desired activity. This joint probability conveniently decomposes into the product of two separate logit-based models, one for location choice and one for activity choice. Although not stated explicitly, this joint probability is consistent with two-stage nested logit models as described in Ben Akiva and Lerman (1985). The two level nested logit can be depicted as follows:



The explanatory variables used in utility functions are of some interest. They include:

Activity choice model:

1. time spent during the week on the given activity
2. duration of the activity
3. number of times the activity could start during the day
4. the "logsum" (or inclusive value) from the location choice model.
- 5.

Location choice model:

1. travel time to location l
2. town size
3. binary variable equal to 1 if the next mandatory activity also has to be performed at l .
4. binary variable equal to 1 for the location where the next mandatory activity has to be performed.

Van der Hoorn's approach to incorporating *location history dependence* in the location choice model is to build separate models for each of the three possible previous locations. Van der Hoorn then uses binary variables to represent the *future* activity history dependence of location choice (3 and 4 above). These binary variables reflect the observation that if an individual soon has to be at a location in order to perform a mandatory activity, then the probability of choice of that location should be larger than otherwise (indicated by positive, significant coefficients in the estimated model). This combines not just location, but activity dependence into one binary variable. Thus, the history *and* future location dependence of activities is built into van der Hoorn's location choice model, although not using the same technique.

In the activity choice model, an activity history dependent variable is derived from knowledge about each individuals *weekly* activities. Instead of time spent in the previous sequence (as adopted by Kitamura and Kermanshah) the total time spent during the week on any given activity is used to represent the history dependency. This variable was found to be positive and significant in the estimated model for working men, but this was not interpreted by van der Hoorn. The positive sign implies that activities with larger amounts of total time devoted to them during the entire week will have more time devoted to them on any given day. This essentially represents a measure of "time budget" to the model. The variables "number of times per day the activity could start" represent external constraints on the time spent in activities (e.g. opening hours of facilities). The coefficient is negative indicating that the fewer the times an activity can be started the larger the probability it will be started in any given (allowable) period. The final variables in the activity choice model is the "logsum" or inclusive value from the location choice model which is shown to be effective in validly representing the location choice since it is significantly different from and between 0 and 1. Basically, this value implies that the larger the utility associated with the locations available for a specific activity, the greater the probability of choosing that activity.

To account for the role that different socio-economic factors play in the model, separate sets of models were built for each of five person groups: working men, working women, housewives, children/students, and other people. Only the results for working men were reported in the article. The models are used in a simulation system that describes the distribution of a population across the 16 activity types and 3 locations during the day. For each quarter hour, the proportion of people engaged in mandatory activities is *taken as the observed value* from the data base, while the remaining population is assigned to activities and locations using the logit models.

2.4.1.2. Simultaneous models

Simultaneous models attempt to model activity schedules as the choice amongst a set of pre-defined activity-travel sequences/patterns, rather than on their sequential construction. One such model is the "Travel-activity Scheduling Model for Workers" proposed by Kawakami and Isobe (1990). It uses the same utility framework as previous models, but focuses on the choice among pre-defined activity-travel sequences/patterns. The range of possible patterns is defined upon examination of all possible patterns in a travel data set.

Kawakami and Isobe show that for workers, this process can lead to a manageable number of patterns when activities are limited to the choice of work and non-work, and the activity-travel patterns are divided into two branches: before and after work. For workers in Japan, seven typical activity-travel patterns were defined (e.g. home-work, home-non-work-work, home-non-work-home-work). By taking work as fixed in time and space, three choices remain: the choice of whether to participate in non-work activity " a " or not, the choice of activity-travel pattern " j " and the choice of location " l " for the non-work activity. This is expressed as a product of marginal and conditional probabilities, translating into a three-level nested logit system. In the first stage, explanatory variables include working hours and socio-economic characteristics of workers. If workers have decided to participate in non-work activities, then they move to a second stage which determines which pattern is chosen in order to maximize utility. Explanatory variables at this stage include travel time and duration of the activity. The

duration of the activity was also more important in the model for the before work branch, reflecting the more constrained nature of the journey to work. The third stage involves the choice of activity location, which also affects time allocation to activities through the trade-off relationship between travel time and activity duration (i.e. that people would prefer to spend more time in activities than in travel). Explanatory variables at this stage include travel time, activity duration and a measure of the attractiveness of the activity location.

This rather simple approach is a desirable feature of the model, since it limits the possible combinations to a finite set that can be represented as a choice problem. The models at each stage predicted between 67 to 76% of observed patterns. It is interesting to note that the % right was lower in all cases for the after work branch models. This is perhaps the result of the added complexity in choice after work which involves more non-work activities and the choice among a larger set of activity-travel patterns. However, Ben Akiva and Lerman (1985) caution against the use of "% right" since it can mask poor goodness of fit, especially in cases where the choices are dominated by one particular alternative. Indeed, this is the case for travel-activity patterns, as a large portion (85%) consisted simply of going to work and return home with no non-work activity participation. It is difficult to determine if all patterns were predicted with equal efficiency. The authors do report a 0.97 correlation between estimated and observed travel activity patterns, which suggests that this is not the case, although reporting the % right by type of pattern in level 2 would help matters further.

2.4.1.3.Tour-based models

Tour-based models group trips into tours representing round-trip journeys based at home. They differ from previous approaches by separately modelling all tours that form an activity schedule for a particular day, instead of choosing one particular pattern for the whole day, as in the case of Kawakami and Isobe (1990). Although tour-based systems have been developed extensively in Europe over the past decade, their design has not

been reported extensively in popular journals. Bowman and Ben-Akiva (1997) provide a summary of the most recent system being developed in Stockholm, Sweden.

In the Stockholm model system, the work tour is conditioned by mobility and lifestyle decisions such as car ownership and work location. The work tour is modelled as a nested logit model, including the decision of who will work on a particular day and by what mode. All other activity and travel decisions are conditioned upon the work tour. For instance, the shopping tour model shown determines: (a) how many shopping activities the household will undertake, who will do them, the type of tour on which they will be done, and the mode and destination of the tour; (b) the assignment to individuals and; (c) if assigned to a worker, whether the activity occurs on a home-based tour, a work-based tour, or chained in the work tour. Additional decisions are generally incorporated as additional tiers in a nested logit model structure.

Although they class this model as the most advanced state of the practice of activity-based travel forecasting models, Bowman and Ben-Akiva (1997; 1995) criticize the model for the lack of connection among multiple tours in light of intertour temporal-spatial constraints, and the lack of a time dimension in the model structure. These shortcomings are dealt with directly by their own daily scheduling model system that views the choice of activities and travel as one multi-dimensional choice. The authors deconstruct the daily activity schedule into a set of "tours" which are imbedded in a hierarchical nested decision structure. First, the choice of daily activity pattern is made, which entails the decision about the primary activity for the day (home, work, school, other), the structure of the primary tour (e.g. Home-work-home, home-work-other-work-home), and the number and purpose of secondary tours. In the prototype, a total of 55 possible patterns were identified, excluding those involving at-home activities. This choice is said to overarch and tie together all the individual tour decisions.

It is interesting to note that the definition of primary versus secondary tours was intrinsically linked to the priority of the activities within the tour, using a simple rank-

order categorization of activity priority based on its type (the assumption being that work is the highest priority, followed by work-related, school, and all other purposes) or in the case of a tie, by type and duration, the assumption being that longer duration activities are high priority.

The authors highlight the main weaknesses of the models - that tying tours together in the daily activity pattern results in a very large choice set which is behaviourally unrealistic and computationally burdensome, resulting in literally billions of alternatives. This, despite the fact that the prototype model aggregated activities to four categories (home, work, school and “other” activities), time into four periods, and secondary stops on tours were completely omitted.

2.4.2. Alternative rule-based models

The preceding models have relied mainly on the traditional utility maximization framework to replicate specific aspects of the scheduling process in limited combination or to capture the choice of an entire daily activity pattern. However, the behavioural validity of the utility maximization framework as a description of how people actually make decisions has continuously been questioned (e.g. Gärling 1994) and insights from cognitive psychology about how people perform complex scheduling tasks suggests that people apply a large range of heuristics and strategies when faced with such tasks (Payne et al. 1992; Hayes-Roth and Hayes-Roth, 1979). Gärling et al. (1994a, 356) argues that an even more serious issue relates to the tendency of these models to be confined to specifying what factors affect the final choice of *pattern* whereas the *process* resulting in the choice “is largely left unspecified.”

In response to these criticisms, recent modelling efforts have attempted to incorporate alternative “rule-based” behavioural structures in their models, and more explicitly replicate the sequencing of decisions made during the scheduling process. Two early examples of purely “rule-based” approach as applied to activity scheduling are Lundberg

(1988) and Gärling et al. (1986). A more recent example is provided by Vause (1997). Other models that represent a “hybrid” mix of econometric and rule-based techniques are taken up in the next section.

Lundberg’s model proceeds by assigning “arousal levels” to various activities, which change throughout the course of the day (by definition, “arousal” sounds a lot like “priority” or even “utility”, the difference being that the arousal level is dynamic). Based on this attribute, three alternative rule-based decision procedures are used to choose activities. One simply states that the activity associated with the highest arousal at the time of decision making is chosen, provided it exceeds a threshold. This is a form of a “Dominance” Rule as defined by Svenson (1979). A second procedure chooses an activity that meets the threshold and would experience an immediate decline in arousal level if a decision is postponed. A third procedure stipulates that a threshold arousal is reached and the first derivative (slope) of the arousal trajectory function is negative (i.e. arousal is falling after reaching a peak). A mechanism for ties is incorporated. The only shortcoming of this model is that the decision on which strategy to use in what situations is not stipulated.

Gärling et al. adapt a “computational process” approach in their attempt to replace the utility maximization framework with cognitive principles of information acquisition, information representation, memory retrieval, accuracy-effort trade-offs, decision making, and conflict resolution. In a choice situation, production system rules specify:

1. what information is searched under different conditions
2. how the information is evaluated
3. and how the evaluations or judgements are integrated.

In their first attempt to apply this approach Gärling et al. (1986) focused on the formation of a plans (analogous to activity schedules). Plan formation starts with a list of errands to be run. In the first stage, information about where locations are is retrieved from a

cognitive map. In the second stage, the order of visits to locations is specified by means of a heuristic rule which implies that straight-line distance are minimized locally. In the third stage, shortest patterns to travel between pairs of locations are determined. They investigate this model through a series of experiments in which people were required to decide about the ordering of visits in an area they were familiar.

Vause (1997) also adopts a “production system” approach to activity schedule modelling using rules in the form of condition-action pairs to make the various decisions involved in constructing a schedule. Vause first decided to split the scheduling decision process into a set of more elementary decision making modules. These include the choice of activity, location, involved persons, start time, duration, order, mode, and parking, along with the “meta” choice of how to organize all these decisions. The meta decisions must solve questions such as: What activities will be scheduled first? Do people prefer to manage primary activities (work and school) then secondary ones (shopping, leisure, etc.)? Will location or mode be chosen next? Vause suggests the use of “common sense” rules to operationalize their proposed model in the short term, but recognizes that more accurate methodologies are needed to obtain and refine the rule-base for future development.

2.4.3. “Hybrid” and other models

Because of the dominance of utility maximization, and its subsequent criticisms in favour of alternative decision mechanisms, several “hybrid” activity scheduling models have evolved that incorporate principles of utility maximization with rule-based techniques. Several key examples are discussed here.

One of the first activity-based mathematical schedule models designed explicitly for use in understanding travel is the CARLA (Combinatorial Algorithm for Rescheduling Lists of Activities) model, as described in Jones et al. (1983) and Clarke (1986). The model's main purpose was to predict the impact of proposed policies on observed activity schedules. The model sought to replicate detailed time-space paths of individuals

through the consideration of constraints (obligatory, institutional, interpersonal) and choice in the timing and location of activities. The model predicts how people can arrange the activities they choose to take part in, given the constraints imposed by external environment. Because of the strong relationship between individual activity scheduling and household activity scheduling, the model stipulates that any activities which take place jointly between individuals of the same household must also be capable of taking place jointly in the new modelled schedules, giving rise to valid household schedules. The constructs of the model are complex and are not reiterated here (they are best described in Jones et al. 1983). The inputs to the model are a list of activities to be scheduled, their durations and the times of day between which each is allowed to take place. The output is a list of feasible permutations of those activities, where feasible means that the arrangement does not contravene any of the number of rules (logical, environmental, and scheduling) which are either implicit in the design of the algorithm, or are explicitly stated in the model input. CARLA has been applied in practice in terms of replicating actual activity patterns of a sample of individuals. For instance, it has been used to examine the effects of changes in school hours and reductions in the levels of public transport provision.

The framework under which CARLA was designed inspired many other activity scheduling models. Most notable is the work of American researchers Recker, McNally and Root during the 1980's on their STARCHILD (Simulation of Travel/Activity Responses to Complex Household Interactive Logistic Decisions) model. The development of the model was first reported in conference proceedings (Root and Recker 1983; Recker and McNally 1986) and its widespread acceptance is marked by the publication of a two-part article in Transportation Research (Recker et al. 1986a/b). It is presented here as a "hybrid" model because of the combination of detailed constraints used to identify feasible scheduling pattern alternatives and the use of a classification rule to generate the choice set.

What is most interesting about the presentation of the STARCHILD model is the contrast between the theoretical and operational model (Recker et al. 1986a versus Recker et al. 1986b). Whereas the operational model is somewhat limited by data requirements and some rather restrictive assumptions, the authors pose many new fresh ideas and concepts in their theoretical model (many of which have still yet to be taken up by other researchers), including that:

- the generation and allocation of activities occurs at the household level
- a household activity program includes both planned and unplanned activities, and is represented as a list of activities and their salient attributes such as type, expected duration, desired location for planned activities, and the distributions of duration and location for potentially unplanned activities.
- all spatial, temporal, and transportation constraints are embedded in the structure of the activity program.
- travel demand is viewed as arising from a fundamental process of activity scheduling decisions that transforms the individual's activity program into an activity pattern.
- activities are assigned to individuals according to their flexibility, and the ability to perform subsequent activities is iteratively reduced by the distribution of assigned activity locations, necessary durations, destination time constraints, and mode availability.
- unplanned activities must be inserted into an existing pattern that may already contain commitments with varying degrees of rigidity. The probability that unplanned activities may arise is said to influence the amount of flexibility built into the "planned" executable activity program.
- planned activities are assumed to have a fixed destination, whereas unplanned activities could have variable destinations. However, if unplanned activities are restricted to take place within existing simulated tours, the reduction in space-time flexibility from other activities could lead to a tractable destination choice set.

- individuals will have more confidence in estimates of scheduling requirements associated with trips and activities that occur early in complex tours than with those that occur late in such tours, and also more with simple tours than with complex tours.
- implicit in an individual's selection and implement of a specific activity pattern is the selection and implementation of an entire set of decisions concerning the scheduling of activities. The set of activity scheduling decision that could be implemented are termed feasible activity patterns, and it is believed that they must all be identified. (This assumption forms the underlying basis of the model.)

The operational model comprises five stages and integrates a range of methodological approaches including simulation, combinatorial algorithms, pattern recognition and classification, multi-objective programming, and conventional choice models. This process is governed by several model subcomponents which account for household constraints, generate planned activities and corresponding spatial-temporal characteristics, determine modal availability, check the ordering of activities, and compare activities to a distance array which represents the spatial separation between locations of planned activities. Once the set of activity programs corresponding to each household member is specified, the set of feasible activity schedules is generated through a constrained, combinatorial scheduling algorithm, the second stage in the model. Individual feasible activity patterns are reduced in the third stage to a distinct pattern set using classification rules. The fourth and fifth stages involve the choice of activity pattern that can be expected to be executed during the action period, based on a multinomial logit choice model and basic concepts of utility maximization within a constrained environment. The choice of activity schedule is based on the sum of activities' utilities and the disutilities of waiting and travel times.

Despite the focus of the theoretical model on "decision processes", households, the notion of a planned activity program that may later change due to unplanned activities, and the

iterative scheduling of activities according to their flexibility, the operational model produces only in a static “planned” activity pattern that is expected to be executed prior to the actual “action” period. In a sense, this represents only a portion of the scheduling process that Root and Recker (1983) earlier conceived of as a two stage interaction between a “pre-travel phase” involving planned activity programs, and a “travel phase” involving rescheduling due to unplanned activities arising during the travel day. The importance of “unplanned” activities is further exemplified by the fact that in the operational model, the utility of the total potential to participate in unplanned activities is significant in the logit model used to select the activity pattern - to the authors. this indicates that individuals schedule “flexibility” into their activity/travel patterns” (Recker et al. 1986b, 327), but it also strongly suggests that this notion of rescheduling due to unplanned events should be incorporated in the model given that people plan for it in the first place.

From a behavioural standpoint, the operational model assumes that the scheduling process is a static process whereby individuals generate all possibilities, choose the one that maximizes their utility, then execute this schedule as is with no further changes, an assumption that is widely viewed as unrealistic (Ettema, 1993; Axhausen and Gärling 1992). In conclusion, however, the authors do concede that “extensive rethinking of planned versus unplanned activities appears appropriate” and that “a less static simulation structure which can reflect pattern formation as a dynamic process” needs to be integrated into the model. On the whole, the STARCHILD model was perhaps the most well developed and documented activity scheduling model to emerge in the 1980's, and its value may rest more in the theoretical concepts and ideas introduced and the potential to extend the somewhat restricted operational model.

In review of activity scheduling models including CARLA and STARCHILD, Gärling et al. (1994a/b) noted several of their shortcomings, including:

- The failure to explicitly represent the fact that travel decisions may in varying degree be interwoven with their execution, and that temporal revisions of such decisions are not modelled.
- The failure to model changes over time as a function of repeated experience of the environment.
- They only consider one decision at a time instead of the simultaneous modelling of all household members which would more adequately represent the constraints under which decisions are made.

In response to the complexities of previous models and these shortcomings, Gärling et al. suggest the use of Computational Process Models (CPMs) in development of a single coherent framework for activity scheduling. They base this on the ability of CPMs to model the kind of interdependent decisions involved in household activity scheduling, while at the same time incorporating behavioural principles which do not rely on the utility maximization framework of the previous models. These models assumed that individuals will use *heuristic rules* to build an activity schedule, mostly resulting in a satisfactory but not optimal solution. They describe CPMs as a more realistic model of how people think when they solve problems, involving a set of rules in the form of condition-action pairs that specify how a task is solved. For instance, if the task is to choose one alternative in a choice set, system rules can be developed to specify what information is searched under different conditions, how the information is evaluated, and the how evaluations are integrated. The system is said to rely on cognitive processes involving the acquisition and storage of information, memory retrieval, accuracy-effort trade-offs, and conflict resolution.

Based on this new framework, Gärling et al. (1994a/b) developed SCHEDULER, a CPM of household activity scheduling. The theoretical framework of SCHEDULER contains a memory representation for a *long term activity calendar* for each individuals within a household. Those activities with the highest priorities are sorted and scheduled in a *short*

term activity calendar subject to a set constraints and the available opportunities. The short term calendar of activities is then executed. Conflicts encountered in the detailed scheduling stage are resolved by changing the sequence of activities, compressing or deleting activities, or postponing departure times. Execution of a schedule can also be performed before scheduling is complete since information may not yet be available. In this case, changes in the schedule are made in subsequent stages of the model. Schedules are also co-ordinated with other household members to ensure that interdependencies are met. SCHEDULER is interfaced with a GIS which provides a representation of the activity environment based on the location and opening hours of activities and details of the transportation network. Choices of location are made for each activity based on the temporal sequencing of activities. A detailed schedule is finally formed using all the information in the environmental map and the long term activity calendar. At this point, conflicts may still exist, which are resolved by changes in activity sequencing or postponing of activities. Finally the schedule is stored back into the short term activity calendar which guides the execution of activities.

Based on some preliminary applications of the model, Gärling et al. make several suggestions for future refinements. First, the conceptual framework does not provide explicit guidelines for the assignment of priorities for activities. The authors suggest rank ordering of activities with respect to their priorities would be one solution. A second shortcoming of the model is use of actual maps of the activity environment and transport network as a substitute for the cognitive maps used by individuals in reality. The authors attribute most of the error in destination choice exhibited by the model to this shortcoming. Another obstacle to CPM development concerns the need for more complex data sets to estimate and validate the model. Golledge et al. (1994, 100) also recognizes a "need both to work out the set of behavioral assumptions entailed by such a conceptual framework, and to develop means to operationalize the framework." Recent work by Golledge et al. (1994) and Kwan and Golledge (1995) used a Geographic Information System to operationalize the SCHEDULER model.

In a more recent application, Gärling et al. (1998) incorporates several simplifying assumptions in order to operationalize the SCHEDULER model, including that:

- a) a subset of activities from the agenda is assumed to be available to schedule in a given time cycle
- b) variation in utilities of activities over time are given
- c) routine activities are defined as fixed in time and space and their utilities are high when scheduled to be performed, otherwise they are low
- d) no learning takes place
- e) scheduling is assumed to consist of incremental choices of the activity, the location and that start time (duration is fixed and assumed to be the minimal - if the time slot open is not large enough, the activity is not chosen; if it is longer, then either another activity is squeezed in or wait time accrues)
- f) choices are made according to a single rule in which a set of hierarchically organized factor are combined linearly

The last two assumptions were made for computational ease (although the authors recognize that previous evidence suggests that different choice rules are used in different situations), and lead to the operationalization of the model. First, an activity priority function is defined to determine which activity j is chosen at time t . This linear function depends on the readiness to perform any activity (which decreases as the number of activities already scheduled during a given time cycle), the utility of performing the activity in a given time slot (these utilities are given and range from 0 to 10 for each hour of the day), and the cost of performing the activity. Costs are in turn a function of travel costs, wait time, and time pressure (defined as the difference between the fixed activity duration and the time window available to do it in). This function is used as a basis for a computer simulation of the hierarchically organized scheduling decisions and step-by-step addition of activities to an individual schedule. However, it is unclear in the paper how various coefficients in the priority function are derived via the simulation.

The shortcomings of the model addressed by the author include the lack of alternative decisions rules, the lack of mode choice in the model, and the focus on individuals as opposed to simultaneous modelling of other involved people in order to capture constraints validly (for instance, in the household). Gärling et al. conclude by suggesting that new computerized interact methods for collecting data on activity scheduling are needed (for example, Ettema et al. 1993) in order to empirically test the model.

The activity scheduling model SMASH presented by Ettema et al. (1993) draws upon the combined work of Recker et al. (1986a/b) and Gärling et al. (1994a/b) to produce the first operational model of the “process” of activity scheduling. The model starts with a given agenda of activities to perform along with their attributes including the earliest start and end times, fixed durations, fixed priorities (measured on a 1-10 scale) and the attractiveness of locations. The scheduling process is represented by a series of sequential steps taken to construct a schedule from these activities. The model combines CPMs with discrete choice techniques to compute the utilities for choices to add, delete, or substitute activities from the agenda at each step in the construction of an individual's schedule. A combinatorial algorithm is used to create all possibilities to perform these basic actions at each step. For instance, for substitutions, all activities in the schedule can be replaced by all activities on the agenda, which can be inserted on every position in the sequence. Of all the possibilities, the action that gives the highest utility is performed. The process terminates when no choice results in a positive utility.

The utility of each action is related to several factors. State-dependent variables are defined for each of the three possible actions (add, modify, substitute), including number of actions of each type taken so far and the number of steps since the last performance of each action. Seven generic variables are also included that capture attributes of the schedule resulting from action. For instance, the % of scheduled activities weighted by their priority captures the tendency for people to schedule as many activities as possible, especially those of high priority. The location of activities on schedule in relation to unscheduled activity locations accounts for the propensity of individuals to incorporate

future activities in their scheduling activities. Other variables relate to travel distances and attractiveness of locations. The importance of each variable in the utility is gauged by a parameter that is later adjusted by hand in the simulation to explore its impact. The authors note that the next major step is to link the model to observed behaviour so that parameters can be estimated more accurately. The authors accomplished this through the use of an interactive computer experiment (Ettema et al. 1994, see also section 4.2 for more detail), the results of which are reported in Ettema et al. (1995a).

One model that stands out from the norm in activity scheduling models is the optimization model of Recker (1995) who poses a solution to the household activity pattern problem using a variant of the "pick-up and delivery problem with time windows" used in operations research. Overall, the framework as described represents a utility maximizing structure incorporating constraints that reflect the household's decision alternatives, resulting in a mechanism for generating the set of feasible alternatives that are likely to be considered. In the most general case considered in the paper, the model seeks out an optimization of the "interrelated paths through the time/space continuum of a series of household members with a prescribed activity agenda and a stable of vehicles and ride sharing options available" (Recker 1995, 62). This is accomplished through the minimization of a household travel disutility function that is subjected to a myriad of constraints. The proposed components of the household travel dis-utility function include travel costs, travel time, risk of activity incompletion or of not returning home due to stochastic variations in travel times and activity durations, the amount of delay in returning home due to trip chaining, and the extent of the travel day for each household member. Examples of the constraints used relate to travel budgets, time spent away from home, vehicle capacity, and the number of sojourns in any tour.

In an example application for a two-person household with two personal vehicles, the activity inputs include a fixed number and fixed duration of scheduled activities (3 activities in the example), the time windows of available start times for each of these activities, the time window for the return-home arrival from each activity, the travel time

and costs associated with the fixed locations of each activity, and the overall earliest start and latest end for travel to activities for the day. The constraints include a total travel cost budget amount, travel time budgets for each household member, and the maximum number of sojourns allowed on each tour. The household's objective function minimizes total travel costs, total travel time, delay returning home due to trip chaining, and the extent of the travel day for each household member. The resulting solution is the optimal time/space path taken by the two household members and vehicles in order to complete the three scheduled activities amongst them.

More "realistic" solutions to this same problem are obtained from the original case by adding further constraints to the solution. These include constraints that reflect the restriction that certain activities cannot be performed by certain household members, that costs are associated with performing out-of-home activities, that some members may not perform any activities outside the home, that vehicles are shared or may not be used, or that ridesharing is an option. The latter option involved the most complex formulation, involving an array of temporal, spatial, and coupling constraints on vehicles and household members that, for instance, prohibiting linkages among illogical activities, ensure that household members have a connected path, allow vehicle transfer at home between household members, or ensure that activities accessed as a passenger are coupled with a chauffeuring trip.

Recker's model appears to have overcome, at least for the cases presented, the complex problem (as identified by Small 1982) of choosing an activity schedule to maximize an objective function, by incorporating constraints that limit the number of feasible alternatives likely to be considered. The model also conveniently embodies a clear time of day component by incorporating the notion of "time windows". The similarity between "constraints" and "rules" (for instance, the stipulation that a serve-passenger activity have one and only one driver could be construed easily as an "if...then" rule) also conforms to the behavioural principles espoused by cognitive psychologists about how people solve complex problems. However, no indication is given as to the number of

feasible alternative generated, and how closely the choice amongst these patterns represents actual behaviour, making this model prone to the same criticisms of previous models that resulted in a maximum utility choice among all feasible patterns.

Another alternative to utility maximization has recently been introduced by Ettema et al. (1995b). Their model extends the application of *hazard models* to activity scheduling in order to account for the continuous nature of the decision making process underlying activity performance. The model simultaneously describes the duration of the present activities and the choice of the next activity given certain temporal and spatial characteristics.

2.5. Summary and Commentary

Activity-based approaches to travel analysis have made extensive contributions to the understanding of travel behaviour and the likely impacts social and policy changes on travel which have been difficult to analyze with traditional modelling techniques. The 1970s saw the initial development of the theoretical framework for viewing travel as part of an activity-based framework. These efforts drew upon the seminal works of Hägerstrand and Chapin, especially the emphasis on space-time patterns of activity. The 1980s saw major advances in methodology, particularly model development, as well as initial application of models to policy analysis. Several important conference proceedings summarized the cumulative efforts of researchers in the field. The increasing number of articles appearing in mainstream journals also marked the acceptance of activity-based concepts and the recognition of the emergence of a new 'paradigm'. The early nineties have seen important contributions to the development of modelling techniques which have become more operational but require further validation and unification before they are fully applied in practice. Indeed, a recent poll of travel behaviour researchers reveal that activity modelling is considered the number one priority for research (Hensher 1995).

The major impetus for this research is a need for improved models to assess the impact of travel demand management policies that have emerged as the focus of transportation policy. These needs have led to the development of models of specific aspects of activities, and more recently to the modelling of entire activity-travel patterns or "schedules".

Many different categorizations of activity scheduling models have been made in the literature, and in this review two important dimensions were stressed: 1) whether the modelling approaches are static in nature (i.e. estimate activity patterns simultaneously in one step) or sequential (i.e. step-by-step dynamic structure), and 2) whether they adopt an econometric (i.e. utility maximization and optimization) or "rule-based" psychological approach (i.e. sub-optimal "satisficing" style rules) to model development. Distinctions are also made between theoretical versus operational models, the latter being exclusively based on some form of observed data.

Previous modelling efforts have relied mainly on the traditional utility maximization framework to replicate the scheduling process as a singular static decisions in isolation or in limited combinations. Familiarity with these techniques, and the availability of existing data, has encouraged further development of this approach to activity modelling. The primary direction of this stream of activity models is similar to the previously adopted four-stage modelling approach, wherein the primary concern for model development is on statistical associations, rather than behavioural relationships (Golledge 1997).

However, the behavioural validity of the utility maximization framework as a description of how people actually make decisions has continuously been questioned (e.g. Gärling 1994). Criticisms focus on the unrealistic assumption that individuals have full information about the choices they face in terms of the alternative and their attributes, and that individuals have the capacity to integrate information and determine optimal solutions. Specifically, the main criticism of simultaneous schedule choice models, such

as Kawakami and Isobe (1990), CARLA and STARCHILD is that they first lead to the generation of all feasible activity-travel patterns, of which one is chosen based on principles of maximum utility. Even with constraints/rules designed to limit the choice (as CARLA and STARCHILD incorporate), the assumption that people choose amongst a large set of patterns to maximize their utility is an unrealistic since people are rarely aware of all possible patterns available to them.

In the case of “tour” based models, the behavioural assumption is that the activity scheduling decision structure consists of a series of subsequent choices that can be described by discrete choice models. However, simply adding more nests or levels to the utility maximization model to account for the complexity of scheduling is insufficient on behavioural as well computational grounds. For instance, Bowman and Ben-Akiva’s (1997) attempt to build upon the Stockholm Tour type model by incorporating the time dimension led to the addition of yet another nested level to their model. Not only does this involve a behavioural assumption about how timing decisions are made, but computational limits meant that only four time periods could be included for choice, which is clearly inadequate for policy analysis. Extension to more precise time periods would cause serious problems in a nested logit system. The same criticism/limitation holds for other nested modelling approaches, such as Van der Hoorn’s (1983) model, wherein the addition of a location level to the nested model includes only three possible location choices, which was clearly inadequate for use in most metropolitan areas. Adding more and more nests to a nested logit modelling approach also involves further and further assumptions about how decisions are structured and people actually perform activity scheduling, and it seems they have a clear limit in terms of how many dimensions can ultimately be included into the model.

Several of the models reviewed appear to be well conceived from a theoretical standpoint, as was the case with STARCHILD and Bowman and Ben-Akiva’s models, but their operationalization suffered from a limited focus on the use of utility maximization discrete choice techniques. The array of criticisms of this approach, and the serious limits

they place on the development of scheduling models, begs the question of whether these techniques have reached their limit. Granted, they have been shown to be adequate for certain limited decision scenarios, but the complexity of activity scheduling necessitates at least a combination of techniques.

Perhaps the more behaviourally sound utility maximization based models were the sequential history/future dependent models, such as that of Kitamura and Kermanshah (1983). These models constructed activity-travel patterns by sequentially adding activities to a sequence of activities to form an activity schedule. These models showed us that activities cannot be modelled simply by examining the characteristics of the activity and the individual alone, but must incorporate aspects of activities that proceed (i.e. history dependencies) and follow (i.e. future dependencies) the given activity, as well as aspects of the individuals household to which he/she belongs. However, these models suffer the same criticisms of other utility maximization models in that they assume all choices are made the same, and they assume a specific sequence in decision making.

In response to these criticisms, recent modelling efforts have attempted to more explicitly replicate the sequencing of decisions made during the scheduling process, under alternative behavioural structures. The most advanced of these models is Ettema et al.'s SMASH model. The model is more complete than SCHEDULER and includes factors that are known to affect activity scheduling. It differs from STARCHILD in that the schedule is successively constructed by maximizing utility in each scheduling rather than for the schedule as a whole. Although this model is the most innovative sequential scheduling process model to date, several key criticisms can be noted. Firstly, the authors highlight that "the mechanisms of the model allow for the adjustment of the schedule during the travel phase", however, this adjustment is limited only to substitution of activities between the agenda and schedule, ignoring other adjustment possibilities such as changes in duration and location. The authors also note that changing travel times and unexpected activity durations effect the utility in a sense that the chance of completing the schedule may vary, but they do not go on to describe how this is incorporated in the

model (especially considering that durations are fixed on the agenda), or more seriously, how it effects adjustment of the schedule during execution of the schedule. In this way, the SMASH model is still somewhat limited to the same “pre-travel phase” of scheduling as the STARCHILD model. The authors also note that the “priorities of activities may change during the course of day”, which is misleading considering that activity priorities are fixed on the agenda at the start of the model. Overall, these behavioural limitations may seriously hamper the models applicability to certain policy analysis that inherently invoke a rescheduling response involving more than just substitution of activities.

These criticisms may be due in part to the limitations of their interactive computer experiment, MAGIC (Ettema et al. 1994), which was limited to investigating the underlying activity scheduling process in a lab setting essentially ignoring the portion of scheduling decisions made during execution of an individual’s schedule (see also section 4.2 for further discussion). Because of this limited focus, they found that individuals used very straightforward planning procedures when scheduling, in which activities were scheduled in the same order as they were planned, and that only a limited amount of rescheduling occurred. This differs substantially from the earlier findings of Hayes-Roth and Hayes-Roth (1979) who observed a much more opportunistic scheduling process over time (see also section 4.2).

The Ettema findings were used in general to support the more recent models of Gärling et al. (1998) and Vause (1997), which may explain why they too are limited in the extent to which they capture the complexities of the scheduling process. Both models fall short of directly addressing how scheduling decisions are subsequently modified during execution, and struggle with assumptions concerning the sequencing of decisions. This, and other aspects of their models are addressed more directly in comparison to the results of this thesis in the concluding chapter (see section 6.2)

What is important in this context is that these approaches, to varying degrees, attempt to limit the assumptions made about the underlying scheduling behaviour of individuals and

households so that models can be used to assess the impact of policy initiatives that previous models were simply incapable of doing. However, as pointed out in the review by Bowman and Ben-Akiva (1997, 31), even these models “can be challenged as to the validity of its decision protocol”, noting that in each model they reviewed, “specific assumptions about how the decisionmaker goes about the search and decision are structured into the simulation. These assumptions may be wrong in enough cases to invalidate the model’s parameter estimates and predictions.” These assumptions may be the result of an overall temptation to jump too quickly to model development before doing adequate behavioural research.

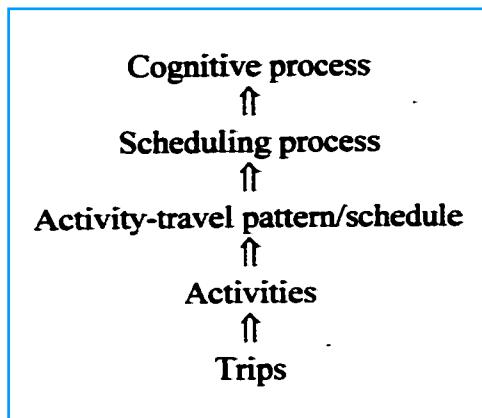
2.6. Future Directions

From the literature, it is clear the contributions to the complex field of activity scheduling are scattered. Specific aspects of scheduling have been tackled using existing techniques and data, but have not come together to provide a fully operational scheduling model that could replace the traditional four-stage transportation planning model. Scheduling models based on existing econometric techniques are severely limited by their behavioural assumptions which limit their applicability to policy assessment. Alternative theories about activity scheduling that have been introduced are quite difficult to operationalize (e.g. SCHEDULER). Operational scheduling models that have been developed (e.g. SMASH) have been criticized by practitioners for their complex data requirements and as noted, are still limited in their ability to capture more complex rescheduling of activities.

It is evident that alternative approaches are needed to build household activity scheduling models. What is not always made clear is that underlying activity schedules is a decision “process” that presumably occurs over time within a household context. When the set of decisions defining the activity schedules (the when, where, and with whom decisions) are coupled with their planning and execution over time, they define an activity scheduling “process”. Relatively few models have addressed this latter process as a means of predicting activity-travel outcomes. However, from a behavioural standpoint, the

distinction between “activity schedule” and “activity scheduling process” models is becoming ever more crucial to the future of activity-based models.

Exploring this distinction further, consider the following series of dependencies:



It is widely agreed that trips are derived from the need to participate in activities outside the home. Activities themselves form a larger activity-travel pattern or schedule that is intrinsically linked. This thesis purports that activity schedules are the result of a scheduling process that occurs continuously over time and between individuals and households. The scheduling process itself is dependent upon a cognitive process within the brain. As one moves up in this framework, a greater understanding of trips and travel patterns is achieved, especially of the more complex trip chaining, off-peak, and discretionary trips. The trade-off in understanding comes at a price in terms of the complexity of the phenomenon and of the observation task.

Despite these complexities, travel behaviour researchers are increasingly recognizing the need for in-depth research into the household activity scheduling “process”. Early on, Pas (1985, 461) noted that existing theories and methodologies dealt almost exclusively with travel and related behaviour at particular points in time, but that “it is increasingly being recognized that understanding travel and related behavior requires the development of models of the process by which travel and related behavior change.” Jones et al. (1990, 41) noted that “household responses to changes in transport and land use supply characteristics may be varied and complex. They include reorganization of trips into

tours, reassignment of trip/tasks among household members and complex rescheduling of activities and travel. Conventional models of travel demand consider only simple adjustments in the daily travel pattern.” Polak and Jones (1994, 2) state clearly that “the degree to which travellers will be able or willing to adjust the timing of their journeys in response to Road Pricing charges will ultimately depend upon the nature of these scheduling processes. The development of improved understanding of these processes and the translation of these understandings into operational modelling techniques is a major research priority.” Lawton (1997, 117) has pleaded for “smaller samples of households, with real compensation for the level of effort, together with the use of direct contact surveys utilizing interactive computer based techniques.” Axhausen and Gärling (1992) emphasize in general, that the rescheduling of activities is at the core of many of the changes in travel behaviour brought on by recent policy initiatives related to information technology and transportation demand management. Thus, it is becoming ever more important that the development of travel forecasting models capable of assessing these types of emerging policies need to explicitly account for how people would temporally and spatially adjust their travel behaviour, which is dependent on an underlying process of activity scheduling.

The problem of activity scheduling is three fold:

- The details of the process are largely unknown, particularly in terms of how schedules are formed within a household over time
- Its complexity makes the observation task very challenging
- Even with full information, the resulting modelling tasks requires the piecing together of at least the basic dimensions of the activity scheduling decisions that account for how they are formed and potentially modified.

The paradox, as outline above, is that this complexity brings simplicity to our understanding of travel patterns - indeed , it may be the only way to really understand of the full variety of travel patterns.

Surprisingly, very few data collection efforts have been performed to specifically meet this end. Hayes-Roth and Hayes-Roth (1979) cognitive model of planning, and Ettema et al.'s (1993/1994) SMASH model are virtually the only two models that are based on actual observations of the activity planning process. Hayes-Roth and Hayes-Roth used a "think aloud protocol" to investigate the kinds of behaviour exhibited when people are posed with a series of errands to perform. Ettema et al. (1994) used an interactive computer experiment to identify activity scheduling heuristics and the types of steps people used to make changes to an existing activity schedule. Many other similar data collection efforts have been performed, but the goal has been to elicit people's "stated response" to specific changes in policy (e.g. Lee-Gosselin 1990), as opposed to investigating the process which people/households reach their decisions.

Specifically, what is needed are data collection efforts aimed at identifying the steps households take in building activity schedules and how they are modified during their execution, a shortcoming emphasized by Gärling et al. (1994). Ettema's "Method of Activity Guided Information Collection" is an example of a tool to collect data on individuals' activity scheduling behaviour, and offers the most promising starting point for such efforts.

CHAPTER 3 LINKING ACTIVITIES AND INTEGRATED URBAN MODELS

This chapter is intended to place activity scheduling models in a wider context of integrated models used for urban planning. This highlights the fact that, despite the move towards more complex "scheduling" models, the end goal remains the same: to predict the travel demands generated in an urban area.

3.1. Theoretical Linkages

Growing environmental awareness and recent legislation in the United States such as the Clean Air Act of 1990 and Intermodal Surface Transport Efficiency Act of 1991, have provided a detailed mandate for the forecasting of emissions and air quality in urban areas. There is a growing consensus that significant vehicle emissions reduction cannot be achieved by transport policies alone, but require complementary land-use policies that promote longer term reductions in the need for travel via higher density, mixed-use urban forms suitable for public transport (Wegener 1998). The urgency of this issue has renewed interest in integrated models of Land-use, Transportation, and the Environment (LTE). Making the connection between activities in general, and activity scheduling in specific, to LTE models provides an important context from within which this thesis has developed and will contribute in the long term.

LTE models have from the beginning been based on the paradigm of the 'land-use transportation feedback cycle', which states that land-use and transportation interact in a pattern of circular causation, as presented by Wegener (1995). Each stage in the cycle has typically been treated as a subcomponent of an integrated LTE model. Several authors have made suggestions related to the incorporation of activity-based approaches with LTE models. In a summary of a workshop on "Transportation, Urban Form, and the

Environment", Pisarski (1990) notes that the most basic relationships believed to need further investigation and data collection are the underlying demographic and social changes and current activity patterns that are the basis for travel demand. More recently, Wegener (1995; 1998) stresses that future LT models need to respond to "a new generation of activity-based travel models" that require more detailed information on household characteristics and activity locations. Although Wegener recognizes the potential role of activities in land-use modelling, he does not fully incorporate these ideas into the conceptual models he presents on the "process models of urban change" and the "land-use transportation feedback cycle". Breaking the feedback cycle into long term (labour and residential mobility) and short term processes (activities/travel) is one way to improve these models. This would conform to theories proposed by (Clarke, 1986) and recently by Gärling et al. (1986, 1994) that activities are scheduled according to a short and long term activity calendar, although residential and labour decisions have yet to be placed in such a context. For the most part however, LTE modelling has continued in a business-as-usual fashion, focusing on single-purpose trips and the integration of traditional travel demand models.

One relatively "state-of-the-art" microsimulation model of LTE that does incorporate an activity focus is the TRANSIMS model (Barret et al. 1995, Smith et al. 1995). The "Household and Commercial Activity Disaggregation Activity Demand" sub-module is designed to be probabilistic in nature, in that for a given set of demographics (provided by a microsimulation of households), a distribution of activities will be produced for each household. Associated with each activity is a set of parameters defining the activity importance, the activity duration, activity location (for mandatory activities) and a time interval during which the activity must be performed, if it is performed at all. The mechanisms used to actually *schedule* the list of activities are not described in either paper, and this is currently a major "question mark" for future development.

In addition to playing a direct role in microsimulation models such as TRANSIMS, an activity scheduler can be directly linked to a residential mobility microsimulation model.

such as that proposed by Miller et al. (1987), by providing input variables to the residential choice process. This would expand upon traditional residential choice models which use only “work trip” accessibility as a variable in the model (e.g. Putnam 1995) and could provide especially useful for certain population segments that are relatively insensitive to the work trip accessibility (e.g. telecommuters). The scheduler could also be used to define a subset of activities that could feasibly be evaluated by a household in a new residential location. These could be represented by a set of high priority activities that are normally scheduled in advance of other activities. The activity scheduler could also play a role in defining the “triggers” for residential mobility. Keeping track of residential mobility in a microsimulation may also play a complementary role in the construction of activity schedules, allowing one to consider history dependent variables that effect activity schedules.

Overall, there is much potential to link models of activity scheduling to integrated LTE and microsimulation models. Those factors that are modelled within an integrated land-use and transportation simulation models, including housing market changes, lifecycle changes, car ownership, residential choice, etc., can all be linked to the household activity scheduler, as an impetus for change. As well, the activity scheduler may feed and feedback information into other model components, either in terms of assisting with the choice/change given current or potential activity patterns generated by the activity scheduler, or as a definite “feedback” loop. How the linkages are made, and at what time scale are additional issues that must be resolved.

3.2. Integrated Models and Activity Scheduling - A Conceptual Framework

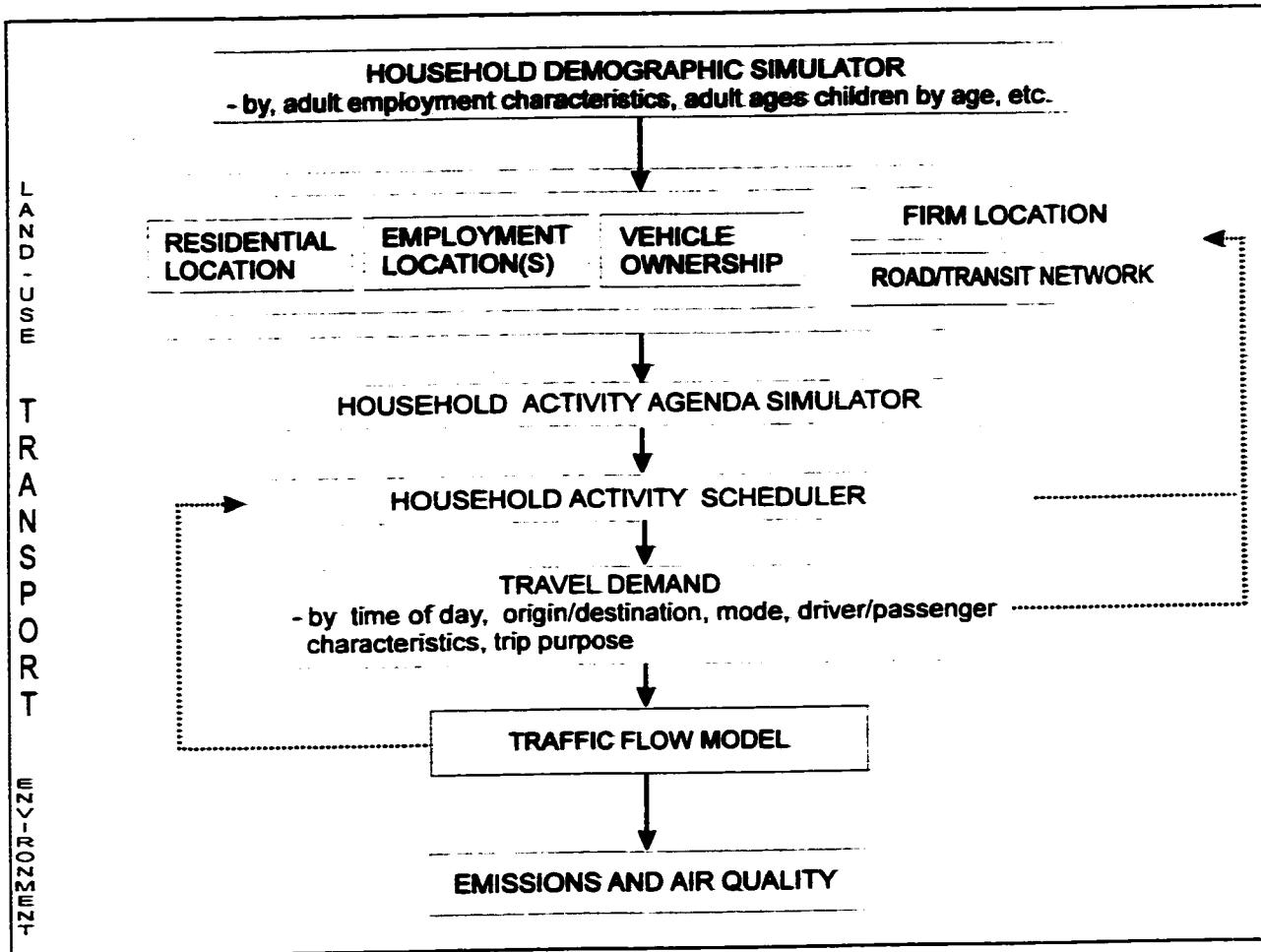
Although considerable advances in activity-based models have been made, they have, for the most part however, been developed in relative isolation from the more integrated models of land-use, transportation, and the environment. Important questions remain to be answered and/or debated in the literature. What potential do activity-based travel models offer for forecasting? Should models of human activity simply be another

component in integrated urban models? Or, will they bring about fundamental changes in overall model structure? Perhaps more importantly, how do we begin to make the necessary connections that could lay the basis for new model developments?

A conceptual framework of how an activity scheduler would contribute to an integrated model of land-use, transportation and the environment, is presented in Figure 3.1 (italics in the text represent components in the figure). The upper portion of the model focuses on long term *Land-use* and demographic processes, including *Household Demographics*, *Residential Location*, *Employment Location*, *Vehicle Ownership*, and *Firm Location*, and the *Road/transit Network*. Each of these sub-modules are currently being developed within the micro-simulation platform of the ILUTE model (Miller and Salvini 1998). It is proposed that several of these sub-modules will input information to the *Household Activity Agenda* and/or *Household Activity Scheduler*, at specified intervals or as events unfold in the microsimulation to support creation of new travel demands as an impetus for change (the process of goods/service movement is not dealt with here).

The *Household Activity Agenda Simulator* consists of a list of household activities, along with the salient attributes that influence their scheduling, such as their desired frequencies and durations, possible start-end times and location choice sets. Some of these attributes would likely be probabilistically related to individual/household characteristics based on activity diary data (or perhaps, modified travel diary data), in a similar approach to that adopted in the TRANSIMS model. The *locations* of home, work, school/daycare and other mandatory activities could be taken as given from previous sub-module steps. The location choice set of other activities would require a model of an individuals cognitive map, perhaps simulated based on residential and employment location histories. The adaptation of the activity agenda in the long term, such as in the case of learning new activity locations or activity types, would be a necessary component of this sub-model. Simulated changes in the agenda as a result of policy (e.g. shorter working days, longer working hours for females, increased telecommuting) would be reflected in changing attributes of certain activities that effect scheduling patterns and resultant travel patterns.

Figure 3.1 Household activity scheduling within an integrated land-use, transportation and environment modelling framework



The *Household Activity Scheduler* would take the agenda of household activities and model the steps/process by which the activities are sequenced in time and space. Such a model is proposed in Chapter 5, specifying how a set of prioritized activities are sequenced and subsequently modified to form a schedule. The output from the Household Activity Scheduler would include the *Travel Demands* of each household member by time of day. This would include the start time of each trip or trip-chain, the origin, the destination(s), the day of the week, the driver/passenger characteristics, trip purpose, mode, initial travel times. Initial travel times could be based on shortest path, or perhaps could be simulated based on knowledge of network flows by time of day in

previous time periods. The output is designed to feed into a *Traffic Flow Model* that will then generate network flows and updated travel times due to congestion. The updated travel times can be used to feedback to the Household Activity Scheduler in the form of new activity start/end times, resulting in further scheduling modifications. The process would continue until a threshold of scheduling changes is achieved.

The feedbacks from the activity scheduler and the network assignment to the land-use system are not shown in detail, however, it is proposed that the activity scheduler be run at each time step in the microsimulation involving a change in the upper portion of the model, in order to generate new travel demands, network flows, and environmental emissions. The activity scheduler could also be used to feed information to a residential choice model, in the form of the variables that indicate the potential utility of activity patterns associated with a set of residential choices for a given household. Practically, the activity patterns that could be feasibly evaluated by a household in a new location would be restricted to high priority or “routinized” activities. The activity scheduler could be used to generate attributes of this more limited set of activities.

The benefits this modelling approach brings to the integrated models are two fold: the beginnings of the extensions of the model to the full day and the incorporation of new types of explanatory variables in the model that could be used for forecasting and policy scenario analysis. It would also represent one of the first attempts to incorporate activity-based models with integrated land-use transportation models, addressing the major concerns of Wegener (1998), and bringing forth a potentially new era in integrated modelling efforts.

4. CHAPTER 4 DATA COLLECTION METHODOLOGY

Authors Note:

This chapter is reproduced from a paper titled "A computerized household activity scheduling survey" submitted to the journal *Transportation*^t. Eric J. Miller, my thesis supervisor, is included as a second author. An earlier draft of this paper was presented at *The Eighth Meeting of the International Association of Travel Behaviour Research*, Austin, Texas, September 21-25, 1997. Copyright for this latter paper is held by the authors. Prof. Miller has provided his permission to reproduce this paper in this thesis. The paper has been modified slightly to minimize redundancies and to improve overall flow and continuity.

^t As of August 24, 1998, the acceptance of this paper had not been confirmed.

4.1. Introduction and Research needs

To further support these emerging activity scheduling and travel forecasting efforts, travel behaviour researchers are increasingly recognizing the need for in-depth research into the household activity scheduling process. In a review of activity-based literature, Axhausen and Gärling (1992) note that what can be drawn from previous studies is that activity participation and duration depend on day in the week and time of day. Such choices are thus influenced by previous and planned activity participation, and that social interaction within households is an important factor. Additional findings suggest that people schedule their activities with a longer time horizon than a day, and that a number of time horizons are planned simultaneously. Axhausen and Gärling go on to note that the details of the process of activity scheduling are largely unknown, and that this is one of the most urgent problems in need of further investigation. Specifically, they note that methods need to be developed to study this process in more detail than in the past, including techniques that combine observation of activity scheduling:

- 1) *in situ*
- 2) under simulated but realistic conditions and
- 3) under experimental conditions using techniques developed in psychology.

These suggestions are similar to those of Lee-Gosselin (1996), who identifies a need for tracking, gaming-simulation and experimentation to further understand activity "processes" rather than "states". Some of the key issues that Axhausen and Gärling state are in need of new methods include how scheduling decisions are organized over time, why, when and how scheduling decision are revised, and how activities depend on the demands of other people, especially within households. It is clear that existing activity diary techniques can only provide a limited amount of information on these issues, and without further empirical work, activity schedule modelling will continue with strong behavioural assumptions that limit their potential.

4.2. Previous empirical studies of the underlying activity scheduling process

Despite the need, very little fundamental empirical research has been conducted into the underlying activity scheduling process, outside of descriptive studies of revealed activity patterns. Exceptions include Hayes-Roth and Hayes-Roth (1979) and Ettema et al. (1994). Ettema et al. used an interactive computer experiment to identify the types of steps taken by subjects to perform a scheduling task. Assuming that activity scheduling is a daily problem-solving process, individuals were presented with a list of 29 activities and asked first to specify the attributes of the activities (e.g. duration, frequency, location choices), and second to use a computer program to construct an activity schedule for the next day via a step-wise process of adding, deleting, and modifying the order and locations of activities on screen. Results showed that respondents applied an average of 12.9 scheduling steps, the majority of which (89%) consisted of add operations. Of these add steps, 83% were included as the last activity of the schedule at the time. These findings led Ettema et al. to conclude that subjects use rather straightforward planning strategies in which the activities are scheduled in the expected order of execution with only few changes being made regarding locations, mode and sequencing of activities.

Ettema et al.'s findings contrast with the earlier, more qualitative findings of Hayes-Roth and Hayes-Roth who used 30 "think aloud protocols" from five subjects to investigate the kinds of behaviour exhibited when they were posed with a series of errands to perform in a simulated urban environment. Subjects' plans were seen to develop incrementally at various points in the simulated planning space and temporal sequence, and not strictly forward in time. Subjects were also found to plan "opportunistically", developing temporally-anchored sub-plans at arbitrary points in time. Overall, planning decisions at any given point were found to influence subsequent decisions concerning plans made earlier or later in time. These findings contrast directly with the more systematic top-down planning process observed by Ettema et al.

There are many reasons for the differences in findings of the two studies, foremost of which relates to the difference in methods used. In Ettema et al.'s case, scheduling occurred with elicited activities in a known environment, producing a very straightforward and perhaps routine series of tangible scheduling steps recorded on computer. In Hayes-Roth and Hayes-Roth's case, scheduling occurred with simulated activities in a simulated environment, producing a very complex and detailed verbal record of the scheduling process. However, one common characteristic of both studies is that they occurred in a laboratory setting, and although both attempt to be as realistic as possible, they only capture a portion of the activity scheduling process. The other portion consists of those scheduling decisions made during the actual execution of the schedule, coming as a result of unexpected events, continuing changes in planning decisions, and interaction with the environment and other people with whom activities take place jointly. In order to advance our understanding, an alternative approach is needed that combines observation of the scheduling process under more realistic planning conditions and is capable of capturing routine as well as complex scheduling processes. This will require, at the least, a more extended observation period and a household as oppose to individual setting. The next section addresses such an approach.

4.3. Data Collection Approach

Before suggesting data collection methods, we must first attempt to conceptualize the major aspects of the activity scheduling process. On a fundamental level, activity scheduling reflects personal and household related basic human *needs* constrained in time, capability, and in space by the urban environment. These needs can be viewed as manifested in a household's activity *agenda*. Activities on the agenda can have a wide range of (perceived) characteristics that affect their scheduling, including duration, frequency, time limits, priorities, involved persons, costs, locations, etc. The process of scheduling begins as individuals in the household *add* (or assign) activities from the agenda to their schedules. These decisions, along with timing, sequencing, location, mode, and route choice decisions, occur over varying time horizons in an on-going

process. Up until, and during, execution of activities, the schedule may be continually modified (including the decision to *delete* activities) in response to change. The *decision structures/rules* adopted throughout the scheduling process may range from the routine to the very complex, depending on the situation at hand, the degree of cognitive effort required, and the characteristics of the people involved.

This conceptualization highlights three main aspects of activity scheduling that should be targeted in data collection efforts:

- 1) the generation and recording of a household's activity agenda (a manifestation of "needs")
- 2) the process of activity scheduling as it occurs over time (multi-day) in a household setting
- 3) the decision rules that underlie the various individual/joint decisions made

Innovative recording/surveying techniques are needed to capture as many aspects of the process, while minimizing intrusion into people's lives and maximizing behavioural validity. One way to bring the various aspects of the problem together would be to use a computer-based survey approach, which has been used in the past to investigate detailed behavioural phenomenon (e.g., Jones et al. 1989; Ettema et al. 1994; Kalfs 1994). The use of computers not only speeds data entry, but can improve data quality, provide graphical displays for interactive discussions, and automatically record information such as sequencing of inputs. The use of computers in activity/travel surveys is considered to be a very recent phenomenon (Richardson et al. 1995) and has been limited mostly to an interviews in which the researcher records all the information. There is much potential to expand the use of computerized surveys to overcome the difficulties of recording data on the scheduling process over a multi-day period and provide a forum for the interactive discussion of decision rules and complex behavioural response to policy initiatives.

4.4. Computer-based household activity scheduling survey design

This section presents the design of an experimental computer-based household activity scheduling survey that serves as a forum to collect data on various aspects of the household activity scheduling process. An application of the survey to a sample of households is presented in the section to follow.

The main objectives of the survey are to establish a household's activity agenda from which all activities are drawn and to track the *sequence* of steps whereby activities from the agenda are added, deleted, and subsequently modified during their execution to form household weekly activity schedules. This is accomplished through a household interview (section 4.4.1), a week-long computer-based survey (section 4.4.2), and a follow-up interview. While considerable potential exists in the follow-up interview for in-depth discussion, currently, it is used only to review the results of the survey and retrieve the laptop computer. Underlying decision rules are discussed in terms of future survey design (see section 4.8).

4.4.1. Up-front interview and the household's activity agenda

The purpose of the up-front interview is to record basic household member, mode, and residential information along with the household's activity agenda. The household activity agenda consists of a full list of activities performed by household members, along with their attributes. Theoretically, it represents the household's activity "choice set." Practically, it allows easier choice of activities during scheduling with a link back to their attributes from the agenda. Perhaps most importantly, defining the agenda gives the household a feel for the level of detail to be recorded, helping to avoid confusion and improve the completeness and consistency of the data across households.

All information is entered by the interviewer into computerized "forms" linked to database files, so that the CHASE program (see section 4.4.2) can access and display the

information back to the user in choice situations. For instance, when prompted for the specific activity type within a main group, the user need only pick it from a list that are already familiar with (or choose "new" if needed).

To collect this information, a set of main activity categories were defined, each including a list of up to ten pre-defined "generic" activity types that could be presented to households for possible inclusion in their agenda. This listing, presented in Table 4.1, is based in part on previous activity diary and time-use surveys (e.g. Portland Oregon Household Activity Survey in 1994; Statistics Canada Time-use Diary 1986). Household members were asked to describe, in their own words, the specific activities of each type that they perform, along with their attributes including:

1. which household members it is applicable to
2. the locations where it takes place, including at-home, in the Hamilton Study Region (specified by census tract zone number and a description - see also section 4.5.1), and out-of-region.
3. whether the activity involves any costs or expenditures
4. the last time it took place
5. the frequency that it takes place (number of times per day, week, month, or year)
6. the normal duration of the activity
7. the days of the week that it takes place on
8. the earliest start and latest end times for the activity

Attributes 4-8 can be specified twice, if for instance, the activity start and end times, frequency, or duration, differed by day of the week. Attribute 3 was pre-determined in most cases. Certain attributes were not sought for some activities to avoid confusion or because they would be awkward to estimate with any degree of accuracy.

For all activities except shopping, only the most frequented locations for the household were pre-defined. For shopping, household members were asked to define "all the

Table 4.1 Generic activity types used to define a household activity agenda

| BASIC NEEDS | WORK/ SCHOOL | HOUSEHOLD OBLIGATIONS | SERVICES | JUST FOR KIDS |
|-------------------------------------|---|--------------------------------------|-----------------------------------|-----------------------|
| Night sleep | Work | Cleaning/maintenance | Doctor | Tag along with parent |
| Wash/dress/pack | School | Meal preparation | Dentist | |
| Home prep meals | Daycare | Chauffeuring | Other professional | Play, socializing |
| Bagged lunches | Volunteer work | Chauffeuring and passively observing | Personal (Salon, barber, laundry) | Homework |
| Restaurants (family, spouse, alone) | Special training | Attending to children | Banking | With babysitter |
| Delivered/picked-up meal | Other work/school | Pick-up involved person | Video store | Other just for kids |
| Coffee/snack shops | | Other errands | Library | |
| Other basic needs | | Other obligations | Other service | |
| SHOPPING | RECREATION/ ENTERTAINMENT | SOCIAL | OTHER | |
| Minor groceries (<10 items) | Exercise or active sports (aerobics, fishing, cycling, walking, etc.) | Visiting | Tag along travel | |
| Major groceries (10+ items) | Movies/theatre | Hosting visitors | Pleasure driving | |
| Housewares | Other spectator events | Cultural events | | |
| Clothing/personal items | Playing with kids | Religious events | | |
| Drug Store | Parks, recreation areas | Planned social events | | |
| Mostly browsing | Regular TV programs | Bars, special clubs | | |
| Convenience store | Unspecific TV | Phone/e-mail >10 min | | |
| Pick-up meal | Movie video | Helping others | | |
| Other shopping | Relaxing/pleasure reading/napping | Other Social | | |
| | Hobbies (crafts, gardening, etc.) | | | |
| | Other rec./entertainment | | | |

locations they know of" to participate in the activity - in essence, defining their location "choice set." Although this could have been done with other activity types, shopping was a focus in this first study because the choice set is more easily defined, both subjectively on the part of household members and objectively in terms of defining all locations in the actual urban environment.

4.4.2. *The Computerized Household Activity Scheduling (CHASE) software program*

Once the preceding databases are complete, adult household members are shown how to use the CHASE software program on a laptop computer left in the household. The program is written in Visual Basic and runs in a Windows 95 platform, using an external

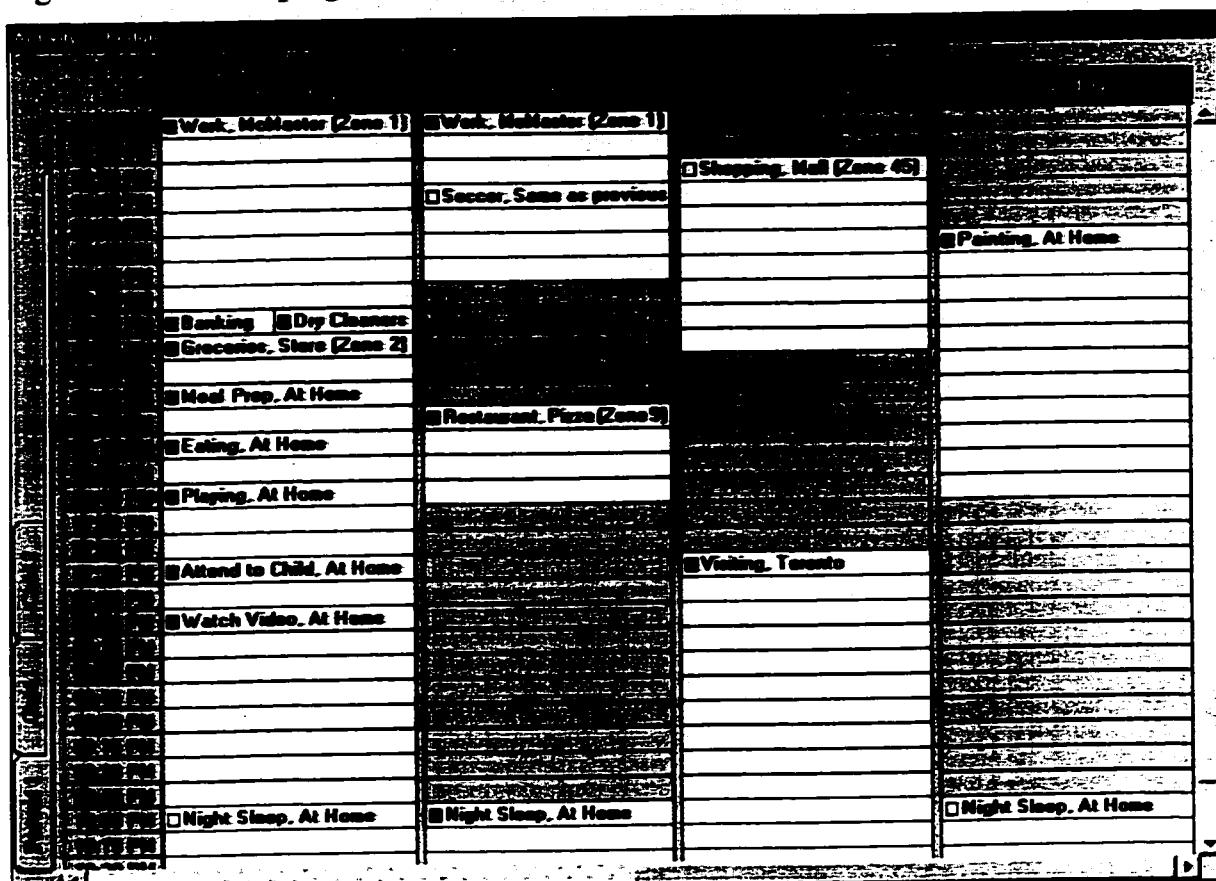
mouse and keyboard for data entry. The program was designed, developed and tested by the author from February to April 1997.

Adult household members begin recording their schedule decisions on a Sunday evening for activities that cover the following week (Monday-Sunday). They are given the following basic instructions:

- Try to log in to the program at least once a day for the entire week.
- Starting tonight, add activities anywhere in your schedule that you have already thought about doing before logging on to the computer. These include even those activities that you think may change at a later date.
- On subsequent days (or tonight if applicable), continue to add new activities to your schedule, but review your previous and future entries and modify/delete them according to any changes that have occurred. This may include modifying/deleting a past event to reflect what actually occurred, or modifying/deleting a future planned event because of further changes or refinements in your plans.
- Include all activities that last longer than 10 minutes; the exception is for short activities involving travel - include all of these (e.g. quick stop at the dry cleaners).
- You may overlap activities that take place at the same time (e.g. eating and watching TV) or that intervene within a longer activity (e.g. going out for lunch at work).
- Activities start when you leave for them and end when you leave from them. In this way, travel time to the activity is counted as part of the activity, whereas travel time away from the activity is captured by the next activity.
- Try to complete the schedule alone; do not access your partners' schedule.
- To parents: Access your childrens' schedule by choosing their respective tabs on your scheduling screen.

The CHASE program main screen is shown in Figure 4.1. A household member's weekly schedule is displayed as a series of columns depicting the days of the week from Monday to Sunday, and a series of rows depicting 15 minute time blocks starting at

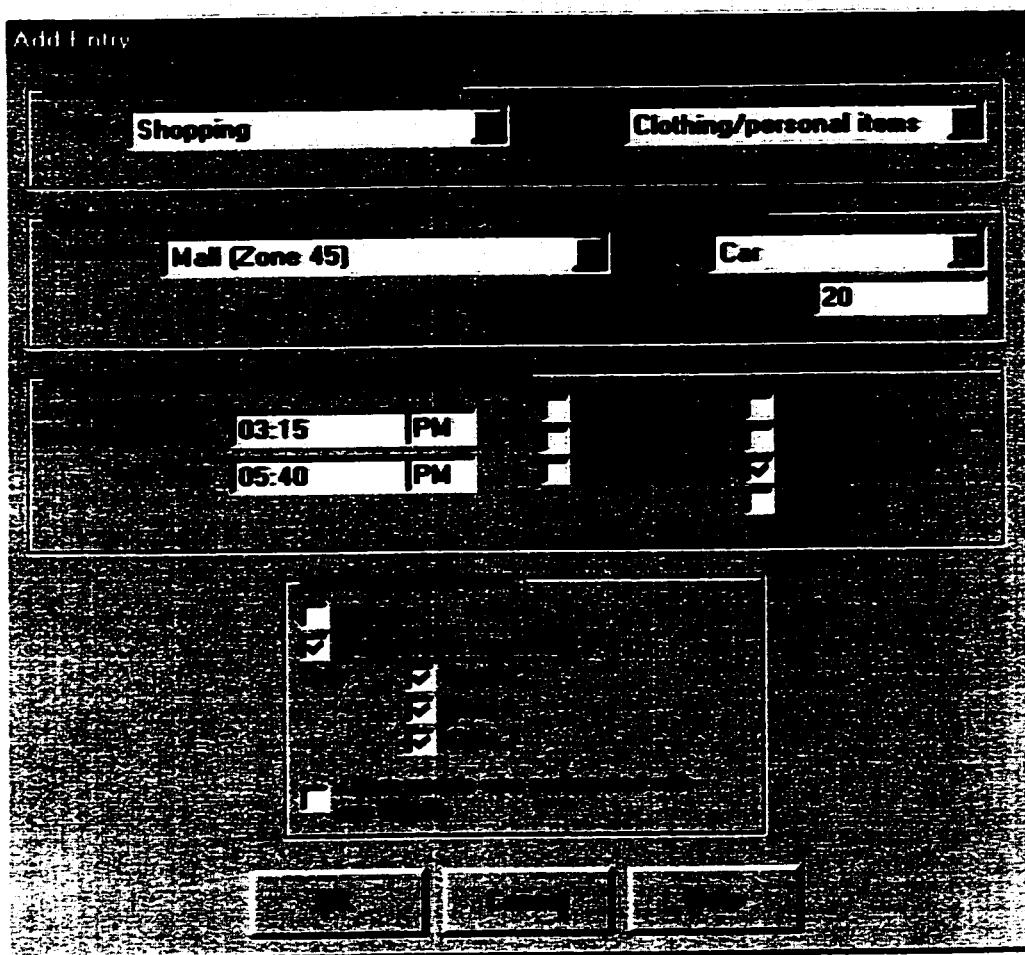
Figure 4.1 CHASE program main screen with example entries



Note: Actual screen is in colour.

midnight. At any one time, the user can see four days of their schedule across the top, and seven hours worth of time down the side - scrollbars allow the user to adjust the view. The example shown depicts four days of a parent's schedule, as it would look on Friday. For parents, tabs along the left side of the screen allow them quick access to their children's schedules. Each activity on the schedule appears as a series of 15 minute coloured blocks, with the first of these boxes normally displaying the activity type and location. Activities may start and end at any time, but the display will truncate to the nearest 15 minute time block. Multiple short activities in the same time block will scroll horizontally.

Figure 4.2 The add/modify dialog box



The main menu in Figure 4.1 includes the options to Add, Modify, or Delete an activity. To add a new activity, the user first selects a series of time blocks using the mouse, then selects the add command. This brings up the “Add Entry” dialog box depicted in Figure 4.2, which prompts the user for the activity type, location, mode, travel time, and involved persons. For the most part, the user simply points and clicks his/her choices, as follows:

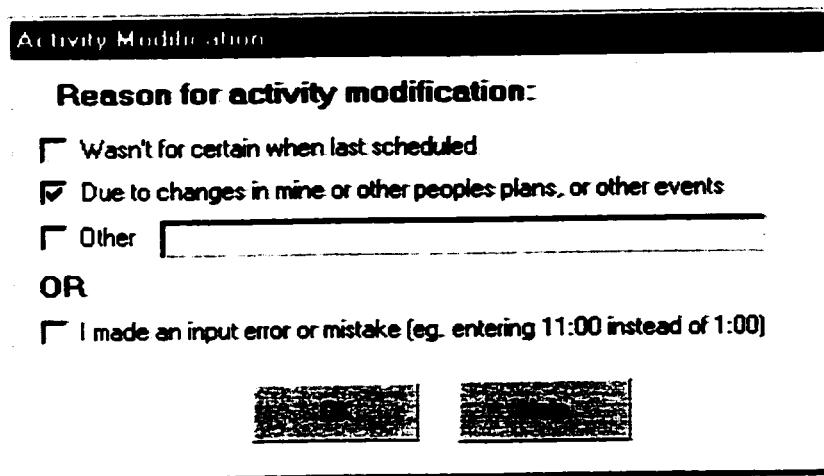
- From pull-down lists, the user first selects the activity “group” (these are the same for all users) followed by the specific “activity” within the group. Only those activities from the household activity agenda that are applicable to the given user are listed,

along with the option to specify a “new” activity. A dialog box prompts the user for basic attributes of any new activities.

- The activity location is chosen from a pull-down list that includes the locations specified in the agenda as applicable to the specific activity (at-home; one or more locations in the Hamilton Region specified by zone and description; out-of-region). The user can also specify a “New/other location in the Hamilton Region” or choose “Same as previous”. “Out-of-region” is associated with a prompt for the city/town name.
- After choosing the location, a mode and travel time to the activity may be specified. The program includes logic to detect when mode and travel times are necessary (e.g. when the previous activity location is different). Modes defined for each user in the up-front interview are listed along with an option to define a “new” mode. Note that although travel in itself can be considered an activity, adding it to the beginning of an activity is believed to be a more natural and simpler approach than creating extra activity boxes on screen.
- By default, the start/end times and the day corresponding to the outlined box on the main screen are displayed, but they can easily be changed. When adding activities, the user may also specify multiple days - however, once added, each day is stored and treated separately.
- Lastly, the user specifies the people who are involved in the activity. The first names of household members appear in the list provided. “Other people” is explained to the user as those people with whom they had to co-ordinate plans.

To modify an existing activity, the user simply selects it on screen and chooses the modify menu command. This brings up the same dialog box depicted in Figure 4.2. The user can then proceed to modify any of the previously entered attributes. Alternately, if the user only wants to change the start or end time of an activity, he/she can interactively select the edges of an existing activity box on screen and “drag” them to new times.

Figure 4.3 Modification reasons dialog box



Aside from the basic add, modify, and delete scheduling options, the program automatically prompts the user for all additional information. This includes prompts necessary to track the scheduling process accurately, prompts for other information of interest, and prompts designed to encourage accurate and timely completion of the schedule.

In terms of tracing the scheduling process, it is important to determine whether a modification or deletion is the result of a simple input error (e.g. entered the wrong time by mistake) or whether it reflects a genuine change of plans. Thus, after every modification or deletion, the user is prompted for their reasoning, as in Figure 4.3. For deletions, the option “I moved it to a totally new time slot” is added to the list (if selected, the user is prompted to modify the activity instead by changing the timing and/or day, since this would maintain the series of changes made to the activity). Equally important, if users enter an activity on their schedule after it has occurred, they are asked to “Indicate when you actually made the decisions to <add/modify/delete> this activity.” A check-box list is presented (similar to Figure 4.3) including the following choices: “During the activity”; “Just before the activity”; “Prior to the activity on the same day”; “More than a day ago on <pull down list of days>”; “Prior to this week”; or “It is a routine even with

no real decision associate with it." This information is necessary to place the decision in the context of previous scheduling steps. In most cases, if the user has not skipped a day, one of the first three choices will be valid.

Two additional information prompts were built into the program to experiment with functionality and gather more detail from users. In the case of shopping activity entries, the users are prompted to specify more detail on their reasoning. For modifications and deletions, the prompt is similar to Figure 4.3 except that the first three check-box choices are replaced by an open-ended text entry boxes. For activity additions, the user is asked separately why he/she chose the particular activity, the time period and day, and the location, followed by text entry boxes in each case. This information could also serve as a reminder during any follow-up discussions of the underlying reasons for specific scheduling decisions.

The second prompt concerns the costs of activity performance, which is expected to influence how it is scheduled. The program is designed to prompt for activity costs the following day (or at most two days later) once the schedule for the day in question is completed. Activity costs on Sunday are prompted for on the same day once the schedule is complete. A dialog box appears on exit from the program asking users in sequence to "Enter all the applicable costs associated with the following activity: <activity details>." The list of costs includes parking fees, participation fees/tickets, household goods/services, personal goods/services, meals and beverages, babysitter fees, and other.

To encourage accurate completion of the schedule, all inputs are immediately checked for validity and the user is prompted to provide all necessary activity attributes when entered. The program also includes logic that assures that each household members' schedule for a particular day is fully completed at most two days later. If not, the user is prompted to fill in all time slots. The program also detects overlapping activity entries, in which cases the user is given the option to modify either of the overlapping activities, or accept the apparent conflict. Further checks for mode conflicts and verification of joint activity

participation were attempted, but had to be sacrificed for this first application because of their increased complexity and resource requirements.

A single database file written by the program records every add, modify and delete scheduling step made by household members. Each addition results in a new line of data that stores the scheduling attributes derived from Figure 4.2, a cross reference to household agenda file, the date and time of data entry, and a field indicating that it is "currently" displayed on the given household member's schedule. Modification steps also result in a new line of data, but include a cross-reference to the preceding schedule line ID that was modified, which is subsequently marked as no longer being "current." Deletion steps are written similarly, except that both the new and the previous scheduling lines are no longer marked as "current." All other supplemental information is stored in linked files.

4.4.3. Instrument bias

As in all social surveys, the very act of observation changes the behaviour of the subjects being observed. In the CHASE survey, respondents recorded their own behaviours, the results of which were displayed back to them in the form of a weekly schedule. The most direct impact this has is to encourage people to schedule further while they are entering information - something they would not naturally do at the time. To reduce this bias, respondents were reminded during the upfront interview, and on the welcome screen displayed after every login, only to record those decisions already contemplated before login. Respondents were also asked not to enter information in the presence of their spouse in order to discourage communication about joint scheduling decisions.

Asking people to record their own behaviour comes with biases of its own. Scheduling decisions tend to be made all day long, whereas people recorded them in the CHASE program usually only once a day. The result is that the actual number of scheduling decisions will be under-reported, especially those of a minor nature. For example,

someone may pre-plan their lunch hour for a specified time, but the morning of, they may make plans to eat later because of work pressures, and still later, make plans to eat with someone at a specified time. Then just before lunch, they may get caught in traffic and arrive late to lunch. What is recorded in the CHASE program later that evening may only be the end result - a single modification to the pre-planned lunch hour as opposed to the three modification that occurred in reality. To reduce this bias would mean providing people with a means to record their decisions closer to when they occur - which becomes an obvious operational problem. Despite this bias, at this point in our understanding it was felt that the CHASE program still provides a level of depth beyond any previous techniques.

4.5. Survey application

Four laptop computers with external mice were used to conduct the survey. One machine was used for all interviewing while three were rotated amongst households on a weekly basis. Up-front interviews were conducted on weekends (before Sunday evening) and lasted 1.5 to 2 hours. Laptops were dropped off on Sunday evening and picked up the following Sunday evening. This time frame was chosen so that the computer could then be immediately delivered to a new household starting the following week. Because of this limitation, the Sunday evening is the only portion of the schedule that the user would not have a chance to modify for the following day.

4.5.1. Sample characteristics and study area

A total of 42 households (70 adults, 20 children) were recruited during April-Dec 1997 via advertisements on the McMaster University campus in Hamilton, Ontario. Three additional households were used solely to pretest the survey instrument. Households were offered \$50 to participate in the survey. One complete household and two adult (spouses) schedules was excluded from analysis because the data provided was of suspect quality. Four childrens' schedules also remained incomplete. This left a total of 66 adult

and 14 child schedules for analysis from 41 households. Fourteen of these households were married couples, 13 were married couples with young children aged between 2 and 10 (six with two children, seven with one), and 14 were single person households. A similar distribution of these household types is found in the population as a whole (1991 Census data for the Hamilton CMA reveals the following household proportions: married couples -24%; couples with 1 or 2 children - 29%; one or more single persons - 26%; other - 21%). Adults were either working full-time (35) or part-time (4), conducting post-graduate research full-time (19) or part-time in conjunction with other part-time work (4), or were undergraduate students (4; 3 of which had part-time jobs). The majority of households were located within two kilometres of the McMaster University campus in Hamilton, which is situated at the very tip of the western end of Lake Ontario.

The Hamilton study region consists of the cities of Hamilton and Burlington, and the towns of Dundas, Ancaster, and Waterdown. These urban areas form a rough V-shaped area surrounding the western tip of Lake Ontario and total approximately 80 square kilometres. The population in this area is approximately 600,000 people (Hamilton alone is has approximately 320,000 people).

Map booklets used by households to look up the zone number associated with activity locations consisted of a binder containing ten colour maps no larger than 22 x 28 cm, plus one regional map showing the placement and page reference for each individual map. Maps were based on standard road maps (scale of 1:25,000) that included all road/rail/bicycle paths, a wide range of landmarks, and shaded areas representing built-up, park, shopping, industrial, and institutional land-use areas. A total of 204 census tracts zones were overlaid on these maps and numbered sequentially.

4.5.2. Sample bias

Although every effort was made to obtain a variety of household types, the sample is not representative of the population. It should be stressed, however, that this first application

of the CHASE survey is experimental in nature. It can also be argued that the biases in the sample would have a greater impact upon observed activity and travel patterns, as opposed to the underlying cognitive decision process which may exhibit more stability across different samples.

4.6. Survey Results

The results presented here are intended to assess the performance of the experimental survey design. Mean values are quoted in some cases with plus or minus one standard error to indicate the degree of variability associated with each estimate.

4.6.1. Activity agenda characteristics

The activity agendas of the 41 households included a total of 1,887 activities. This represents an average of 42 activities applicable to each adult and 30 activities applicable to each child. The majority of these activities (83%) were pre-defined in the up-front interview, whereas the remainder (17%) were defined as "new" activities during the week (note however, that 55% of these "new" activities could have been coded as existing activities). By location, households indicated that 34% of activities occurred only at-home, 48% only out of the home, and 14% in- or out-of-the-home. Only 4% of activities were specified as occurring solely outside the study region. The distribution by activity group for adults ranged from 8% (work/school) to 21% (recreation/entertainment).

4.6.2. Completion times and days

On average, adults spent 16 minutes per day to complete their own schedules, and 9 minutes per day for their children. The pattern by day of the survey, as shown in Figure 4.4, shows that the first two days had longer durations, followed by fairly consistent login durations (averaging about 14 minutes per day for adults) until the weekend. The amount

Figure 4.4 Login durations and skipped days, by day of the week

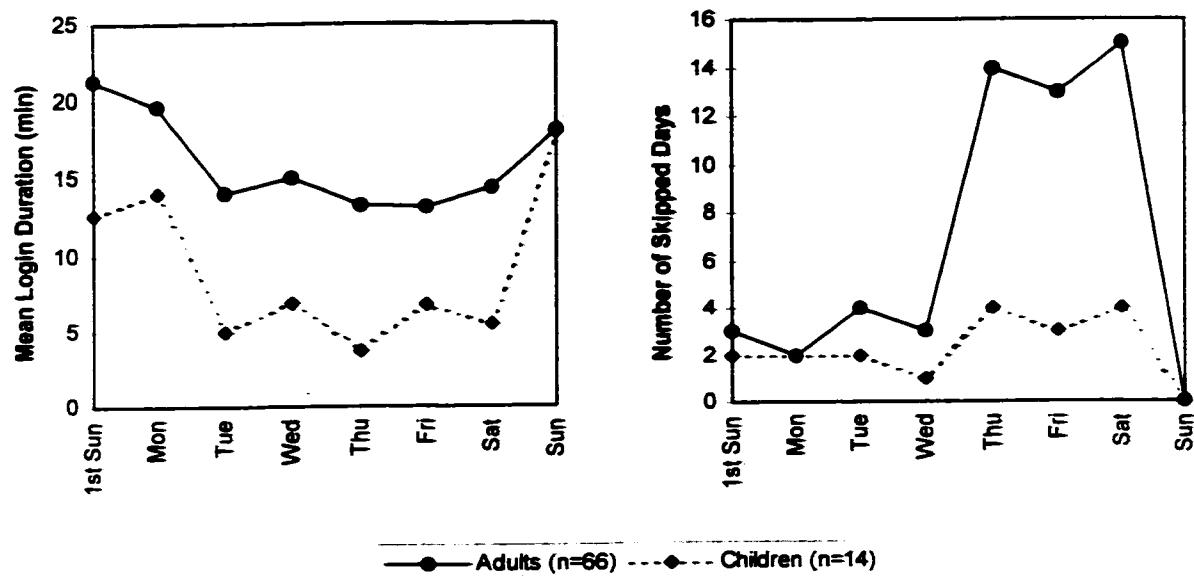
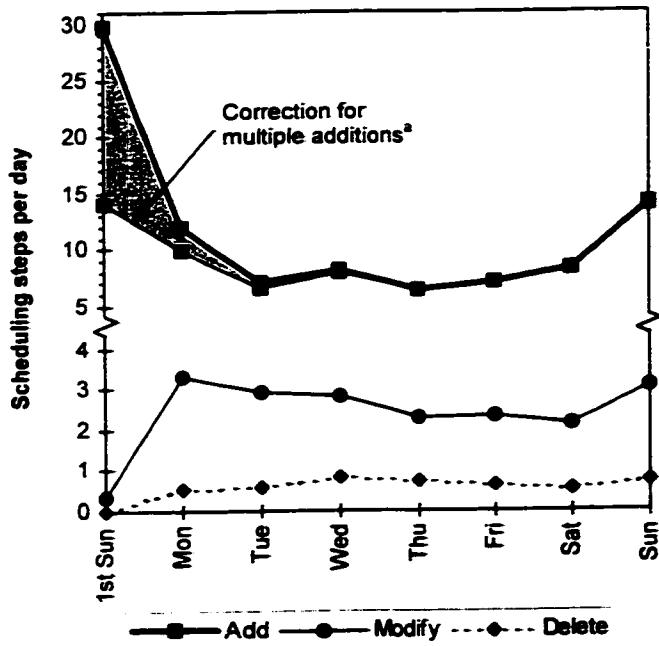


Figure 4.5 Scheduling steps per adult per day, by entry day



Note the difference in scale at the break.

^a Multi-day activity additions (e.g. add work Monday-Friday) considered as single addition decisions.

of time spent completing childrens' schedules fluctuated more, although the small sample size makes it difficult to generalize.

As seen in the second graph in Figure 4.4, household members only occasionally skipped their daily login session, mostly on or near weekends. In total, 54 of the 528 possible adult login days were skipped, or about 10% of days. After discussing this in the follow-up interview, most people indicated that they were out of the home for most of the day (or out of town) on the days they missed. For children, 18 of the total 104 scheduling days were skipped.

4.6.3. Scheduling and activity/trip patterns

Overall, the 66 adults in the sample recorded a total of 6,040 add (79%), 1,290 modify (17%), and 305 delete (4%) decisions to schedule 5,735 activities and 2,269 trips. On average, this represents 12.1 ± 0.6 add, 2.4 ± 0.1 modify, and 0.6 ± 0.1 deletion steps made to schedule 12.4 ± 0.2 activities and 4.9 ± 0.1 trips per adult per day.

The scheduling and activity rates were further investigated by day of the week to determine if any patterns were evident and if any fatigue effects could be detected (see Figure 4.5). Activity additions were found to be significantly higher at the beginning and end of the week, but remained at fairly constant levels otherwise. The increase at the beginning of the week is partially explained by high frequency of multi-day activity additions at the start of the scheduling week for such routine events as work and sleep (a correction for this is shown in the figure). The number of modifications made throughout the week were relatively more stable after the first scheduling day, although a slight decrease is detectable. The number of deletion steps varied very little after the first day.

The activity patterns to result from the daily scheduling process are shown in Figure 4.6. The decline in the overall activity rate as the week progresses is a direct result of the varying activity participation rates by type. The decrease in work/school activity and

Figure 4.6 Activities per adult per day, by day of the week and activity type

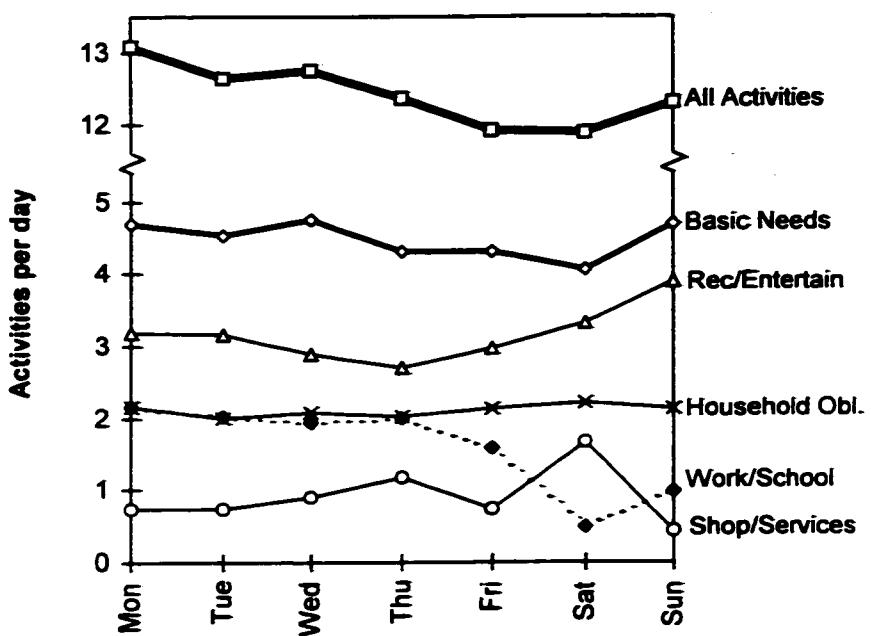
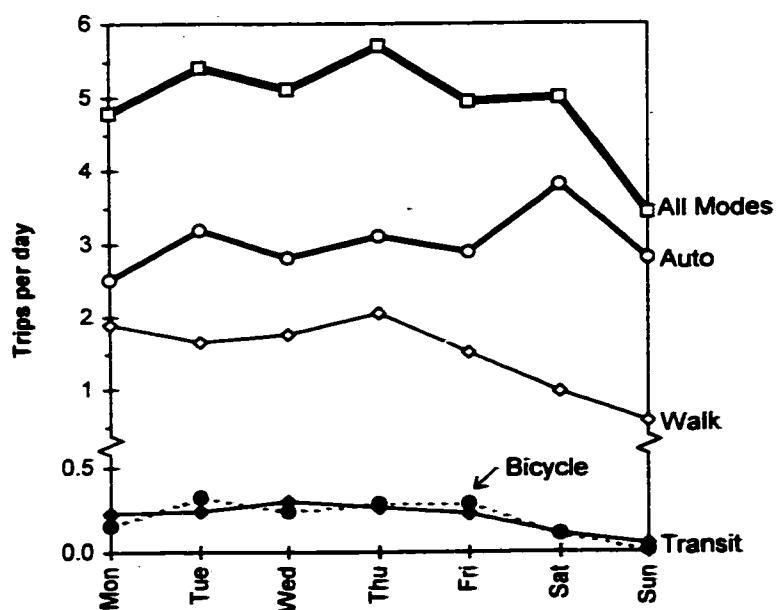


Figure 4.7 Trips per adult per day, by day of the week and mode type



Note the difference in scale at the break.

subsequent increase in recreation/entertainment/social activities and shopping on weekends is as expected, given the employment status of those in the sample. Shopping/service activity also experienced a slight peak during mid-week, associated perhaps to a slight decline in recreation/entertainment/social activities. The decline in basic needs from Thursday to Saturday is a direct result of people staying up past midnight to participate in other activities, and hence not entering a night sleep activity in the evening for that day.

A similar weekday versus weekend pattern in trip rates was also evident, as shown in Figure 4.7. Overall, trips rates fluctuate, but do not follow any significant pattern. However, when examined by mode type, a clear increase in auto trips on Saturday is traded off for reduced walk, bicycle and transit trips. Interestingly, the weekday auto trip rate of 2.9 ± 0.3 trips per adult per day is similar to the rate of 2.8 derived from the larger scale 1996 Transportation Tomorrow Survey (TTS) for persons aged 25-44 in the Hamilton region. It was expected that the auto trip rate would be higher as a result of the activity-based approach adopted in CHASE, however, the characteristics of the individuals in the small sample may be much different than the population as a whole contributing to the lower rate (e.g. a higher proportion of students, fewer auto owners).

Overall, what is most important in context of this analysis is that no unexplained gradual decline in the level of activity and trip reporting was evident, except on weekends, which are fundamentally different than weekdays in terms of trip modes and activity types. In fact, taken together, the sum total number of activities and trips reported per adult per day from Monday to Thursday were very stable at 17.9, 18.0, 17.9, and 18.1 respectively. Friday and Saturday were comparable at 16.8 and 16.9, followed by 15.7 on Sunday (the standard error for each estimate was approximately 0.7).

4.6.4. Reasons for scheduling choices

In addition to the 1,595 activity modification and deletion scheduling decisions made for tangible reasons, another 1,043 were reported by users to be the result of input errors and were subsequently excluded from analysis. It is interesting to note, however, that after the first day when input errors averaged 3.5 ± 0.6 per adult per day (representing 90% of modifications and deletions), they immediately decline to about 1.8 ± 0.4 per day (35% of all modifications and deletions) and remained at that level for the rest of the week.

For shopping activity scheduling additions, modifications and deletions, users provided more detail on the reasons for their choices. For the 294 shopping activities added, users typed in an average of 9 words explaining the choice of the particular shopping activity, 10 words explaining the timing, and 8 words explaining their location choice. For modifications (55 occurrences) and deletions (13 occurrences), users provided an average of 14 words describing why they modified/deleted the activity. More detailed content analysis of the responses to identify the opportunities and constraints that effect shopping is left for later analysis.

4.6.5. Scheduling time horizons

In total, 51% of additions, 21% of modifications, and 19% of deletions were recorded by adult household members in advance of the event actually occurring, while the remainder were recorded "after-the-fact." Because users were asked to indicate when they actually made the later decisions (see section 4.4.2), the various time horizons on which activity scheduling decisions were actually made can be examined, as in Table 4.2. Results indicated that only about one half of all activity participation decisions are planned one or more days in advance, with a substantial portion (30%) occurring spur-of-the-moment. Modifications to planned activities are made on different time horizons than additions - most notably, modifications tend to occur more spur-of-the-moment (60%). Cancelling of activities also appears to involve more advanced thought compared to modifications, as fewer are made spur-of-the-moment (41%).

Table 4.2 Adult scheduling decisions by time of occurrence

| Time Horizon | % Add (n=6040) | | |
|-----------------------------|----------------------|-------------------|------|
| | Modify (n=1290) | Delete (n=305) | |
| One or more days in advance | 52.7 | 15.5 | 18.5 |
| On the same day | 17.1 | 24.4 | 40.9 |
| Spur-of-the-moment | 30.2 | 60.1 | 40.6 |
| TOTAL | 100% | 100% | 100% |

4.7. Discussion

The results presented in this chapter are intended as a basis to assess the performance of the experimental survey design and to address future survey design issues.

The first issue to examine is the up-front interview. The interview served to adequately establish a household's weekly agenda of activities to the extent that few "new" activities needed to be defined throughout the week. Respondents also had no reservation about providing information on a large portion of in-home activities. The potential for an "explosion of information" concerning in-home activities (Stopher 1996) was minimized by the careful pre-definition of the household activity agenda, which gave the household members a "feel" for the level of detail that was to be reported during the week. The map booklet was also successful in capturing the specific zonal location of 96% of the out-of-home activities in the study area.

The daily process of logging into the CHASE program proved to capture the majority of scheduling decisions that were made before events actually occurred. Increasing the frequency of logins (say to twice daily) would only serve to marginally decrease the number of scheduling decisions recorded after-the-fact, as most of these decisions occurred close to or during execution of the event. However, increasing the frequency of logins would improve the ability to determine the exact sequence with which pre-planned, day-of and impulsive decisions are made throughout the day. The survey does fail,

however, to provide complete information about when routine events are formulated and how far in advance activities planned prior to the week were made. One possible way to improve this would be to ask users when every decision was made (not just those made after-the-fact), although this would increase the burden on respondents.

One of the primary reservations about multi-day surveys in the past has been the increased respondent burden that tends to lead to higher fatigue levels and under-reporting of trips on later days (Lawton and Pas 1996). Results presented here suggest that these effects were minimal. Scheduling additions did not decline after the initial period of scheduling, and the slight decline in modifications throughout the week could be attributable to the fact that fewer activities are present on the schedule to be modified as the week progresses. The consistent length of login durations after the initial period of scheduling also supports this contention. The relatively few skipped scheduling days on or near weekends is more reflective of the difficulty in logging into the home-based survey while travelling out of town, or perhaps the lack of regular routine that prevails during weekdays for employed persons, as opposed to any fatigue effect. Perhaps more importantly, the detailed examination of activities and trips per day showed no unexplainable drops in the amount of information provided, especially from Monday to Thursday. The variations in activities and trips on weekends appears to reflect normal changes in activity behaviour for the sample in question.

Thus, the survey appears to have minimized the potential of multi-day surveys to provide less information on subsequent days, especially the possibility of under-reporting of trips. This is likely due in part to the fact that respondents can enter information early on in the survey process about activities/trips on later days, and because the entry of information via computer is less burdensome and more intriguing than writing it out by hand. The pattern of input errors supports this contention, as after just one session, users quickly caught on to the program functionality. This was also evident during observation of users during upfront interview program demonstrations. Simply providing the user the

opportunity to enter information at their own pace anywhere on their schedule, as it occurs and is fresh in memory, is also a key factor.

The survey also appears to have minimized the burden on respondents overall, as an average of only 18 minutes per adult scheduling day was required to complete the survey. By comparison, Kalfs' (1994) electronic time-use survey required an average of 30 minutes per day over three days to record details on an average of 20.4, 19.9 and 18.2 activities and trips per day. (this survey used a "tree-structured" questionnaire program designed to prompt users for details on their activities in sequence, including two prompts for information of interest and extra questions for selected activities). In addition to taking substantially less time per day, the CHASE program did not lead to any gradual weekday reductions in the number of activities and trips reported (they remained stable at about 18.0 per day, as reported in section 4.6.3). The survey also goes beyond activity-travel patterns to capture the scheduling decisions of all household members over an entire week as they occur *in situ*. The efficiency of the CHASE program, brought on by the more familiar, flexible, and graphical design (as opposed to a sequential structured design), went a long way towards reducing the burden on respondents to obtain this detailed information.

Despite the absence of any consistent decline in information provided, patterns in data entry were evident. Most notably, activity scheduling steps and login durations were higher on the first and last day of the study period. This pattern is somewhat expected, given that the sample consist of employees, researchers and students who work predominately Monday-Friday. The first Sunday was dominated by a higher level of add entries due to the addition of routine multi-day activities (e.g. work, sleep) and other pre-planned events known at the start of the week. Modifications and deletions were naturally close to zero as events had not transpired to cause any genuine changes in a person's schedule. The most obvious explanation for the higher number of additions login durations on the final Sunday is that users needed to "catch-up" on their scheduling for the preceding two days (note that program functionality assures that users who log in

daily complete any incomplete proceeding day before continuing). This is partially because many of these "weekend" decisions were relatively more unpredictable on the user's part (and are entered after-the-fact), and because the few days that were skipped during scheduling tended to be near or on weekends.

It is clear from these results that overall, the survey design was successful in capturing the most detailed and quantitative information on the underlying scheduling process and activity patterns to date. The survey resulted in the reporting of 2.5 times the number of modifications per day compared to the previous findings of Ettema et al. (1994), suggesting that many more changes in scheduling occur in reality. Furthermore, the survey goes beyond previous data collection efforts by observing scheduling over a much longer period time and for the entire household. This allowed us to answer some fundamental questions about when activities decisions get made, when planned activities change, and when they get cancelled.

4.8. Future survey design issues

At this early stage in our understanding of the underlying activity scheduling process, there is much potential and need for further small scale survey work. Several key areas include the identification of underlying decision rules, the observation of more complex scheduling responses, and the capturing of more spatial detail on the scheduling process.

The decision rules used throughout the scheduling process, in response to both routine and new situations, are of considerable importance to eventual model development. One way to investigate decision processes is through the analysis of verbal protocols provided by subjects who are asked to vocalize their thought process either by "thinking aloud" during a problem solving exercise, or by providing a retrospective report. Svenson (1989, 67) recommends that these type of analysis be conducted in "conjunction with conventional analyses of human behaviour", such as studies of final decisions. Considering this, a clear opportunity exists to add the collection of verbal protocols to the

survey design. These should target the decisions that underlie each step in the scheduling process that are measured quantitatively (i.e. conventionally) by the CHASE program. Among the various issues that need to be overcome include the choice of when to conduct such an experiment. A retrospective approach could be used in the follow-up interview to record verbal protocol pertaining to actual decisions made throughout the week, but these would likely suffer from memory problems (Ericsson and Simon, 1984). Alternatively, household members could be asked to "think aloud" while "simulating" the completion of their weekly schedule on computer during the up-front interview, or while modifying it in response to a SR exercise in the follow-up interview. The latter approach would likely lead to a more detailed verbal record of the decision process compared to that derived from the more "routine" nature of an up-front scheduling exercise.

The CHASE survey methodology could also be extended to capture the (likely) more complex activity scheduling responses to changed circumstances or policy initiatives not necessarily encountered during everyday scheduling on any one week. The most obvious way to address this issue would be to use the CHASE program with a panel of households over a period of time including a known change (e.g. purchase a car) that presumably will affect scheduling. A second approach would involve the use of Stated Response (SR) experiments in the follow-up interview. This would provide the necessary stimulus for change, while the CHASE program would provide both a familiar interactive setting for the display of the household's previous weekly schedule and a means to record the household response via the steps taken to modify their weekly schedule. This latter approach is not only of value to the current survey design, but it helps to overcome the difficulty in designing SR experiments to capture "the added complexity of activity pattern or trip chain changes as a part of the response to situational change" (Lawton and Pas 1996, 143).

The challenge in capturing more detail on the spatial aspect of household activity scheduling comes in designing such an application without undue burden on respondents. Recently, Global Positioning System (GPS) equipment has been used to provide passive

traces of vehicle movements, coupled with basic trip information provided via a hand-held computer system (Murakami and Wagner 1997). It is feasible that such technology be used to trace all spatial movements, via a personally outfitted system. Coupling such an approach with a hand-held version of the CHASE program could bring about a maximum amount of information with a minimum of respondent burden. While the details of such an interface are complex, one approach would be to adopt a GIS platform that could both reduce and display the GPS point data in the form of continuous "routes" on a network - information that could be stored and displayed via the CHASE program that would naturally focus on the scheduling of activities at "nodes".

The benefits of computerized surveys are certainly not limited to the activity scheduling process. Applying a "scheduling" approach to alternative problems could provide several distinct advantages, particularly if longer term observation periods are desired. The most obvious application is to traditional activity and travel diary techniques. Even though the goal is strictly to obtain observed patterns, the benefits of a scheduling approach cannot be ignored - particularly in terms of the quantity and quality of information provided and the relatively low level of respondent burden. A scheduling approach could also meet the measurement challenge posed by Mokhtarian and Salomon (1997) for a more comprehensive means to examine telecommunication activities. In fact, the development of a CHASE-based telecommunication diary could be relatively straightforward task. involving the definition of different modes of communication in the household agenda that could be tied to relevant attributes for such activity. Such an approach would provide not only a deeper understanding of how telecommunication activity is related to observed travel and activity patterns, but how it is scheduled among them.

The most important practical and long term future design issue concerns the reduction of survey costs in terms of computer hardware and human resources. The most efficient approach to addressing these issues would be to conduct the survey via the internet. As home-computing and the internet become as commonplace as telephones, the possibility of obtaining a larger random sample of households increases. Conducting the CHASE program over the internet is in fact already possible under the constructs of Visual Basic.

but requires further development. This would eliminate the need for new computer hardware and improve the ability to monitor scheduling progress. However, to be completely internet dependent, the definition of the household activity agendas would have to become automated in order to eliminate the need for the upfront interview. This could be done by either defining generic household activity agendas or by querying the user to sequentially build the agenda on their own. The map booklet currently used could also be replaced by an on-line map (several of which are currently available on the internet), which could provide several advantages on its own, particularly if the user can be prompted to trace their route pattern or identify the specific location of their activities.

4.9. Conclusions

The survey approach presented in this chapter has sought to capture information on a process (activity scheduling) for which little is known, yet which represents the underlying force behind the seemingly complex activity/travel patterns exhibited in an urban environment. The pre-definition of a household agenda, coupled with a computer-based survey design, proved to be a practical approach to gathering a wealth of information on the underlying process, while minimizing the burden on respondents. Results indicated that activity scheduling involves considerable amounts of planning and revisions that occur on a variety of time horizons both before and during the execution of activities. This lends credence to the importance of observing the scheduling process *in situ*, as oppose to in a simulated setting, although the latter may be the only means of adequately gaining insights into underlying decision rules. The results also have serious implications for the design of travel demand models that are intended to forecast the impacts of recent policy initiatives that invoke a scheduling response by individual and households. Much further analysis of the survey results is warranted in order to gain an improved understanding of the activity scheduling process and to support the development of operational scheduling models.

There is also much opportunity to build upon the present survey approach to provide further insights into the scheduling process and to address alternative research problems. In the event that such an approach becomes necessary in the development of future travel demand models, the results and ideas presented here suggest that scheduling data could be obtained on a much larger scale via the internet without increasing the level of respondent burden beyond current diary techniques. Of course, many logistical concerns would need to be overcome, however, the development of computerized survey instruments of this type clearly has the potential to transform the way activity-travel behaviour data is collected and how we assess the impacts of emerging policy initiatives.

CHAPTER 5 EMPIRICAL RESULTS AND CONCEPTUAL MODEL DEVELOPMENT

Authors Note:

This chapter is reproduced from a paper titled "A Conceptual Model of the Weekly Household" presented at the *Network on European Communications and Transport Activities Research Euroconference*, Israel, April 19-25, 1998. Kay W. Axhausen (was included as a second author. Dr. Axhausen served in supervisory capacity while I was on an extended research visit with him. His address is: Institut fuer Strassenbau und Verkehrsplanung, Leopold-Franzens-Universitaet (Institute of Road and Traffic Planning, University of Innsbruck), Technikerstr. 13, Austria - 6020 Innsbruck, e-mail: k.w.axhausen@uibk.ac.at. Copyright for the paper rests with the authors. Prof. Axhausen has provided his permission to reproduce this paper in this thesis. The content of the paper has been modified slightly to minimize redundancies and to improve overall flow and continuity.

5.1. Introduction

The goal of this chapter is to describe a conceptual model of the household activity scheduling process, based in general on empirical evidence gathered using the Computerized Household Activity SchEduling (CHASE) survey. One of the main goals is to support the development of an operational scheduling model to be used within an integrated land-use and transportation model, such as that presented in section 3.2.

This chapter begins with a brief review of activity scheduling, with a focus on how activity “priority” is depicted and related to the scheduling process. A conceptual model of the household activity scheduling process is then provided. Empirical evidence derived from the survey is used to support its development. Analysis focuses on the basic process of activity scheduling as it occurs over time, including an examination of how far in advance decisions are made and how they are subsequently modified during their execution. The various modelling structures and decision rules incorporated in the conceptual framework are outlined and discussed.

5.2. Activity Scheduling and “Priority”

Over the past several decades, a strong argument has made for the use of an activity-based approach to improve travel demand modelling in an effort to better forecast the impacts of emerging transportation policies. The focus of activity-based models has been on replicating entire activity patterns or “schedules.” Progress using traditional modelling techniques has been slow, and can be criticized for their behavioural and computational shortcomings. Part of the problem is the ignorance of the reality that complex activity-travel pattern are really just the “outcomes” or “symptoms” of a much more fundamental scheduling decision making “process” that is simply not captured by existing models. Because of this, existing models are simply incapable of address the impacts of emerging policies which inherently invoke a rescheduling response, which is dependent on an underlying process of activity scheduling.

In response to these criticisms, recent modelling efforts have attempted to more explicitly replicate the sequencing of decisions made during the scheduling process, under alternative behavioural structures, as discussed in section 2.4. Although the advance of these “sequential decision process” models is a relatively recent initiative, several authors have noted that a key missing ingredient is a lack of a “unifying” framework (Ettema and Timmermans 1997; Recker 1995 - see also section 6.4). Perhaps more important, has been the lack of empirical evidence to support and guide their development. The conceptual model presented in this chapter addresses both these issues directly.

One important theme discussed throughout the scheduling literature is the notion of activity “priority.” In the early work of Cullen and Godson (1975) activities were viewed as being prioritized according to their importance, frequency, involvement of others etc.. and also constrained due to time, money, transport modes available, opening hours at particular points in time. In terms of scheduling, they stressed the importance of different degrees of “flexibility” associated with activities and how they effect scheduling - wherein an individual’s schedule for a day is formed by articulating activities with less fixitity around those activities with high spatial or temporal fixitity or both. with these latter activities acting as “pegs” in daily activity scheduling. Kitamura (1983) was able to examine the sequencing of observed activities in trip chaining compared to their fixities, finding a tendency for activities of less flexibility (i.e. more spatial or temporal fixity) such as serve passenger, school and work, to be pursued in a trip chain before more flexible activities, such as social-recreation and shopping.

In the SCHEDULER model (Axhausen and Gärling 1992; Gärling et al. 1994a/b). it is assumed that a set of activities is chosen from the individual’s memory and a selection made in order of priority - “for most people the selected activities are likely to consist of a few with high priorities to be performed during the day” (Axhausen and Gärling 1992, 331). Once a schedule is formed with the highest priority activities, attempts may be made to find less prioritized activities in the long-term calendar that fit into open time

slots. Perhaps most important, it is recognized that priorities are generally enduring but change depending on changes in saliency of different goals.

This research suggests that priority has a dynamic quality, wherein activities of different types have priorities that change over time in response to different situations. It has also been suggested that activity priority in scheduling is related to the relative flexibility and fixity of activities, wherein inflexible and highly fixed activities are chosen first for scheduling, followed by more flexibly and less fixed activities. Clearly, any model of activity scheduling should consider a measure of activity priority, in order to account for the variety and complexity of the decisions made during the scheduling process.

5.3. Conceptual Model Development

The data used to support the conceptual model presented in this chapter is based on a subsample of 55 of the 66 adults from the CHASE survey, as described in the previous chapter. Eleven adults were excluded from the analysis either because they had skipped the first Sunday of data entry (a crucial day in terms of the analysis), or had skipped more than 2 days in a row of data collection.

The weekly household activity scheduling process model presented below is supported by empirical analysis and by various flow diagrams that provide a visual means to connect the various components of the model (see Figure 5.1 - Figure 5.3). The model was originally designed by the author during March and April 1998, with subsequent "fine-tuning" and modification resulting from collaborative discussions with Tommy Gärling (Dept. of Psychology, Göteborg University, Sweden), Reginald Golledge (Dept. of Geography, University of California, Santa Barbara), and Kay Axhausen (Institute of Road and Traffic Planning, University of Innsbruck, Austria). Although the ultimate goal is to implement the model as a computer algorithm, this is not necessarily a binding restriction on the design, which represents a long-term development program. Note that *italicized* terms in the text refer directly to components of the model in the figures.

Figure 5.1 Weekly household activity scheduling process model

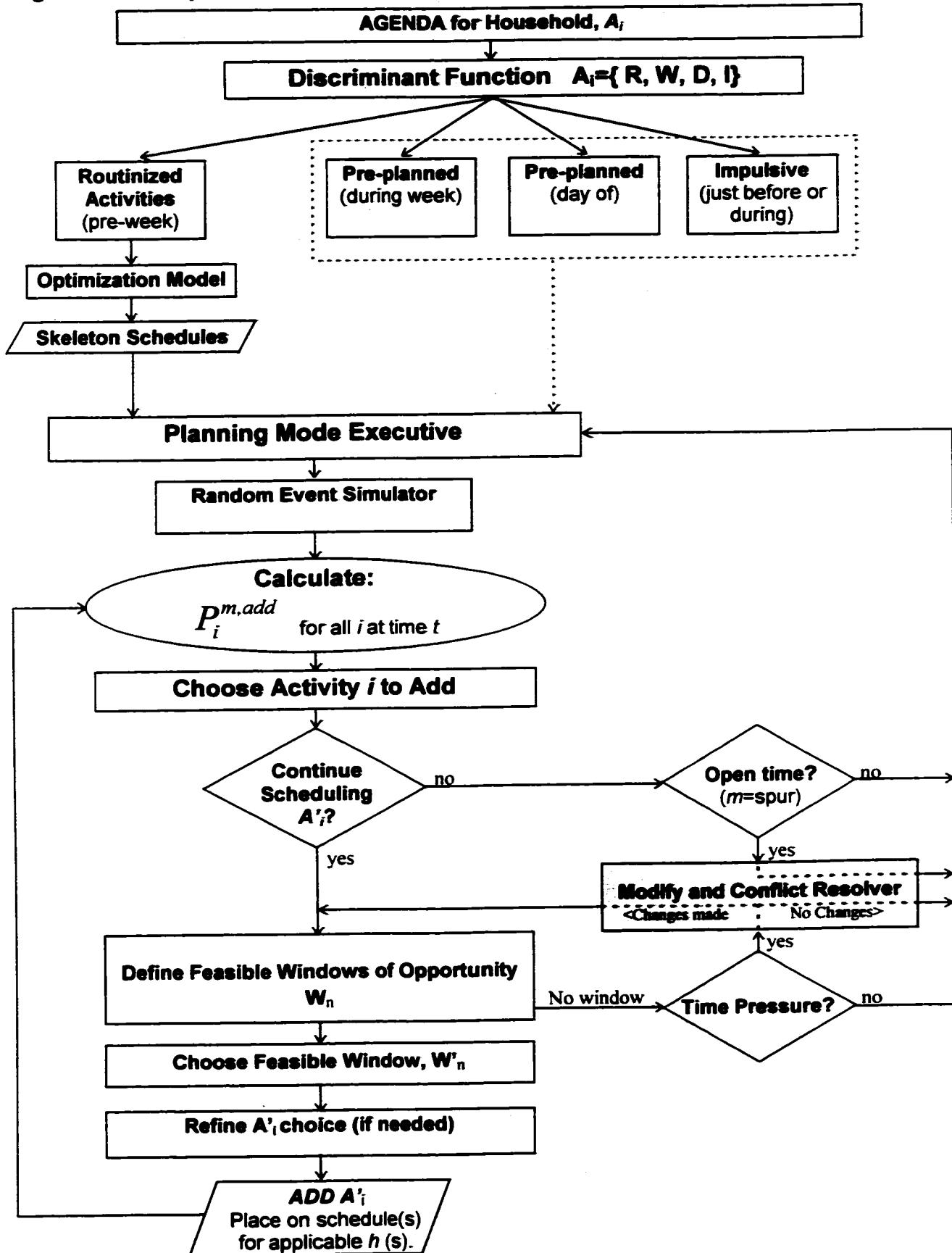


Figure 5.2 Modify and conflict resolver sub-model

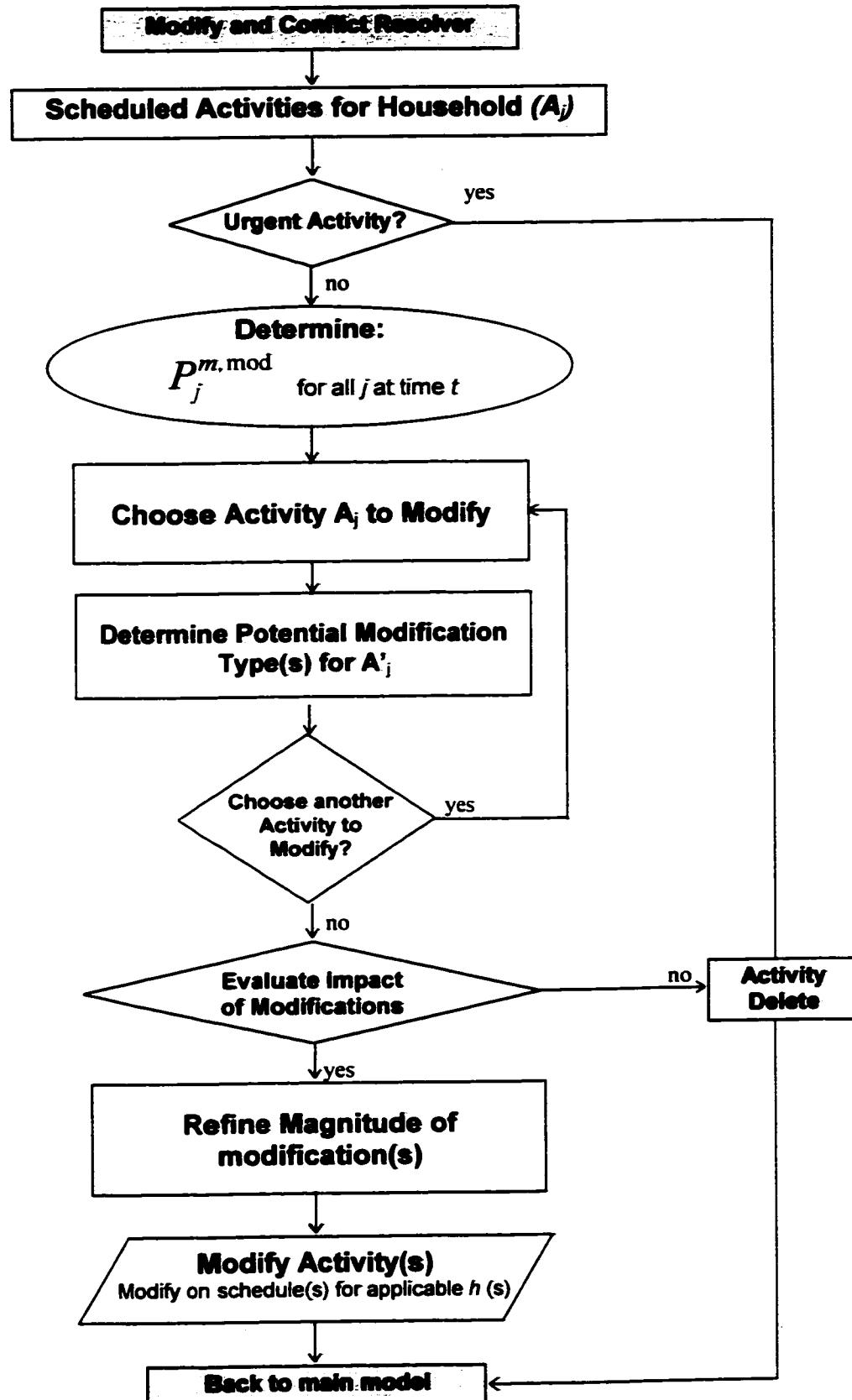
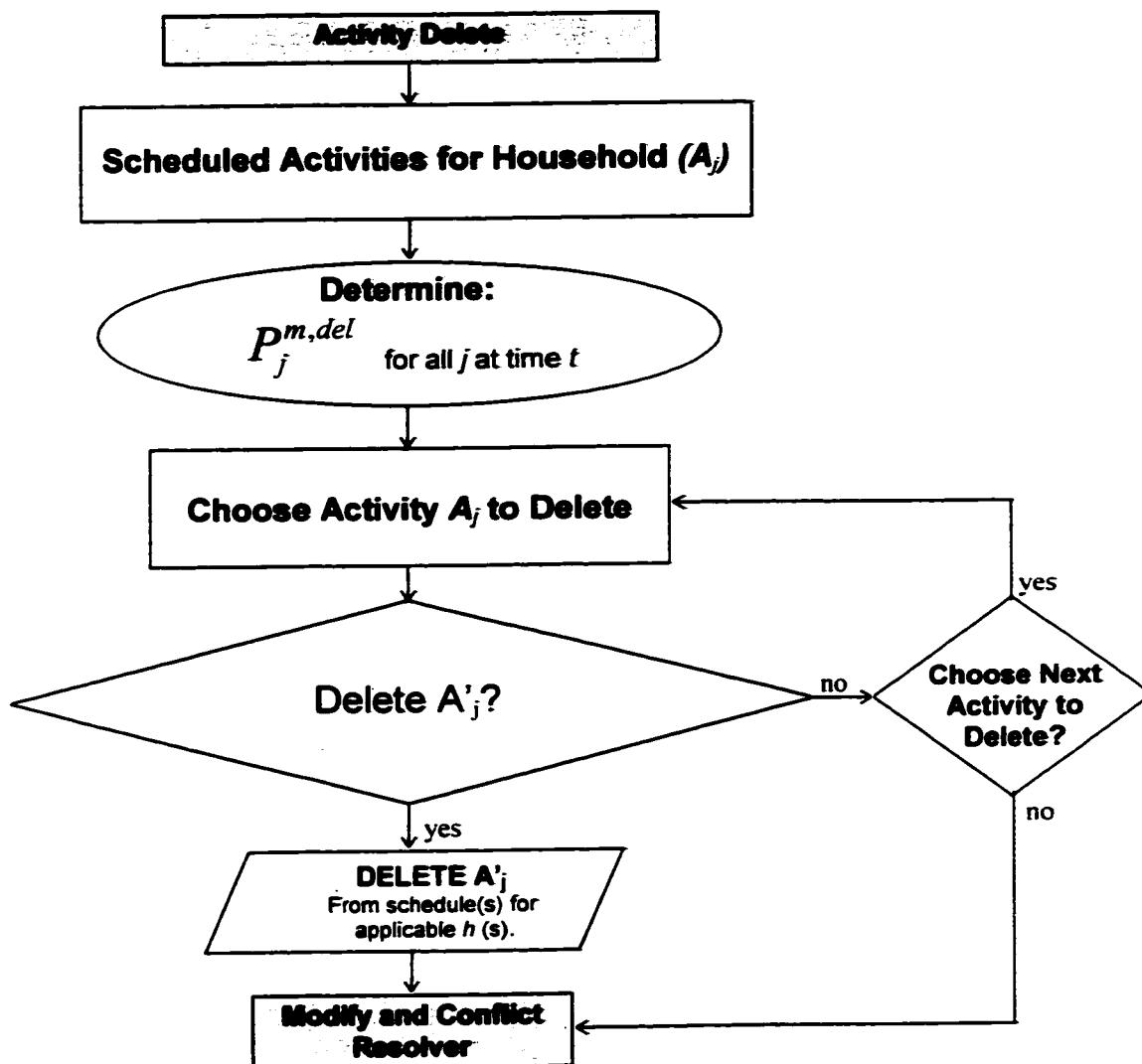


Figure 5.3 Delete sub-model



Foremost, it should be stressed that activity scheduling is a behaviourally complex process that spans across many time horizons and individuals. This has not only required innovative observational tools, but also complex modelling structures. However, the trade-off comes in an improved understanding of and ability to forecast complex travel behaviour that would not be possible without a knowledge of the underlying scheduling process that gives rise to this complexity. The reader is thus encouraged to review the conceptual model from start to finish, as any one component in isolation cannot be understood without examining the whole.

5.3.1. Basic structure

To assist with an understanding of the overall model design, a summary of its basic structure is provided here. In general, the model attempts to dynamically replicate the scheduling process as it occurs over time through the use of various modelling constructs and decisions rules run in sequence. It begins by taking a household's *weekly agenda* of activities, and establishes a set of *routine activities* and a *skeleton schedule* for the week. This is followed by scheduling decisions (additions, modifications, deletions) made during execution of the schedule. These include pre-planned decisions, decisions made the day-of, impulsive decisions, and decisions that result from random events. A *Planning Mode Executive* controls the flow of decisions, which inherently involves the movement through time. Decisions about what activities to schedule at any given moment are determined by the priority of activities on the agenda. Priority is determined as a function of static activity attributes from the agenda and dynamic aspects of the schedule at the particular moment. Once an activity is chosen for scheduling, a feasible window of time is chosen, and refinements in the activity made before it is placed on the schedule for a particular household member(s). Refinements include any needed duration, timing, location, or mode choices. In many cases, these refinements will be highly constrained given the relative fixity of the activity in time and space and/or the constrained nature of the circumstances, making these choices rather straightforward.

Conflicts that arise due to random events or time pressures, or cases where activities may be extended to fill time, are handled by the *Modify and Conflict Resolver*. This procedure takes the previously scheduled activities and determines those most likely to be modified. A set of possible modifications is determined, and a choice is made as to which ones to implement and to what extent. If the (set of) modification(s) does not meet the requirements of solving a conflict, then the *deletion of an activity* is considered. The procedure for deletion is similar to modification, except that the activity attempting to be scheduled is compared directly to the revised priority of the activity chosen for potential deletion. If none of the deletions is justifiable, then the model reverts back to the beginning, and the originating activity is left unscheduled. If an activity is deleted, control reverts back to scheduling to assess the size of the window feasibility.

The following sections describe the model in more detail.

5.3.2. *The household activity agenda*

On a fundamental level, activity scheduling reflects personal and household related basic human needs constrained in time, capability, and in space by the urban environment. These needs can be viewed as manifested in a household's activity *agenda* which represents the initial input to the main model as shown in Figure 5.1. A simplified example weekly agenda is provided in Table 5.1. The agenda consists of a list of uniquely defined activities that a household could potentially perform, including highly infrequent activities that are only occasionally performed to fill up free time. Each activity on the agenda is viewed as having a unique set of (perceived) attributes that affect their scheduling, including duration (min, max, mean), frequency, time limits, involved persons, costs, perceived locations, etc. If an activity constitutes several unique subtypes

Table 5.1 A simplified household weekly agenda example

| Activity, Ai | Applicable Household members | General location | Attributes | | |
|----------------|------------------------------|-------------------|-----------------|------------------|-----------------------|
| | | | Duration (mean) | Freq. (per week) | # Perceived locations |
| Work | Male head | home | 2 | 2 | 1 |
| Work | Male head | out-of-home | 8 | 5 | 1 |
| School | Child 1 | out-of-home | 8 | 5 | 1 |
| Grocery Shop | Female head | out-of-home | 1 | 3 | 12 |
| Grocery Shop | Male and female | out-of-home | 2 | 1 | 12 |
| Active Sport | Male | out-of-home | 1 | 1 | 2 |
| Activity Sport | Male and female | out-of-home | 2 | 1 | 1 |
| Chauffeuring | Male and female | out-of-home | .5 | 5 | 1 |
| Socializing | Male and female | in or out-of-home | 3 | 2 | 10 |
| etc. | | | | | |

that differ substantially in their attributes then they should be defined separately (e.g. work at the office, work-at-home; minor grocery shopping, major grocery shopping, clothing shopping). What is key to the success of the scheduling model is not the activity types as defined by traditional means (e.g. work, school, shopping, mandatory, discretionary etc.), but rather their salient attributes that serve to explain how they are scheduled in the context of an on-going process. This gives the model the ability to address any number of individuals/household types, regardless of their employment status or preferences.

Although the derivation of household activity agendas are of considerable interest on their own, they are taken as exogenous to the process of scheduling in the short term. It is assumed that household agendas in a given urban area can be separately simulated or otherwise derived at regular time intervals as required by the scheduling model. The process by which these agendas are derived is an important component of the overall model, but is beyond the scope of this thesis. Our suggestion at the moment is that the agendas need to be based on key socio-demographic characteristics of the household, household resources and constraints, and environmental factors. Attributes such as duration and frequency could be based on existing activity diary data, whereas the set of perceived locations would need to be simulated with a cognitive model using inputs such as the location and length of stay at current residences and employment locations.

Incorporating the learning of new locations, new activity types, and the modification of activity attributes over time would be an important aspect of this model. An argument for linkages between the agenda and scheduling via learning processes in the long term is an important future consideration (e.g. as you execute your schedule you become aware of new locations for activities that should be added to the agenda).

5.3.3. Routine weekly activity “Skeleton”

Empirical evidence derived from the CHASE survey shows that households begin the week with a firmly established set of *routine weekly activities*. The number of scheduling steps made by adults per day, as displayed in Figure 4.5, shows that an average of 34 activity additions per adult are made on the first Sunday for the week to follow. Figure 5.4 shows for what days these additions were made for (looking only at the “additions” made on the “First Sunday”), indicating that these activities make up about 45% of the activities that take place on weekdays, and about 20% of those that take place on the weekend. The remainder of activities are planned as the weekly schedule is executed (discussed in the next section).

Of the decisions made on the first Sunday, a full 70% were part of multi-day entries (the activity was added on 2 or more days simultaneously), with 80% of these consisting of entries across 4+ days. Comparatively, on Monday, only 21% additions were part of multi-day entries, followed by 2%, 6% and no more than 1% on remaining days of the week. Such entries are indicative of highly frequent and routine activities, as suggested.

Further evidence suggests that other key factors differentiate the activities pre-planned on the first Sunday besides their routine nature. First, they tend to be of a longer duration than subsequent days averaging 208 minutes long for adults in the sample. This was significantly higher than activity durations that were pre-planned one or more days in advance during the week (110 minutes), planned the day of (79 minutes) and planned impulsively (72 minutes), as confirmed by two tailed t-tests ($p < 0.0001$ in all three cases).

A rough examination of the activity types scheduled on the first Sundays also suggests that more highly fixed spatio-temporal activities tend to be pre-planned before the week starts (e.g. work, chauffeuring, sleeping, sports events). Further empirical analysis using an appropriate discriminant analysis technique will be performed to further differentiate these types of activities from other activities on their agenda based on their key attributes, including duration, frequency, and indicator variables of temporal and spatial fixitivity (see also Table 5.2 for further details on these variables).

It is reasonable to assume that these routinized activities pre-planned before the week starts are the result of a long-term thinking and experimentation process, and thus represent an “optimized” pattern or “skeletal” basis around which other scheduling decisions are made during the week. Given this, it is reasonable to assume that an *optimization model* would be appropriate to derive the *weekly skeleton schedules*. This model would use the discriminated activities as input, which represent a much more limited choice set of activities that more closely match the assumptions to which these models are based (i.e. that activities are scheduled in an optimal way). These techniques include those that start by generating all possible feasible combinations of skeleton structures and choosing the most optimal of the set (e.g. Recker 1995). The details of this model form, and how it would deal with a weekly optimization problem, are left as a long term research goal.

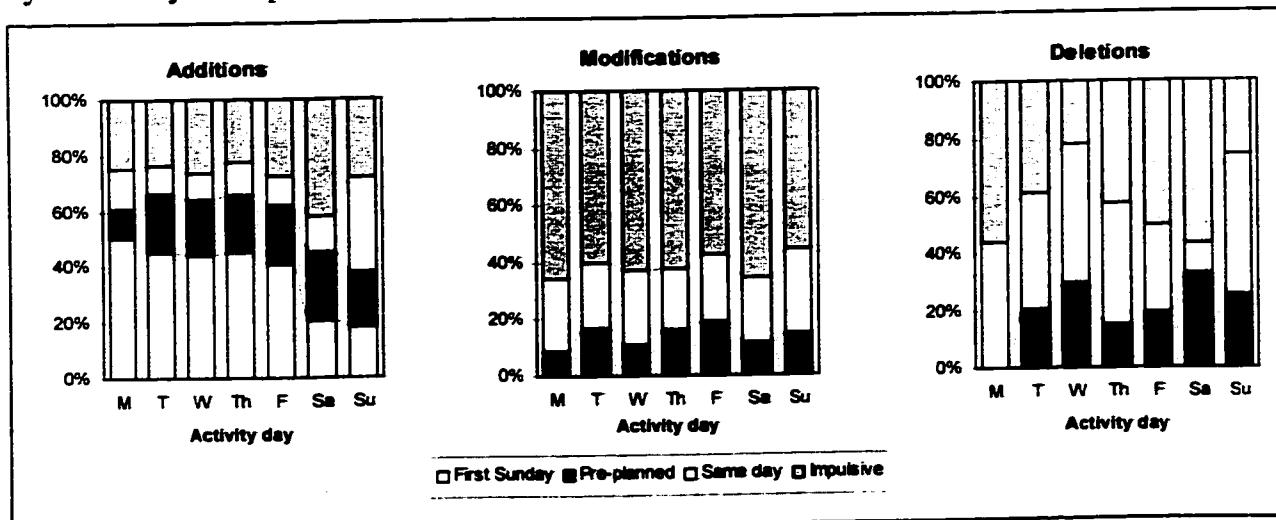
5.3.4. Weekly scheduling process

The remainder of this chapter focuses on the more deliberate scheduling decisions made during the week as the schedule is executed. Figure 4.5 from Chapter 4 showed that after the first Sunday, adults make about 8 additions, 2 modifications, and 1 deletion per day during the execution of their schedule over the course of the week. These steps were taken to complete their schedules, which include an average of 12.4 activities and 4.9 trips per adult per day.

Figure 5.4 shows that the scheduling decisions applicable to each day are made on various time horizons. Outside of the routine activity additions made on the first Sunday (38% overall), a substantial proportion of additions are scheduled impulsively just before execution (28% overall), on the same day (20% overall), or are planned one or more days in advance (15% overall). The amount of pre-planning differs by day of the week. Most notably, more impulsive additions decisions occur on Saturdays, whereas more "day of" decisions are made on Sundays.

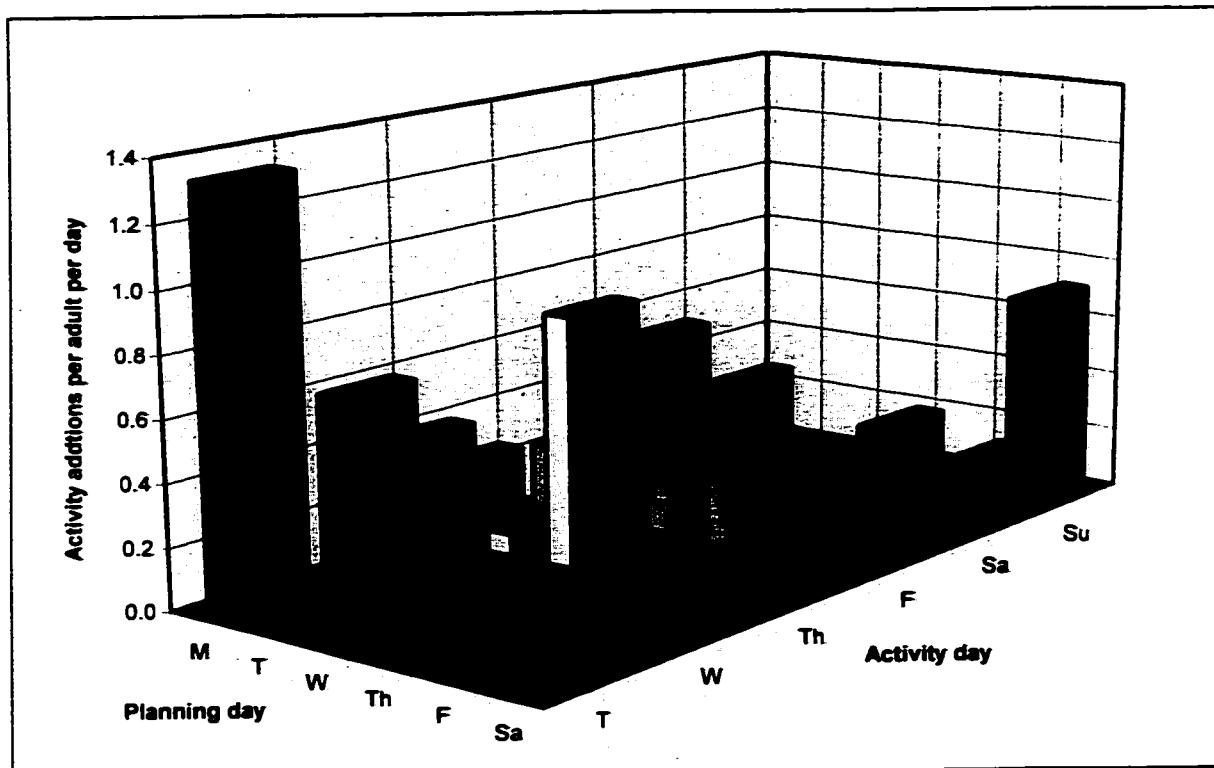
Modification decisions exhibit a significantly different pattern from additions. The vast majority tend to be made impulsively (62% overall), compared to on the same day (24% overall) and planned more than a day in advance (14% overall). This pattern is fairly consistent across the days of the week, as shown in Figure 5.4. Compared to modifications, more advanced thought appears to be put into deletions as a higher proportion are made on the same day (38% overall) and lower proportion made impulsively (41% overall).

Figure 5.4 The proportion of additions, modifications, and deletions made for each day[†]. by when they were planned



[†] Note how this differs from Figure 4.5 which shows the number of additions, modification and deletion steps by entry day.

Figure 5.5 Pre-planned[†] activities (exclusive of the first Sunday) by planning day and activity day



[†]These are restricted to those activities actually entered more than a day before the event occurred and that were not part of a multi-day entry.

Figure 5.5 shows in three dimensions, the distribution of activity additions planned on one day, by the activity day they are planning for (exclusive the first Sunday, which is shown in Figure 5.4). It clearly shows that in addition to pre-planning for the next day (62% overall) people also reach out and make additions on future days as the week progresses (38% overall), in an opportunistic fashion.

This evidence strongly suggests that activity scheduling is a dynamic process reflecting continued addition and revisions to a schedule over time. Scheduling represents a mix of routine followed by continued pre-planning and impulsive decisions made over the course of the week. This differs substantially from the notion that activities are planned and carried out in sequence all at once. Thus, if the goal is to develop a behaviourally sound

model then a dynamic model is needed - one that can simulate the fundamentally different types of decisions that occur over time.

The conceptual model presented in Figure 5.1 to Figure 5.3 attempts to account for the complexities of the scheduling process with a mix of empirically derived functions and a series of decision rules that serve to sequentially simulate the construction of activity schedules over time. Activity scheduling decisions including additions, modifications and deletions to each household members schedule, simultaneously implemented as a series of pre-planned and impulsive decisions. At the heart of the conceptual model is a "momentaneous scheduling priority" function that drives that selection and inherent sequencing of activity choices at each stage in the process.

5.3.4.1.Momentaneous priority

Research to date thus suggests that a notion of "priority" is an important dimension in the construction of sequential scheduling models, particularly as a determinant for the sequencing and choice of activities. The current model proposes that much of the complexity of the scheduling decision process is related to the changing level of priority associated with activities that household members have on their agenda at any one moment in space and time. Estimating a modelling function of priority is at the heart of the conceptual model.

Although activity "priority" has been proposed as the determining factor in the choice of activities to schedule in previous models (e.g. SCHEDULER), it has remained a difficult attribute to operationalize because of its highly subjective and dynamic nature. Asking people to assess the priority of a list of activities is difficult not only because of a definition problem (how the researcher defines/explains what constitutes high versus low priority will largely effect the results), but because the priority of an activity depends on the situation at hand. Any one static assessment of the priority of activities will be inadequate to deal with all possible situations that arise during the scheduling process.

This stresses the importance of differentiating between an activity's "general/overall" level of priority (all things being equal) versus its "scheduling" priority (which depends on the situation). For instance, a person may tell you that being at home with their children is generally a higher priority than being at the pub with friends. However, under the right circumstances (e.g. just spent the whole day with your children, they are now sleeping, and the person hasn't been to the pub in a while), you may find this person at the pub. Any measure of priority must be able to account for these observed differences.

If "scheduling priority" determines the choice of activities in a given situation, then any measures of such requires observations of activity scheduling choices under a range of situations - precisely what the CHASE survey is designed to accomplish. The following modelling function of "momentaneous scheduling priority" is thus proposed for development:

$$P_i^{m,s} = f(X_i, S'_i, M'_i, H, E) \quad [1]$$

Where:

- P_i : Priority of activity i in scheduling mode m for scheduling operation s .
- m : Scheduling mode - pre-plan, day-of, and impulsive planning
- s : Scheduling operation - add, modify, delete
- X_i : Attributes of activity i in household agenda
- S'_i : Scheduling state characteristics of activity i at time t .
- M'_i : Spatial possibilities for activity i at location l
- H : Household characteristics
- E : Environmental characteristics

At any moment in the scheduling process over the course of a week, the priority of activities in the household agenda can be evaluated in terms of their relative priority, given values for the attributes in the model. Separate models would be constructed for

the priority of activities for addition, modification or deletion to the schedule (represented by the subscript s). The form of the model is also proposed to depend on the mode (m) of scheduling (pre-planning, day-of planning, impulsive decisions).

The explanatory variables in the $P_i^{m,s}$ model include a range of static variables (A_i , H, E), and dynamic scheduling state variables (S_i^t, M_i^t) that continuously change over time (t) and space (I). The scheduling state variables are what makes this model unique to date, and give it the power to explain the apparent behavioural complexities of observed activity-travel patterns. The range of potential explanatory variables are outlined in Table 5.2. Of particular note are the history and future dependent variables that account for the likelihood that activities that have taken place recently relative to their frequency, or that have been pre-planned for a future time, would have lower priorities. Also, the temporal and spatial fixity, and flexibility of activities is captured by a combination of activity and scheduling attributes. Many other variables are included to account for the role habits, travel times, joint activities, and attributes of alternative members schedules that may influence the priority of activities. Other potential time widows for earlier or later time periods are considered in a sense that the priority of a given activity for the given time slot is higher/lower depending on how closely it matches the desired frequency, duration, and timing of the activity in the scheduling space closer than any future time slot, available or not.

The exact form of the $P_i^{m,s}$ model and its estimation would require considerable exploration. If one considers the priority of an activity to be related to the concept of expected "utility" to be derived from the participation in an activity, then $P_i^{m,s}$ could be estimated as a traditional multinomial logit model. The generalized cost, or "utility" (V_i), could then be used as a measure of its priority. Calibrating the model could be performed using carefully selected observations from the CHASE data.

Table 5.2 Potential explanatory variables in the priority model

| Characteristics/ Attributes | Indicator variable | Decision, <i>s</i> | | |
|---|---|--------------------|-----|-----|
| | | Add | Mod | Del |
| Attributes of Activities on agenda X_i | | | | |
| Time window (feasible) | earliest start - latest end time feasible days | X | X | X |
| Temporal flexibility | (min duration)/(time window) (frequency per week)/(# days occur on per week) weekday/weekend dummy (days it occurs per week)/(#days it could occur on) | X | X | X |
| Duration | min, max, mean | X | X | X |
| Frequency | Days between performance (observed or stated) | X | X | X |
| Activity direct costs | {yes/no} | X | X | X |
| Joint scheduling | {joint mandatory, joint optional, individual} | X | X | X |
| Activity type by activity motivation/need | {physiological, institutional, social, psychological, household obligation, household task} | X | X | X |
| Scheduling State at time t, S' | | | | |
| Schedule flexibility/window | (Min A_i duration)/(maximum feasible window size open on schedule) | X | X | X |
| Alternate household member flexibility | as above, for alternative household member | X | X | X |
| Activity history | (Days since last performance of A_i)/(A_i frequency)) Duration of last performance/(mean duration) Number of activities (of same basic type) already scheduled for day or previous week | X | X | X |
| Activity future | { A_i not scheduled, scheduled} Days between last performance of A_i and scheduled performance)/(A_i frequency) Number of activities (of same basic type) on schedule for future day or for week | X | X | X |
| Activity habit history | High frequency of performed before/after other activity | X | | |
| Travel time | Total travel time for day | | | |
| Spatial Attributes, M' | | | | |
| Spatial fixity | # perceived (out-of-home) locations (in vicinity; that are feasible) {only at home, only one out-of-home; in or out of home} | X | X | X |
| Perceived distance | Distance to nearest perceived location for A_i | X | X | X |
| Travel time | Perceived travel time to nearest activity location by fastest available mode for A_i | X | X | X |
| Scheduled activity attributes | Perceived distance in space between nearest activity before/after desired activity A_i | X | | |
| Environmental Attributes, E | | | | |
| Opening hours | opening hour restrictions for A_i | X | X | X |
| Location attributes | Attraction variables for locations for participating in A_i | | X | X |

The behavioural power of the $P^{m,s}$ model is threefold. First, because the model is sequential in nature, the scheduling state variables can be reassessed at each time step in the model after each decision. Certain activities will have a tendency to jump up in priority depending on the circumstances. This allows infrequent, discretionary, or otherwise unusual activities to emerge depending on the situation, contributing to complex activity-travel patterns. For instance, although a person may have a high priority job to get to at 9:00 a.m. and possibly some high priority shopping that needs to get done before the end of the day, s/he may be sitting in a coffee shop at 8:30 located on the way to work. This may be because the person was faced with a short window of opportunity for the activity after having already dropped the children off to school at 8:15 and a close location, allowing for an apparent flexible activity to emerge (coffee) as high priority. Shopping was assigned a low priority at that moment because of the short time window and because few perceived locations were available in the vicinity to shop at.

Second, it simplifies the activity scheduling decisions - empirical evidence suggests that those decisions made before the week commences (on the first Sunday) tend to be highly routine, making the decision about their exact timing and location a relatively straightforward task. Those activities that are more flexible tend to be scheduled within an already constrained spatio-temporal environment limiting the specific choices of location, start-end times, duration, household members involved, and mode choices.

Third, the $P^{m,s}$ model indirectly contributes to the sequencing of activities in terms of the order in which decisions are made (pre-planned vs. impulsive), and the order in execution. This sequencing is not an explicit aspect of the model, but rather reflects the fact that impulsive decisions and, to a lesser extent, day-of and pre-planned decisions, are made in light of the open time slots in the skeleton schedule established on the first Sunday. This implies a certain order among existing activities on a weekly, daily or time window scale.

5.3.4.2. Sequential decision structure

Once the mode of scheduling is set by the *Planning Mode Executive* (described in more detail in the section to follow), the model uses the same basic set of sequential decisions to handle random events, add high priority activities to the schedule depending on the scheduling mode, and invoke modifications and deletions where necessary.

Ignoring for the moment random events, the choice of activity to add (*Choose A_i to Add*) is based on the momentaneous scheduling priority of all applicable activities on the agenda $P_i^{m.add}$ for that particular mode of scheduling. Some practical rules may also be used to limit the choice set in certain circumstances or increase the priority of certain activities directly. The exact method would depend upon the extent to which $P_i^{m.add}$ accounts for these practical constraints via the inclusion of appropriate variables. For instance, the maximum size of any feasible time windows ($\max W_n$) on a schedule relative to the minimum duration of an activity ($\min d_i$) should presumably influence its priority for scheduling. An appropriate variable for investigation might be:

$$\frac{\min d_i}{\max W_n}$$

The smaller this is, the higher the priority should be (negative coefficient). An example of a practical rule to exclude certain activities for choice is as follows:

$$\text{IF } \frac{\min d_i + \min t_i}{\max W_n} > [\beta] \text{ THEN } [P_i^{m.add} = 0]$$

This rule operates by assigning a zero priority to activities that are simply too long to fit in a given time window, considering any travel time to it (t_i). The threshold value of β should be larger than 1 and could be determined empirically, or simply set to a pre-specified value.

Still further rules could be incorporated before the final choice to artificially increase the priority of certain activities (A_i) when dependent/related activities (A_j) have already been scheduled. For example, an out-of-home recreation activity for parents may first depend on a chauffeuring activity for the children (to a babysitter), or a socializing activity (going to the pub) may habitually follow the playing of a sporting event. These would, of course, depend on a well-defined agenda that establishes these dependencies.

Once the momentaneous priority is determined and constraints met, the exact choice of activity to schedule is made based on an appropriate decision rule (*Choose A_i to Add*). The simplest rule would be to select the activity with the highest priority. Alternatively, the choice could be made according to Monte Carlo style simulation procedure. Selection of activities to schedule in this fashion proceeds until a threshold level of priority for the given mode m (*Continue Scheduling A_i ?*). The decision rule used at this stage could be of the form:

$$\text{IF } P_i^{m.add} > (\alpha_m) \text{ THEN [continue]} \quad [2]$$

where the α_m threshold value is determined empirically for the given mode of scheduling (α_m would be relatively higher during pre-planning compared to impulsive planning, reflecting the notion that only high priority activities are pre-planned). This rule implies that only the priority of the current activity in question is considered in the decision. An alternative would be to base the decision on the sum of priorities of activities on the agenda, replacing the left side of the above equation with $\sum_i P_i^{m.add}$. This would reflect the aggregate amount of pressure the particular person is under to continue scheduling activities. If many of the activities that are typically pre-planned are not yet placed on the schedule, then the sum of activity would be high, invoking further scheduling until the threshold level is reached.

Only once an activity is chosen (A'_i) and a decision to continue is reached, are more precise decisions about scheduling made. First, *Feasible Windows of Opportunity* (W_n), must be identified. These are defined as open time periods of length at least equal to the minimum duration of the given activity that fall within the feasible hours for the given activity. Feasible hours are defined by the opening hours of any required facilities (if applicable) and any preferences of the individual reflected in the agenda (e.g. a preference for shopping only on weekends).

In the event more than one window is feasible, another rule is needed to *Choose the Feasible Window* (note: in impulsive scheduling mode, only one window of time is considered, so no choice is involved. However, the priority of an activity for scheduling in the one window may be affected by the number of other feasible windows that exist in future time periods). Given that it has already been established that the activity is of high priority, it may suffice to use a simple rule that the first available window in time be chosen. However, in some cases, other attributes of the windows may be considered such as their length, or the attributes of activities that bound the window. It may be appropriate to develop a feasible window choice model, using attributes of the windows and the activity as determining factors.

Having chosen a high priority activity (A'_i) and identified a window of opportunity (W_n) greatly constrains the remaining choices to a specific spatial-temporal setting. These include the planned choices of activity duration, location, start and end times, mode of travel and involved persons (*Refine A'_i Choice*). In many cases, these choices are already constrained enough that only one is feasible, and in essence, no choice is needed. This would be the case for many pre-planned activities that are highly fixed in time and space and involved persons, and for activities impulsively planned within highly constrained situations.

For those activities where a choice on one or more dimensions does exist, more definitive rules would be needed to make the refinement choices. Rules would be needed to

identify what the alternatives are for each dimension, and second, how the choice is made among alternatives. The scheduling model would provide a means to do the former - i.e. providing a means to limit the range of feasible alternatives to a manageable level, given the spatio-temporal setting of the decision and attributes of other activities in the vicinity. In the case of activity duration, it would naturally be constrained by the length of the time window available less any necessary travel time, and the maximum and minimum duration for the activity. An aggregate measure of the number and magnitude of other high priority activities that may need to be scheduled as of yet may also be used to constrain the upper bound on duration (e.g. $\sum_t P_t^{m,add}$). The location will already be constrained by the perceived location choice set in the agenda and travel time relative to where they are in space and where they may have planned to be at the end of the activity. Practical location constraints related to the household (e.g. at least one parent at home with children in the evening) could also be formed. The modes available would be limited to what is currently available and the implications for travel time. The start time would likely be given from the end time of the preceding activity, whereas the end time would be governed by the duration and opening hours. Who would be involved, if a choice exists, would depend on the scheduling state of various household members. Operationalizing these constraints would require a series of "if ... then" rules to establish the choice set of alternatives.

The actual rules then used to make the choice amongst the alternatives would need to be arrived at through more in-depth cognitive analysis of decision making, which is beyond the scope of this thesis. Operationally, one suggestion might be to use a traditional random utility-based choice models with the constrained choice set, taking the number of choices on each dimension (if more than one) and simultaneously generating all possible feasible outcomes for choice in a nested logit style.

Once refinements in the activity are made, the activity is added to the schedule for the applicable household members ($ADD A'_i$). Control is then returned to the momentaneous priority model, which re-evaluated all activities on the agenda after each addition.

Subsequent additions (and possible modifications/deletions) are then continued until a decision is made to halt scheduling in any particular mode (via *Continue Scheduling?*).

At specified times during this scheduling process, modifications and deletions may occur in response to *random events*, scheduling *time pressure*, or convenience (*open time*). In all cases, this leads to the “*Modify and Conflict Resolver*” sub-model, although upon return, it may proceed in different directions, as shown in Figure 5.1. Each of these processes are described in the following sections.

5.3.4.3. Random Event Simulator (RES)

In the impulsive planning mode, the RES serves to generate “random” or “unexpected” events that require immediate attention for scheduling. Two main types of events may be generated. The first are unexpected changes in the duration of planned activities generated each time the model moves to the beginning of an activity (A_j) in the impulsive scheduling mode (as determined by the *Planning Mode Executive* - see section below for more detail). These events would be based on the distribution/flexibility of the activities duration, as well as changes in travel as a result of unexpected congestion, route changes, or mode changes. The extent of any duration changes would be constrained by some practical rules related to the fixity of activities that follow the given activity - for instance, if a highly fixed activity follows the given activity, then an upper bound on any unexpected changes in duration may be set (e.g. if a recreational event precedes a fixed commitment to chauffeur one’s children follows, then random duration changes should have an upper bound).

In cases where the unexpected change leads to a decrease in duration or an increase that does not cause any conflicts with other planned activities, the changes are made to the schedule, and the model proceeds as is (the free time will be filled through the scheduling process to follow). In cases where a conflict arises, the *Modify and Conflict Resolver* must be evoked. The behavioural response to such a situation is similar to that when

faced with time pressure - one must now squeeze a high priority activity into a time slot that is no longer adequate. To operationalize this behaviour in the model, the activity can be artificially removed from the schedule, while at the same time assigning a high priority to the activity along with fixed start and end times and duration. In this way, scheduling would proceed with the choice of this activity, to the identification of the window, to time pressure, and to the *Modify and Conflict Resolver*, where the conflict would eventually be resolved due to its high priority. After any unexpected changes in duration are implemented, the activity is executed with no further changes.

The second type of random event concerns the simulation of urgent, emergency, or surprise activities that are mostly outside the control of the person. These would be handled by directly assigning a very high priority to the activity item and having scheduling proceed. For immediate urgent activities (e.g. go to the hospital), scheduling proceeds as is, in impulsive scheduling mode. For surprise activities that will occur at a later time (e.g. news of surprise visitors coming to your home the next day), the *Planning Mode Executive* would be called upon to switch immediately to pre-planing mode to make the scheduling changes, then switches back to impulsive planning.

The number and characteristics of random events should be simulated based on observed data.

5.3.4.4. Time pressure

Compared to random or unexpected events, *Time Pressure* is the result of a more purposeful choice process wherein the scheduling of an activity meets with insufficient time windows to conduct it. A decision rule is needed at this point to decide if the given activity priority is still high enough yet to warrant potential modification or even deletion of previously scheduled activities to accommodate its scheduling. Such a rule may be a simple one of the form:

IF [$P_i^{m,add} >> \alpha_m$] THEN [*Modify Conflict Resolver*]

Other more complex rules may be necessary that replace the right hand side of this rule with an aggregate measure of the priority of existing activities (A_j) in the vicinity of the new activity ($A_{\cdot i}$) that may need to be modified. These latter priorities would be re-evaluated for the given moment, as opposed to using their priority level when originally scheduled. The end result is that either the *Modify and Conflict Resolver* searches for a means to increase the size of the window, or scheduling returns to the *Planning Mode Executive* and no further additions are attempted.

5.3.4.5. Open time

Modifications may also be due to convenience, in a sense that a person has *open time* slots and the freedom to extend the duration of previously planned activities or choose a different location/mode in light of the opportunity. This type of modification would occur during impulsive scheduling in the event that none of the activities on the agenda evaluate to a high enough priority for addition to the free time slot (i.e. *Continue Scheduling A'?* No). The *Modify and Conflict Resolver* is called upon to fill up the *open time*. This serves to maintain the continuity of time in the schedule (i.e. a person must always be doing something).

5.3.4.6. Planning mode executive

The result of the momentaneous scheduling priority model are used to choose activities for addition, modification, and deletion to household member's schedules in a sequential fashion. The sequential movement through time is simulated by the *Planning Mode Executive* by controlling movement from one planning mode to the next. During the course of the week, people alternate between pre-planning activities for future days, pre-planning activities for the same day, and impulsive decision making. Weekly pre-planning mode is defined as those scheduling decisions made one or more days in advance of the event. Daily planning mode involves decisions made the same day as the event occurs. Impulsive decisions are made just before or during the activity.

The exact inter-sequencing of pre-planning and impulsive decisions is unknown and remains as a difficult phenomenon to disentangle even with more repeated observation periods. For modelling purposes, one simplifying assumption would be to make all pre-planning decisions before the start of each day, wherein activities are planned for the same day or for a future day depending on the windows of opportunity. This would then be followed by impulsive decisions made at the start and end of each scheduled activity, starting with the first activity for the day. However, it may be argued that pre-planning is revisited during the day, perhaps as needed depending on the state of the schedule.

To briefly review, the model begins with a skeleton schedule for the week, followed by pre-planning during execution of the schedule, followed by an impulsive decisions that occur in between each activity. Thus, once pre-planning halts for the day (*Continue scheduling?* No), the model proceeds in time via the *Planning Mode Executive* to the starting point of the first activity, invoking the impulsive mode of planning. This mode is subsequently invoked at the beginning of each scheduled activity until a pre-planning mode is invoked by the planning mode executive. The model inherently moves through time after impulsive decisions conclude at the beginning of an activity, and the model moves to the end of the activity.

Specifically, in the impulsive mode, the model proceeds to the beginning of the first scheduled activity for the day and first determines the actual duration of the activity via the *Random Event Simulator* (see below for additional detail). This may result in changing the actual duration from the planned activity. Following this, the model proceeds in time to the end of the activity. At this time point, an empty time slot may or may not exist, and a decision is made to impulsively add an activity before the start of the next activity. The choice of activities to add during impulsive planning follows the same procedure as in pre-planning (including the possibility of the generation of a random new activity), except in the handling of empty time windows - whereas empty time windows are permissible during pre-planning, any *Open Time* windows must be filled during impulsive scheduling. In the case where none of the activities on the agenda meet the

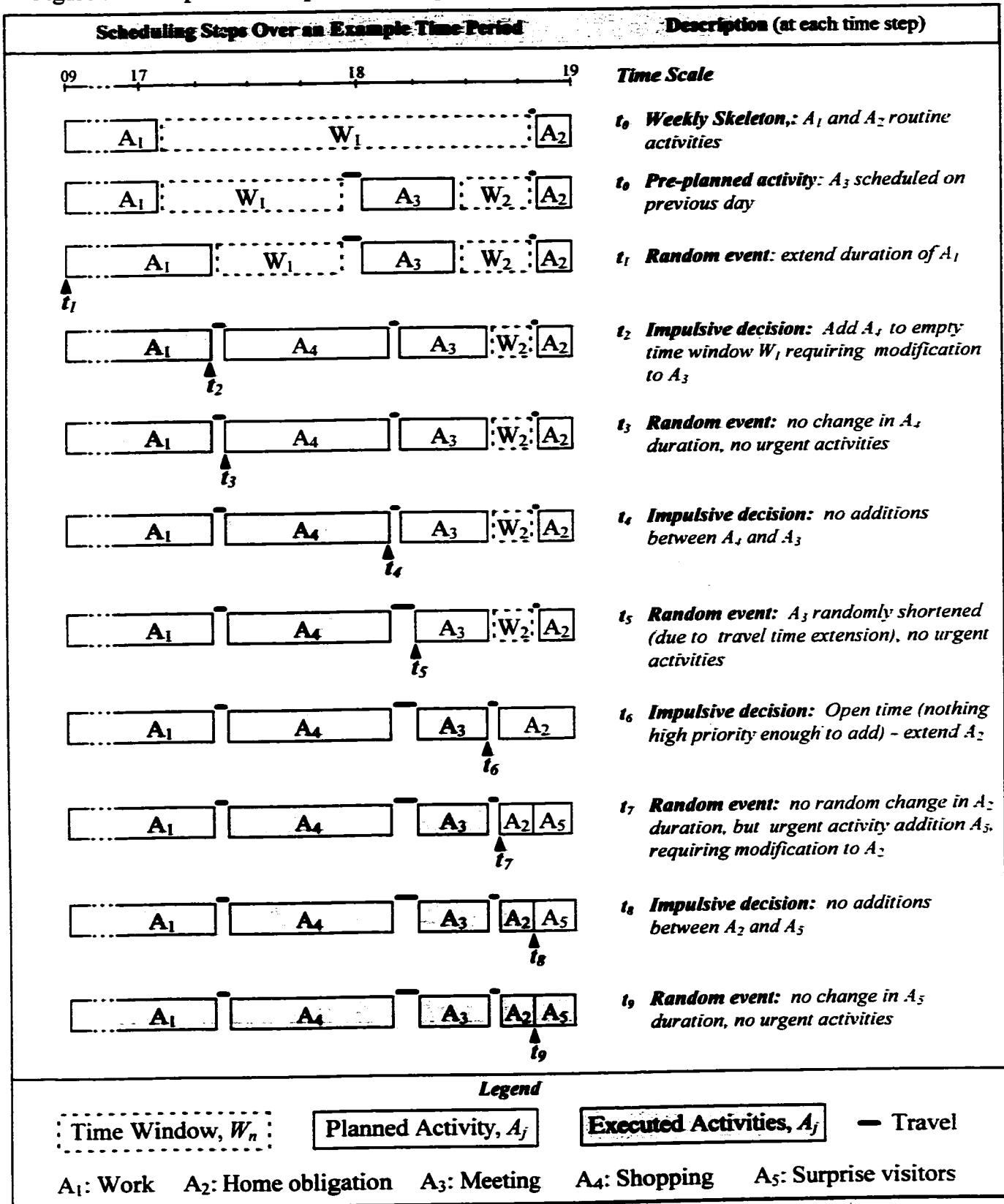
threshold for scheduling set for impulsive planning (*Continue scheduling?* No) then a situation arises in which *Open Time* exists. The *Modify and Conflict Resolver* is then invoked to revisit existing activities (A_j) to choose for modifying in order to fill up the time (see below for details), potentially resulting in a longer duration or new location/mode choices. In either event, the open time slots must be filled before the scheduler moves in time again to the start of the next activity (which may be an activity that was just added), and the procedure repeats itself. In this way, the final executed schedule is formed. A graphical example of this is provided in Figure 5.6.

The example in Figure 5.6 shows how a person's schedule for a particular period of time would be sequentially pieced together by the model, from weekly skeleton to final executed schedule. Each time step is controlled by the Planning Mode executive. First, the skeleton schedule for the given time period starts with just two activities - work (A_1), and a routine household obligation (A_2). Next, a meeting is pre-planned a day in advance (A_3). This pre-planning is followed by a procession of impulsive decisions and random/unexpected events that occur in between each activity in time steps of t_n . Each of these decisions serves to define the end state of the schedule and resulting activity-travel pattern.

5.3.4.7. Modifications

As described in previous sections, random events, time pressure, and open time could potentially lead to the *Modify and Conflict Resolver* (*MCR*), a flow diagram of which is presented in Figure 5.2. Except in the case of open time, the inputs are the list of scheduled activities (A_j), the new activity (A'_i), and the attributes of the chosen time window ($W'_{n'}$) in which the new activity does not currently fit. The minimum time necessary can be taken as the difference between the minimum duration for the activity

Figure 5.6 Graphical example of the sequential steps simulated by the model



(including travel time to the closest possible location) and length of the chosen time window. The option to bypass the MCR and proceed directly to the *Activity Deletion* sub-model for highly *Urgent Activities* is provided - this decision would be based on the level of priority associated with A'_i (in most cases, this would result from high priorities being assigned by the random event simulator). Otherwise, the role of the MCR is to identify activities and specific modification types that could be made to make room for the new activity. In the case of open time, no A'_i exists, and instead the MCR identifies activities that can be lengthened via a set of modifications to fill the empty time.

In either case, the MCR does this by defining a function similar to [1] that determines the “priority” ($P_j^{m,mod}$) of scheduled activities A_j for modification (the subscript i is replaced by a j in all cases, and X_j refers to the attributes of activity j on the schedule). Such a model would be estimated using data on observed modifications, such as that provided by the CHASE survey. In particular, variables that indicate the flexibility of each activity for potential modification should be included in the model. For instance, the differences between a scheduled activities duration (d_j) and the activities minimum duration (min d_j from the agenda) would be a strong indicator of its potential for modification. The proximity of A_j to the window of opportunity, in terms of the number of activities that separate the two, may also be an important determinant, as closer activities are more likely to satisfy the modification need. The number of locations and possible modes available to the user may also signify more flexibility for modification.

Similarly to the addition of activities, once the priority for modification is established, a choice must be made of which A_j to modify (*Choose A_j to Modify*), similarly to the choice of activities to add in the main model in Figure 5.1 (*Choose A_i to Add*). The next step is to *Determine the Modification Types for A_j* and their potential to free up time in order to increase the size of W'_n (in the case of open time, the goal would be the opposite - to fill up time in order to decrease the W'_n). These include just moving the activity in time, decreasing the duration in relation to its minimum, and changing the location or mode to decrease travel time. The maximum possible savings should be identified (e.g. the

difference between duration of A_j and its minimum possible duration; the difference between the travel time to current location and the travel time to the nearest perceived alternative location).

Once these modifications and their potential are identified, a decision must be made to *Choose Another Activity to Modify*. This choice would be based on the increase in the amount of time savings that has accrued from the preceding step compared to the amount of time necessary. Thus, if the ratio of the potential time savings to the time necessary is below a threshold value, then the procedure should stop, similar in structure to the rule in [2]. This would halt the search for modifications at a point where no significant gains are being made.

At this point in the sub-model, the range of potential modifications must be evaluated in terms of their ability to meet the minimum time needed or, in the case of open time, fill up the time (*Evaluate Impact of Modifications*). This would constitute a simple rule wherein the sum effect of the modifications must be greater than the minimum time necessary. If not, then more drastic measures may be considered in the form of *activity deletions*. If they are adequate, then the magnitude of the modifications must be refined such that any potential savings in time is distributed fairly amongst the new activity (A') and the modified ones. For example, suppose a new activity requires 30 extra minutes in order to be scheduled at its minimum duration, and that another activity could potentially be shortened by as much as one hour in order to make room for the new activity. The decision is then how the residual 30 minutes of activity time is distributed between the two activities. A simple approach would be to split the amount of time savings equally after both activities are allocated their minimum feasible values. In this case, 30 minutes of the modified activity are traded to the new activity to get it to a minimum feasible value, and the residual 30 minutes is distributed equally to both, providing an additional 15 minutes of duration. A more complex rule could distribute any residual times saving in proportion to the durations of the activities, or in proportion to their priority. The complexity of this decision increases as the number of alternative modifications

increases. Further analysis of the observed modifications, and more in-depth analysis of the underlying decision process is necessary before more refined rules can be suggested.

Once the refinements are made, the modifications are implemented (*Modify Activities*) and control reverts back to the main model, where the final refinement choices for the new activity are made given the new time window.

5.3.4.8.Deletions

In the event that no set of modifications are adequate to resolve a conflict or schedule an urgent activity, then the deletion of an activity is considered. A flow diagram of this procedure is presented in Figure 5.3. The procedure is similar to the MCR in the inputs, the priority model ($P_j^{m.del}$), and the choice of activity to delete. Following this, a decision then needs to be made of whether the new activity is indeed of much higher priority to warrant deletion of the chosen activity (*Delete A_j ?*). One way to handle this would be to re-evaluate the priority of the chosen activity for addition $P_j^{m.add}$ given the new state of the schedule (this would differ from when it was originally made) and compare it directly to the priority of the new activity. If the discrepancy is large enough (i.e. $P_i^{m.add} \gg newP_j^{m.add}$), then the deletion should proceed, and control revert back to the main model where the resulting time window is then reassessed (note that further modifications or deletions may follow to accommodate the new activity). If not, then other activities may be considered for possible deletion (*Choose Next Activity to Delete?*). In the event that no deletion is feasible, then control reverts back to the MCR and subsequently back to the main model, and the activity is no longer considered for addition. At this point, it can be assumed that a rescheduling responses was simply not adequate to accommodate the scheduling of the new activity, or that the activity was simply not important enough to justify changes to existing activities.

5.3.5. Optimization in the scheduling process

Although the scheduling process proceeds in a sequential fashion, without directly involving the optimization of the schedule as a whole (apart from the optimization already achieved through scheduling high priority activities first), a further degree of optimization is achieved in the scheduling model by revisiting previous activities for modification in the event that *time pressure* accrues, or *open time* results. This leads in the first case to more optimized locations, durations, mode choices, etc. that minimize travel time or durations via the *Modify and Conflict Resolver*, and in the second case by allowing previously planned activities to be optimized in a sense that preferred locations or extended durations are realized. Thus, durations and travel times (via location choices) will only be optimized to the extent that other activities of high priority need also be scheduled in the same time window. Behaviourally, this reflects the notion that people consider optimizing their behaviour only when and where needed and/or possible.

5.4. Conclusions

This chapter has attempted to move closer to the solution of a complex problem in the field of travel behaviour that has hampered development of behaviourally sound forecasting models. As mentioned at the outset, the model represents a continuing and long term development project. The empirical evidence in general justifies the approach taken, however, future development must focus on the specific estimation of the model and the various decision rules so that the model as a whole can be tested and validated. In the case of the momentaneous priority models, they may be estimated using the existing CHASE survey data, with careful selection of variables from Table 5.2 and due consideration to the form of the model. Some of the decisions rules may also be investigated using the CHASE data, however, their exact form would benefit from further investigation of underlying cognitive decision making processes. These rules can be kept simple, and perhaps calibrated by hand, in order to operationalize the model in the short term.

The model also places renewed focus on basic human needs, as manifested in the household activity agenda. Simulation of a detailed activity agenda is crucial to the scheduling model, and represents a significant research challenge. Such development would benefit from re-visiting the “space-time” analysis pioneered by Hägerstrand (1970). The importance of the agenda is also highlighted by the fact that many changes in policy would first need to be implemented via changes in the attributes or distribution of activities on agenda. This would then invoke a scheduling response and subsequent changes in activity and travel patterns. For instance, the implementation of flexible work hours would in the first instance lead to changes in the earliest start and latest end time for work activities in the agenda, which would then have clear implications for scheduling within the household.

The conceptual model also leaves room for a role to be played by existing optimization style models. It attempts to address past behavioural criticisms of these models, by providing a reduced choice set of activities that are amenable to optimization. Applying past successes with these models to a weekly scheduling setting is an important aspect of the success of the overall scheduling model.

And lastly, the development of the CHASE survey will go a long way towards solving the data collection problems that have hampered the development of simulation models of activity scheduling, of which the current one is but one possibility. While ease of statistical estimation and the simplicity of econometric approaches may have been adequate to meet the needs of the past, future models need be far more temporally and spatial accurate in their accounting of behaviour. A focus on activity scheduling, with the support of a new breed of data collection techniques, could take us towards new modelling approaches not previously thought feasible. The opportunity for researchers in travel behaviour, and modellers in specific, to re-think exactly what they really would like their models to accomplish is at hand.

CHAPTER 6 DISCUSSION AND CONCLUSIONS

6.1. Summary

Recent environmental concerns have posed a considerable challenge to urban planners to better manage and plan our built environment. These challenges have led to new demands for innovative analysis and forecasting tools, such as integrated land-use, transportation, and environmental emissions models. However, these and other models are only as good as the human behavioural theory on which they are based. In the field of transportation, a new paradigm has emerged to improve our the understanding of travel behaviour via an activity-based approach. The basic tenet of this approach is that it goes beyond the analyses of single trips in isolation and focuses instead on the activities that give rise to the need for travel. Activity patterns are a complex spatial-temporal phenomenon (as outlined by Hägerstrand 1970), and recent models have attempted to replicate entire activity patterns or “schedules”.

Through a review of the literature, it was found that existing activity “schedule” models lacked a strong behavioural basis which has hampered their development and applicability to travel demand forecasting. Traditional utility maximization modelling techniques appear to have reached their computational and behavioural limit when it comes to activity scheduling. Suggestions for improving this situation have led to a focus on the underlying activity scheduling “process”. However, relatively few researchers have been able to suggest details on how to observe the scheduling process as it occurs in reality. This lack of observed data has contributed to the lack of development of a “unifying framework” for activity scheduling modelling.

This thesis has contributed both a data collection tool for observing activity scheduling (CHASE), and a conceptual model that attempts to provide a unifying framework for

activity scheduling modelling. Empirical evidence showed that activity scheduling occurs on various time horizons, that significant amounts of revisions and rescheduling occurs during execution of schedules, and that planning can be opportunistic and impulsive. This differs from the notion that scheduling is a static and/or sequential process. These findings reinforced the need for interactive data collection methods like CHASE, and pose a significant challenge to the behavioural assumptions of past models and future models.

The CHASE survey represents the first attempt to collect data on the underlying activity scheduling process as it occurs in reality, over time, within a household. The efficiency of the CHASE program, brought on by the flexible and familiar graphical design, went a long way towards reducing the burden on respondents to obtain this detailed information. Indeed, having respondents step through the entire schedule building process *as it occurs in reality*, something that we are all quite familiar with in our daily lives, is an easily understood task. CHASE simply solved the problem of providing a means to efficiently record the process with a relatively low respondent burden (in line with current activity-travel diaries while providing much more information beyond the resulting activity-travel pattern), and the added bonus of minimizing fatigue effects commonly associated with multi-day surveys. This approach goes a long way towards solving the data collection problem highlighted by Bowman and Ben-Akiva (1997) that simulation models of activity scheduling (citing Ettema et al. 1993) require “very complex surveys for model estimation” wherein “respondents must step through the entire schedule building process.” CHASE data can also provide considerable support for other sequential decisions process models, such as those proposed by Gärling et al. (1998) and Vause (1997) that have lacked direct empirical support.

What was not shown in this thesis were several design elements that served to support the development of CHASE. This includes the original design document (25 pages), details on the Microsoft Access computerized ‘forms’ used to collect information in the upfront interview (residence, modes, household members, and activity agenda forms), and the

operations manual (21 pages) written as a guide for several interested research parties that is now available on a world wide web site. Interested parties should contact the author (doherty@civ.utoronto.ca) for access to the site, which includes a detailed description of CHASE, research papers related to the program, and information on how to obtain a downloadable version of the program.

Given the complex data provided by the CHASE survey, the next challenge was to provide a description of the scheduling process, and to provide empirical evidence that supports, in general, the development of a conceptual model of the weekly household activity scheduling process. *This model is intended to form a basis for the long term development of an operational model of the scheduling process - a complex problem that has yet to be solved in the field and to which one thesis would be insufficient.* The model as presented attempts to deal with the complexities of activity scheduling by segmenting the problem into distinct components that have clear interactions and behavioural interpretations, and that allow for the behavioural unification of past econometric and “rule-based” approaches. Many of the computational problems of past models, such as the inclusion of more and more nests in logit models (e.g. tour models) or the addition of endless numbers of constraints in combinatorial algorithms (e.g. CARLA, STARCHILD) are replaced by a more natural flow of decisions over time. The next stage in the development will require the operationalization and testing of various components of the conceptual model using the new types of data and variables provided by the CHASE survey. The development of activity agenda formation models is a particularly critical future development task.

The following sections examine several of these themes in more detail.

6.2. Complexity versus Understanding

“Hägerstrand's (1970) space-time paradigm is elegant in its conceptual simplicity yet in measurement it is horrendously complex. Hägerstrand's

model, as with the outstanding majority of all behavioral models, depicts what is conventionally referred to as revealed behavior but perhaps more correctly should be referred to as the *revealed outcome* of an unrevealed behavioral process. In fact, it is more probable that the set of rules and procedures that define such behavior will exhibit stability than the travel patterns or trip rates that result." (Mike McNally, *personal communication*)

One of the dominant themes of this thesis is the contrast between complexity and understanding -- i.e. the notion that by tackling the complexity of scheduling we may come to a simplified understanding of complex activity-travel patterns. The quote from McNally aptly captures this contrast from a more general perspective, reaching back to its roots in the work of Hägerstrand , and stressing what has become the goal of this thesis: to address the "unrevealed behavioral process." A similar argument is made by Gärling et al. (1994a, 356) that existing models are "confined to what factors affect the final choice, whereas the process resulting in this choice is largely left unspecified."

The results of this thesis challenge the behavioural assumptions of past models that assumed activity patterns are the result of a static process of choosing among a set of activity patterns with the highest "utility." Simply put, if you assume that activities and travel are planned and evaluated all at once, and carried as is in sequence, then a static activity chaining or scheduling model that predicts choice among a set of patterns would suffice. However, this thesis has shown that the decision process is multi-time dimensional, and prone to opportunistic and impulsive planning, as opposed to a "one shot" process. If we want to develop a behaviourally sound model capable of forecasting activity travel patterns that are responsive to emerging policy scenarios that result in a fundamental "scheduling" response (as most TDM and tele-commuting policies do), then a dynamic model is needed - one that can simulate the fundamentally different types of decisions that occur over time. This is, in fact, the major premise of the conceptual model presented.

But does all this added complexity improve our understanding or just complicate model development? It certainly does provide evidence in favour of rethinking our efforts at

trying to fit traditional techniques to new problems and instead apply techniques that are more amenable to the situation. We now better understand the dynamic complexity of scheduling, so why not match this complexity with an equally thought out model? The conceptual model presented here shows how empirically derived functions can be mixed with a series of decision rules to handle the complexities of the range of deliberate decisions made throughout the week to define activity patterns and resulting travel demands. Although much work remains to be done to fully operationalize and test such a model, this “set of rules and procedures” may indeed exhibit more stability than the travel patterns which result, as suggested by McNally.

6.3. Model Comparison

The conceptual model presented in this thesis can be compared to previous sequential activity scheduling process models, such as Gärling et al. (1997), Ettema (1993), and Vause (1997). It is similar to these models in a sense that an activity agenda is assumed to exist, that a sequential approach is adopted to mimic the decisions involved in activity scheduling, that a “meta” decision process exists to control the flow of decisions (similar to Vause) and that alternatives to utility maximization are proposed. It goes beyond previous models, however, in terms of how priorities are assessed, how other household members’ schedules are incorporated in the model, how decisions are organized over time are subsequently modified during execution, and how the two dominant operational techniques (i.e. utility maximization versus rule-based approaches) are “unified” in the model.

Specifically, there are several aspects of the current model that make it unique from past approaches. First, fewer model inputs are assumed to be given (e.g. activity duration, or activity utilities as in Gärling et al. 1997). Second, it is shown how the priority of activities can be derived empirically, as a dynamic function, and how this depends on activity characteristics, scheduling state characteristics, and attributes of other household members. The latter is particularly important for more naturally capturing the constraints

imposed by the household on individual scheduling that have not be adequately captured in past models. Third, the current model incorporates a natural means for the rescheduling of activities that occur during execution of schedules, in the form of continuous addition, modification and deletion to the schedule. This aspect of scheduling behaviour is not addressed directly in Gärling et al. and Vause's model, and is quite limited in the case of Ettema's model. This aspect of the current model largely reflects the new insights made possible by the CHASE data. Fourth, the conceptual model directly addresses the sequencing of activity choices over time, something that past authors have struggled with, assuming either that decisions are made purely sequentially in time, or that some meta-decision process existed as a control mechanism.

In general, the current model also directly addresses the issue of what type of modelling approach is most appropriate to operationalize the model - something that previous modellers have struggled with when faced with the decision of how to operationalize their theoretical ideas. The conceptual model presented shows how both optimal (utility maximization principles) and sub-optimal modelling processes (e.g. sequential rule-based principles) can be unified into one framework in a logical and behavioural fashion. This aspect of the model is discussed further in the next section.

Perhaps most importantly, the conceptual model developments presented in this thesis were based on observed data on the scheduling process. In general, this provided the necessary behavioural support of the conceptual model, and allowed speculation and investigation of specific variables to be used for future operationalization. The design of previous sequential process models, such as Gärling et al. (1998) and Vause (1997), were based on theoretical ideas that were, in general, unsupported by empirical analysis, and both authors conclude by asking for more data on the underlying scheduling process (such as Ettema et al. 1993) for future operationalization and empirical estimations.

6.4. A Unifying Framework

In their review of activity based modelling included in the latest edited book on “Activity-based Approaches to Travel Analysis”, Ettema and Timmermans (1997) conclude that:

“From a scientific point of view, it can be argued that to date a considerable body of knowledge exists regarding aspects of activity and travel patterns. At the same time, however, it should be noted that research in this area has been fragmented and that a *unifying framework* which links researches in different areas is still missing. This is probably due to the complexity of the phenomenon and the applied nature of most activity-based research.” (Ettema and Timmermans 1997, 33, *my italics*)

This contrasts to the sentiments of Recker:

“Despite their conceptual clarity, theoretical consistency and purported unmatched potential for policy application, activity-based approaches to understanding and predicting travel behavior have not progressed much beyond the initial forays into the field over a decade ago. Principle among the contributing factors to this lack of progress has been the absence of an *analytical framework that unified* the complex interactions among the resource allocation decisions made by households in conducting their daily affairs outside the home while preserving the utility maximizing principles presumed to guide such decisions.” (Recker 1995, 76, *my italics*)

Both agree that a unifying framework is still missing in the field that is capable of linking past research. Recker’s comment is particular interesting, since it may be argued that the “lack of progress” he notes is because of the focus on “preserving the utility maximization principles” (not in light of it), which have been strongly criticized as being incapable of providing a behaviourally sound unifying analytical framework.

The conceptual model presented in this thesis seeks to provide a unifying framework for future activity scheduling models. It does so by separating out the complexity of activity scheduling into three distinct components (agenda, routine activities, weekly or deliberate scheduling) that have clear interactions and behavioural interpretations. Spatial, temporal, coupling, institutional, household resource, and transportation related constraints are conveniently conceived as being imbedded in the structure of the

household activity agenda. For instance, a household constraint that parents be at home at a certain hour to care for their children would be represented as a pre-planned activity with highly fixed time and location. Weekly routinized activities provide the skeleton or pegs whereby remaining (more deliberate) scheduling decisions made during the week are made, based on a “priority” function that depends upon the attributes of activities themselves (such as temporal and spatial “fixity” and “flexibility”) and the attributes of the schedule at any given moment. The complexity of the scheduling problem necessitates such an approach, allowing an opportunity to focus in on the scheduling decision process itself and match its complexity with an appropriate dynamic/sequential modelling framework.

Despite sub-dividing the problem, clear linkages between them can be identified and incorporated in the model. The linkages between scheduling and the agenda formation concern the learning process that occurs during execution of the schedule that could alter the agenda (e.g. deciding on new activities, learning of new locations, acquiring information from Intelligent Transportation Systems - ITS). Although some of this learning could be assumed to be minimal for short scheduling time periods, others, such as the incorporation of learning brought on by ITS could be explicitly modelled, as suggested by Ben-Akiva et al. (1996), in the form of impulsive rescheduling. The linkage between routinized and deliberate scheduling decisions is explicitly in the model, as routine scheduling decisions are constantly revisited via rescheduling (modifications) or even new additions of routine activities throughout the week (they actually never leave the agenda).

The most important finding, and one that will form the basis of the most immediate analysis tasks to follow, concerns the distinction between “routinized” activities pre-planned for the week versus those activity decisions made throughout the week as a result of a more “deliberate” choice process. While this distinction between routinized and deliberate decisions has been made in the literature, few have been able to operationally define these choices or place their modelling within a unifying framework. What is clear,

is that the modelling of routine choices has achieved considerably more success using traditional econometric techniques, whereas less success has accrued from trying to model more deliberate choices (Golledge 1997). The two types of choices are obviously interrelated, and most commonly routine activities are said to form the pegs around which more deliberate daily choices are made. However, no empirical evidence is provided on how and when routine decisions are made, how deliberate choices are made, and how they interact. Defining routine activities in terms of their scheduling attributes over time provides a definitive framework for their modelling that has been missing, and provides a natural framework for remaining decisions to be modelled. This framework also provides an opportunity to unify past econometric approaches for the modelling of routine activities with the more recent “rule-based” approaches to the handling of deliberate day-to-day activity choices.

Specifically, this unification of modelling approaches could start with a model such as STARCHILD, which appears clearly amenable to providing a model for the optimization of routinized activities. In fact, the original STARCHILD model made a distinction between “planned” and “unplanned” activities that is similar to the distinction in this thesis between “routine” activities planned before the week commences, and the more “deliberate” activity decisions made as the schedule is executed during the week. The STARCHILD model also produces an activity pattern “that can be expected to be executed during the action period” (Recker et al. 1986a, 314), and that is “sensitive to the possibility of unforeseen events arising” (Recker et al. 1986b, 327), which is behaviourally similar to what people in the CHASE survey were observed to do at the beginning of the week on the first Sunday. The only significant modification would be to restrict the generation of feasible activity patterns to “routinized” activities, and leave “flexibility” in the form of open time periods for the remaining “unplanned” activities scheduled during the week. Thus, the optimal scheduling of routinized activities using a STARCHILD model could be tempered by the utility of reserving flexibility in the schedule. The authors already suggest that the amount of “flexibility” left would depend on the frequency of occurrence of the unplanned activity as well as on the time that has

elapsed since its last occurrence. This notion fits well with those proposed in the current framework.

Tour-based models, such as that of Bowman and Ben-Akiva (1995) could also provide the needed "routinized" framework to start the scheduling process. Although not proven directly, it is suspected that routinized activities will tend to be related to the "primary" tour of the day. Thus, a tour-based model could be used up to the point where the primary tour is developed via utility maximization. This would partially minimize the computational problems exhibited in these models, and provide a more solid behavioural basis for them as they are restricted to scheduling activities that do indeed lend themselves to optimization.

6.5. Future Research Efforts

In general, the research presented in this dissertation has opened the door to new possibilities in data collection and model development for the future. Much further work is needed in both areas to further validate the approach and demonstrate its applicability to forecasting travel demand compared to past approaches.

6.5.1. Survey design

Several key research issues related to the further development of the CHASE survey methodology relate to the internet and spatial component. Translating the program to run on the internet opens the door to larger and cheaper samples, and a higher level of real-time data control. Households would either run the program from a web site, or download it to their home computer and remotely transfer files. Looking long term, it is foreseeable that an adequate random sample of households could be obtained as the internet saturates the household market to levels similar to telephone access.

The CHASE program is highly temporal in nature, and would benefit from a more precise spatial component. The challenge comes in designing the extension without undue burden on respondents. One possibility concerns the combination of a portable Global Positioning System (GPS) with the CHASE program. This would provide a *passive* trace of household members' spatial movements to supplement the highly temporal nature of information obtained through the program. A Geographic Information System (GIS) could be used to reduce the GPS point data to continuous "routes" on a network, while the activity at "nodes" would be linked to information recorded by the CHASE program. A second possibility would be to include an interactive map for "pointing and clicking" exact location choices or even route choices. A GIS could be used to display and record locations, replacing the existing pull-down location choice in the add/modify dialog box in Figure 4.2.

One radical change to the CHASE program would involve complete conversion of the program to a spatial GIS graphical interface for tracking scheduling decisions over space. The schedule of a user on a particular day would be laid out on a map as a sequence of nodes and routes. The user can add activities at nodes and trace routes in-between as the activities get planned and/or modified over time. Upon addition of new activities at nodes, a dialog box could be used to prompt for similar information as to the existing CHASE program. Thus, instead of a "temporal" display, the idea would be to provide a "spatial" display. Allowing the user to define the layout of the spatial display, as opposed to using a pre-existing map, would make for an interesting investigation of the formation of "mental maps" and the impact on scheduling. Even more interesting would be a comparison of the users' spatial schedule to one tracked passively via a GPS/GIS system. as above.

Several other specific changes to the CHASE program are of note. First, a more detailed examination of scheduling processes over time could accrue from incorporating more flexibility in data entry to allow differential planning of activity attributes. For instance, the program could allow the addition of activities without an exact departure time or

location, which are added later by the user as they are decided. This approach would allow more in-depth analysis of the planning process, but would require a more complex graphical display and reminder system that could add to the respondent burden. A second change to the program would involve the addition of a prompt to indicate when users actually made the decisions to add activities entered on the first Sunday, similar to the prompt for "after the fact" scheduling entries. This would target longer term decisions more precisely. A third area for modification involves the development of program logic to check for consistency between activities scheduled jointly among household members schedules, and joint mode use. This could improve the accuracy of the data by prompting users to correct for any discrepancies flagged by the program. In addition to these changes, several specific changes related to the design of the graphical interface, the options provided in dialog boxes, and the way data are stored have been flagged for future modification. For example, the "reasons" dialog box in Figure 4.3 could be redesigned in order to distinguish modifications/deletions that are the result of random versus more purposeful processes.

6.5.2. Future survey application

The flexibility and efficiency of the CHASE program in obtaining highly detailed behavioural information while minimizing respondent burden, makes the program an ideal candidate for a wide range of other research problems. This could include a variety of small sample experimental research projects, as well as the application of the program to larger samples via the internet.

CHASE has the potential to support and/or replace traditional paper-and-pencil and telephone activity and trip diary surveys in the long term. Almost all large urban areas in the U.S. (e.g. Portland, Washington) and several in Canada (e.g. Transportation Tomorrow Survey in the Greater Toronto Area), conduct regular travel and/or activity surveys on a yearly or multi-year cycle. An internet version of CHASE could easily be pared down to form a simple electronic activity/trip diary, with a generic activity agenda

for a set of household types. This approach would bring with it all the advantages inherent in CHASE (reduced respondent burden and fatigue, improved data quality and detail, multi-day potential) along with improved data management opportunities.

Panel surveys are used to gain information from the same sample over multiple time periods. An internet version of CHASE could reduce the complexity of this task by allowing respondents to access a web site to enter information without the need for complex paper surveys or the scheduling of telephone surveys, and by prompting for specific information and detail only where needed in response to user inputs. Surveyors would have an accurate means to track when data entry is actually made and could have real-time access to data. Reminders to complete the survey could be sent via e-mail or other means.

In a more experimental setting, the program could be used to support more micro-analytical investigations of household stated response to a range of transport policies or other stimuli that effect activities and travel. Stated response/preference techniques that are growing in popularity and use for assessing the impacts of future policy scenarios (Lee-Gosselin 1996). In such experiments, the CHASE program provides three main advances:

1. a realistic multi-day, multi-person graphical interface for the depiction of a household current situation
2. a user friendly means of modifying the current situation in response to a particular stimuli
3. an automatic means of tracing of the steps taken to arrive at the change from a base situation

One specific application of CHASE is to the assessment of the impacts of telecommunication on travel. In their review, Mokhtarian and Solomon (1997, 17) conclude in general, that telecommunications do make a difference, but that the amount

of substitution of travel by telecommunication is unknown. They specifically suggest that "much of the impact on travel patterns is moderated through the time-saving (rather than space-saving) capability of telematics and the consequent *reorganization of activities* along the temporal dimension" (my italics). A CHASE approach to the study of the impact of telecommunication, either in the form of an stated-preference exercise or before-and-after panel study, would provide a comprehensive approach to understanding both the observed changes in space and time, and the intermediate *process* by which activities are reorganized towards the observed outcomes. Understanding the scheduling process that leads to observed outcomes could provide the missing link in our understanding of the seemingly complex interaction between telecommunication and travel. It can be argued that the current lack of understanding of the impacts is due to the failure of existing approaches to address this process.

Applications of CHASE could also go beyond the field of transport and urban analysis. One interesting application is to the field of "Time Management". Assessing good and bad time management is a topic of general relevance to everyone. In fact, many people in the household sample for this thesis were quite curious to know the results of the survey in terms of their time use. Using the CHASE program to assess people's time management provides an opportunity not only to assess how time was used, but how it was planned - or in other words, address the time management "process" as opposed to time management "outcomes". Does good time management involve a lot of pre-planning and few impulsive changes? Does poor time management involve more impulsive decisions and high levels of modifications? Correlating indicators of good time management (or indicators of the positive effects of good time management, such as high grades for students, submittal of reports on time, etc.) with aspects of the planning behaviour process could reveal significant new insights into the process of time management.

6.5.3. Future model development

The most immediate future research tasks related to model development concern the operationalization of specific components of the conceptual model using CHASE data. The first step is the development of a discriminant function for routine activities and definition and estimation of the momentaneous priority function. The main goal of these developments is to identify and interpret the most relevant variables for each model. This would serve to advance our theoretical understanding and serve as a basis to refine future data collection efforts. Equally important is the identification/development of the various rules incorporated in the conceptual model, using the CHASE data as a guide and/or a source of data (including the "reasons" data collected for shopping activities). While many of these rules can assume a simple structure in order to operationalize the entire model, future research to identify the types of decision rules underlying the variety of scheduling steps incorporated in the model and how they differ across individuals and situations. This would involve more in-depth probing using techniques such as "thinking aloud" pioneered in psychology.

Equally important to the above development is the somewhat separate need to develop a microsimulation model of activity agendas that includes the relevant attributes necessary for the discriminate and priority functions, and the development of an optimization model for the weekly routinized "skeleton" schedule. Both are crucial to the overall success of the model, but their development is beyond the scope of this thesis. Overriding these developments is a need to develop a computer algorithm capable of simulating the scheduling process in all its components for all people in an urban area.

The ultimate future task is the integration of the scheduling modelling within a larger integrated urban model. The most obvious linkage is through the output of household level travel demands by time of day and day of week, as depicted in Figure 3.1. Such an effort would drastically improve the model's ability to predict the impact of a wider range

of policies or urban form scenarios, as well as provide inputs and feedbacks to other modelling components, such as residential choice.

6.5.4. Data analysis

One of the challenges of examining detailed behavioural processes is the complexity of data coding and processing task. While the CHASE program efficiently recorded the scheduling steps of all household members into a single sequential file with backward linkages, the uniqueness of the data still required special attention even for the simplest of analysis tasks. By the same token, this complexity, and the richness of the data, offers considerable opportunities for further analysis outside of explicit model developments as outlined above.

Analysis ideas include the following:

- An examination of the role of perceived location choice set for and observed choices as it relates to the concept of mental maps.
- Examination of “trip chain” formation, with particular reference to the sequence of observed activities versus when they were planned, and the assumptions of past models.
- Examination of the effects of household lifecycle on scheduling patterns.
- Examination of specific instances of rescheduling behaviour in response to highly unusual and unexpected events (e.g. car breakdown, children sick).
- Content analysis of the keyed-in reasons given for shopping additions, modifications and deletions.

In general, there is considerable research work left to be accomplished before activity scheduling models prove their ultimate worth in furthering our understanding and forecasting of travel demand. Understanding the behavioural foundations is one of the first steps necessary in this process. In some ways, the CHASE survey only scratches the

surface of the underlying activity scheduling behaviour leaving much room for further insights.

6.6. Final remarks

As a research subject, activity scheduling is an engaging topic because of its complex nature, and the fact that there is plenty of room for innovation and the potential to revolutionize the way travel demand forecasting is done. The inductive approach in this thesis represents an attempt to take a fresh new look at this urgent problem. What was shown is that data can be collected, that scheduling is a dynamic process, and that a unifying framework is possible. The enduring contribution of this research will depend on its ability to bring about and promote a new stream of activity-based models that provide planners with new tools to forecast the effects of policies into the next millennium.

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