Some Recent Developments in Activity-Travel Analysis and Modeling

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The Transport Studies Unit at Oxford University has been working on a project that has contributed to many of the ideas and techniques involved in the activity approach to the study of travel behavior. The research itself is briefly described, and some of the major findings of interest to transportation planners are highlighted. The topics covered include the application of the activity approach to the data-collection, data-analysis, and modeling phases of transportation planning, and emphasis is laid throughout not only on the study results themselves but also on the research style. The research approach combines qualitative social-science interviewing techniques with more formal quantitative surveys and analysis, and the result is that each approach complements the other and the combination of both gives insights that are not obtainable when either technique is used in isolation.

The main objective of this five-year study (1) was to obtain a better understanding of household travel behavior and to develop an analytic and modeling capability that would enable this knowledge to be applied in transportation research and planning. The motive for initiating such a line of research was the growing dissatisfaction with the more traditional techniques of modeling transportation demand--techniques that, it was realized, were lacking in behavioral content (2) and were therefore unable to give relevant predictions of response to change.

Traditional approaches to the problem make a number of basic assumptions about the nature of travel decisions that rigidly structure the way in which the subject is viewed. In order to avoid similar constraints on this project, it was decided that an exploratory research design should be adopted by approaching the problem with as few preconceived ideas as possible.

ORGANIZATION OF THE RESEARCH

The approach adopted in the initial stages was to talk to travelers about travel in everyday terms. A number of specific interviewing frameworks were introduced within otherwise undirected household interview sessions, and comparisons were made of the "behavioral relevance" of each framework. It was found that recall and description associated with trip-based frameworks were imperfect, unconnected, and acausal. A framework in which participants discussed travel within the context of activities was found to have a closer apparent correspondence with the conscious planning and organization of travel behavior (an empirical investigation of this qualitative finding is described later in this paper).

Further exploratory studies using the activity framework revealed insights into the character of travel decisions. Individual respondents' emphasis on making travel decisions within the context of household plans or behavior led to our choice of the household as the basic descriptive and sampling unit. Respondents' continual concerns with timing--scheduling activities over the course of the day--stressed the importance of interdependencies, both within the pattern of trips made by individuals and between individuals. Time constraints within the environment (such as fixed and limited shop opening times) were stressed as much as, or more than, distances and travel costs. The importance of synchronizing time spent at home for shared family activities (such as meals and child care) led us to include in-home activity in our later diary surveys.

The results of these exploratory studies (3) enabled us to develop the conceptual framework that shaped the design of the main survey. The latter took the form of a two-stage data-collection exercise in which detailed seven-day activity diaries were collected from all members of 196 households in Banbury, Oxfordshire, and follow-up in-depth interviews were conducted with a subset of those households. The analysis of the results of both qualitative and quantitative aspects of the surveys is also described later in this paper.

The diary survey collected very detailed information about the way in which each respondent spent his or her time over the seven days (each discrete activity was recorded whether in or out of the home). In addition, a considerable quantity of data was collected that described the environment (both spatial and temporal) in which the respondents were operating. Thus, the location and opening hours of every potential activity location were recorded, along with details of the supply of transportation, so that opportunities for alternative activity programs could be assessed. Although it was felt that such detailed data should be collected for this research project, it is shown later in the paper that there is no need to go to these lengths in practical applications of the approach.

Up to this point in the project, we had tended to concentrate on static descriptions of travel behavior. The next phase focused more specifically on the dynamics of adaptation, in a series of supplementary surveys that examined how households adjusted their activity patterns in response to changes in the environment. This topic was also approached by conducting in-depth interviews with households but, since in this case we were asking hypothetical questions (How would you react if...?), it was necessary to impose some logical discipline on the responses. This was achieved by using an interview aid--the Household Activity Travel Simulator (HATS)--which was developed as part of the current project (4). When using HATS, each household member builds a representation of his or her activity schedule on a display board using colored blocks, and changes to that schedule can be simulated by rearranging those blocks. Since HATS embodies, in physical analog terms, the logic of the activity framework, a large degree of realism is introduced to the respondents' hypothetical reactions.

Four such studies were carried out during the project, and these led to a number of generalizations about households' response to change. The range of responses observed was very great but could be understood better if viewed as the adaptation of existing activity schedules. Changes in trip making emerged as a direct result of the new activity patterns. At the simplest level, minor retimings might be applied to the existing activity set, resulting in little or no change in trip making. In more extreme cases, major changes might be made, including altering the set of activities undertaken, their locations, or the method of travel between them. What kind of response is made in a particular case was found to depend on the severity of the imposed change (in particular on whether it required or merely invited a response from the household) and on the structure of the particular family. Households with older children, for example, have more free time and fewer space-time or interpersonal linkages than families with young children and so can more readily absorb certain types of change without major reorganization.

The picture to emerge, then, from the study of dynamic response to change was one of discontinuous and asymmetric forms of adaptation shaped by family structure and space-time constraints. The final phase of the project investigated the feasibility of developing a mathematical model capable of reproducing such responses. This is described in the final section of this paper.

Having described the content of the project in general terms, we now go on to discuss in rather more detail some specific findings that have particular relevance for transportation planning.

COLLECTION OF TRAVEL-SURVEY DATA

The comparisons of the performance of different types of activity diaries led to one particularly important finding: that an activity diary is likely to capture more trip making than the equivalent travel diary. The Banbury survey was timed to follow exactly 12 months after a conventional household travel survey in the same town and was designed to be equivalent in all other important respects, in order to allow comparisons. The activity-diary survey found 4.4 reported trips/respondent, of 66-min total duration, in comparison with the travel survey's figures of 3.9 trips/respondent and 57 min (increases of 13 and 16 percent, respectively).

A comparison of the travel-time results of the two types of surveys is given below (the differences for home-based work and home-based education trips are not significantly different from zero at the 95 percent confidence level):

	Trips per Person per Day		
Trip Category	Activity Survey	Travel Survey	Difference
All	4.37	3.86	0.51
Home-based			
Work	0.88	0.79	0.09
Education	0.54	0.55	-0.01
Other	2.16	1.93	0.23
Non-home-based	0.80	0.60	0.20

The table shows that this discrepancy is accounted for largely by differences in the trip rates reported for discretionary purposes--other and non-home-based--while the compulsory trip purposes show no significant difference (comparisons of travel times by purpose show similar differences).

Clearly, there are a number of possible sources for this observed discrepancy, and so differences between the two surveys in target populations, selected samples, definitions, and seasonal or other temporal variations were checked. But most of the effects were finally attributed to the diary types themselves. It is suggested that an activity diary is a more efficient way of collecting details on trip making, particularly for incidental trips that may be easily forgotten, because

1. At the recall stage, the activity framework enables respondents to adopt a more natural and efficient search strategy, which leads to a more complete recall of travel information;

2. At the recording stage, the activity format requires that time be continually accounted for, and this alerts respondents to forgotten activities and travel; and

3. At the coding and analysis stages, the activity format provides greater opportunity for checking logical consistency and completeness of each record (for example, each shift in location logically implies that a trip has been made).

Such results suggest that the possibility of adopting an activity diary might be considered for some kinds of travel surveys, although the extra accuracy obtained must of course be balanced against the extra cost of the more complex format of an activity survey. The subject is discussed further elsewhere (5).

ANALYSIS OF ACTIVITY DATA

Daily Patterns of Behavior

The main survey resulted in two types of information, neither of which is amenable to traditional techniques of transportation data analysis. The activity diaries give rise to a mass of very detailed quantitative data that describes how households organize their time but is difficult to present without sacrificing much of its detail. The in-depth interviews, on the other hand, result in a rich picture of the motives and mechanisms that underlie the activity patterns but do not lend themselves to other than a "journalistic" style of presentation. We adopted a dual approach to the analysis, in which the qualitative and quantitative assumed equal importance.

Our analysis involved the investigation of a theme that had emerged as being important during the exploratory studies--i.e., that household structure (in terms of the numbers and ages of children) is a major determinant of daily behavior and hence of travel. We therefore developed the following series of eight groups describing the stages in the family life cycle, among which all households could be allocated:

Life-Cycle Group	Description
A	Younger adults without children
B	Families with preschoolchildren
C	Families with preschoolchildren and young schoolchildren
D	Families with young schoolchildren
E	Families with older schoolchildren
F	Families of adults, all of working age
G	Older adults, no children in household
H	Retired persons

For each of these stages, profiles of typical daily family behavior were constructed from the two data sources independently. In the case of the qualitative data (see Figure 1), this was done by noticing any constraints on behavior that emerged from the interviews and building a typical schedule around them (an example might be that in group A, where both members of a household would tend to be employed full time and any shopping must be done either at lunchtime or on the way home). For the quantitative data (see Figure 2), the job can be done analytically, by calculating from the observed data the proportion of respondents of a particular type who are engaging in a particular activity at a particular time.

Comparison of the results showed encouraging correspondence between the profiles derived from the two sources of data. But each type of data has its

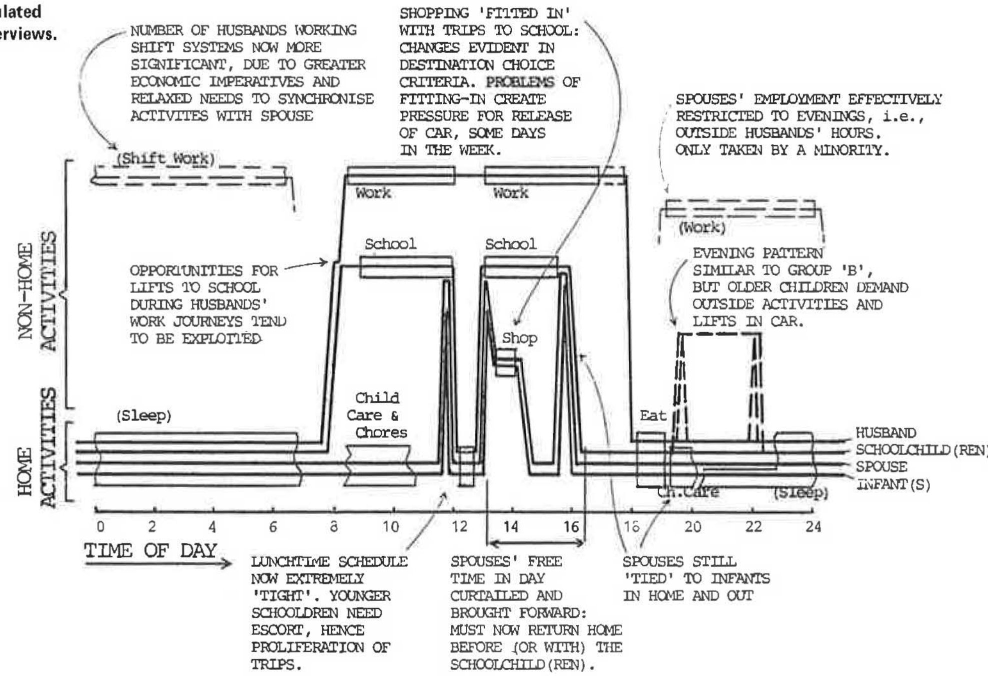


Figure 1. Activity patterns postulated for group C households from interviews.

own contribution to make to the study. The qualitative data allow anecdotal suggestions to be made as to why various features of the pattern appear in the way they do, and the quantitative analysis shows not just "typical" behavior but also the spread of behavior about that mean. In Figure 2, for example, it can be seen that, although few mothers in this group work (because they have young children to look after), those that do so must arrange to work part time either during times when their young children are at a nursery school (the correspondence between the plot for young children at school and mothers working is striking) or in the evening when the father is available to babysit. None of them are at work between 4:00 and 5:30 p.m., when the older children are returning from school.

Analytic Comparisons Between Life-Cycle Groups

We continued our analysis with a comparison of household behavior that used a simpler description of behavior: activity time budgets. This approach ignores the exact timing and sequencing of activities and concentrates instead on the way in which individuals share out the time available to them between different classes of activity. We calculated a time budget for each household as the mean of those of the two main adult members of the family, the budgets being in terms of time spent on each of 26 groups of activities per average weekday.

Differences between the household activity budget of families from different life-cycle groups were investigated by means of a multivariate discriminant analysis. Although the discriminant functions that best explained the variance between the budgets of households in different life-cycle groups are linear combinations of time spent on several activities, they can be interpreted at a simple level as being measures of time spent on child-care activities and in formal work. The first function (child care) explains 62 percent of the between-group variance, and the second (work) explains a further 23 percent.

In Figure 3, each household is plotted against axes that represent the two discriminant functions on one of eight graphs (one graph for each life-cycle group). The households from particular life-cycle groups do indeed tend to lie in clusters, which implies that they behave similarly. But, whereas groups A, B, C, and H are reasonably clearly defined, it is difficult to distinguish between groups D, E, F, and G. More formal analysis confirms the existence of these five fairly distinct clusters.

In Figure 4, we have plotted merely the centroids of the cluster of households that make up each life-cycle group. This representation brings out the idea of a classic path through the life-cycle groups for a typical household. Starting as a young married couple at A, they change their activity patterns drastically with the arrival of the first child and move to point B. As the family develops, they follow the path through points C, D, and E until the change between groups F and G (families with adult children and older couples with no children) is negligible. Retirement brings another major change in activities, represented by the move to point H. There are, of course, other paths for people who adopt alternative life-styles (6).

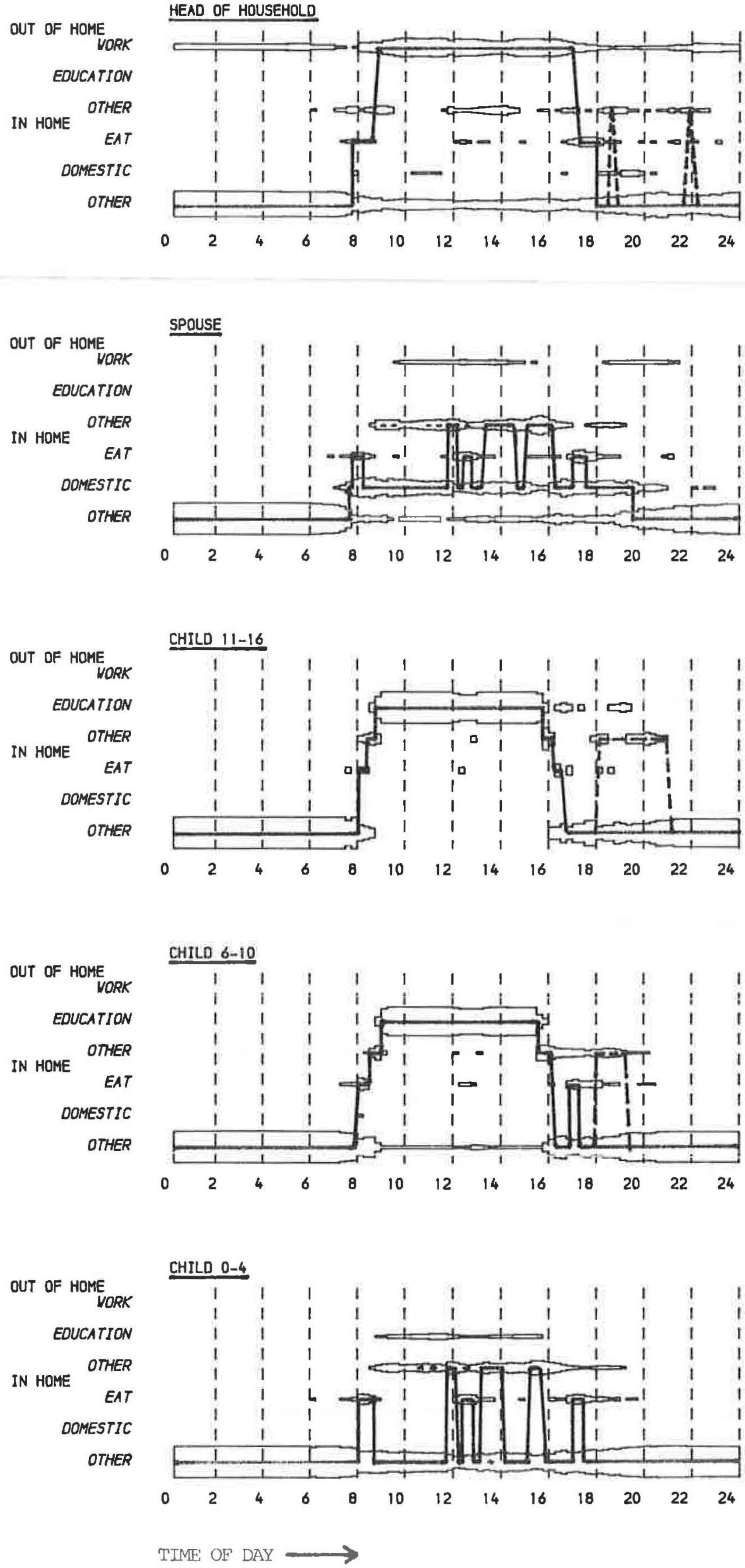
Relations Between Activities and Travel

Finally, in our analysis of behavior patterns we look at the impact on travel of the differences in activity patterns across life-cycle groups. An analysis of trip "circuits"--sequences of trips that start and end at home--reveals basic differences between the travel patterns of families from different life-cycle groups, particularly in terms of the complexity of the travel arrangements made (see Table 1).

In group A, since both members of the households tend to be employed, most of the nonwork activities take place as part of a work circuit. In fact, more than half of the spouses' work circuits also involve shopping.

In group B, the arrival of the first child has the expected effects. Most obviously, the wife now makes very few journeys involving work and, since she is now at home during the day, she can do much of the family shopping (30 percent of her circuits

Figure 2. Measured activity patterns for group C households (Thursday).



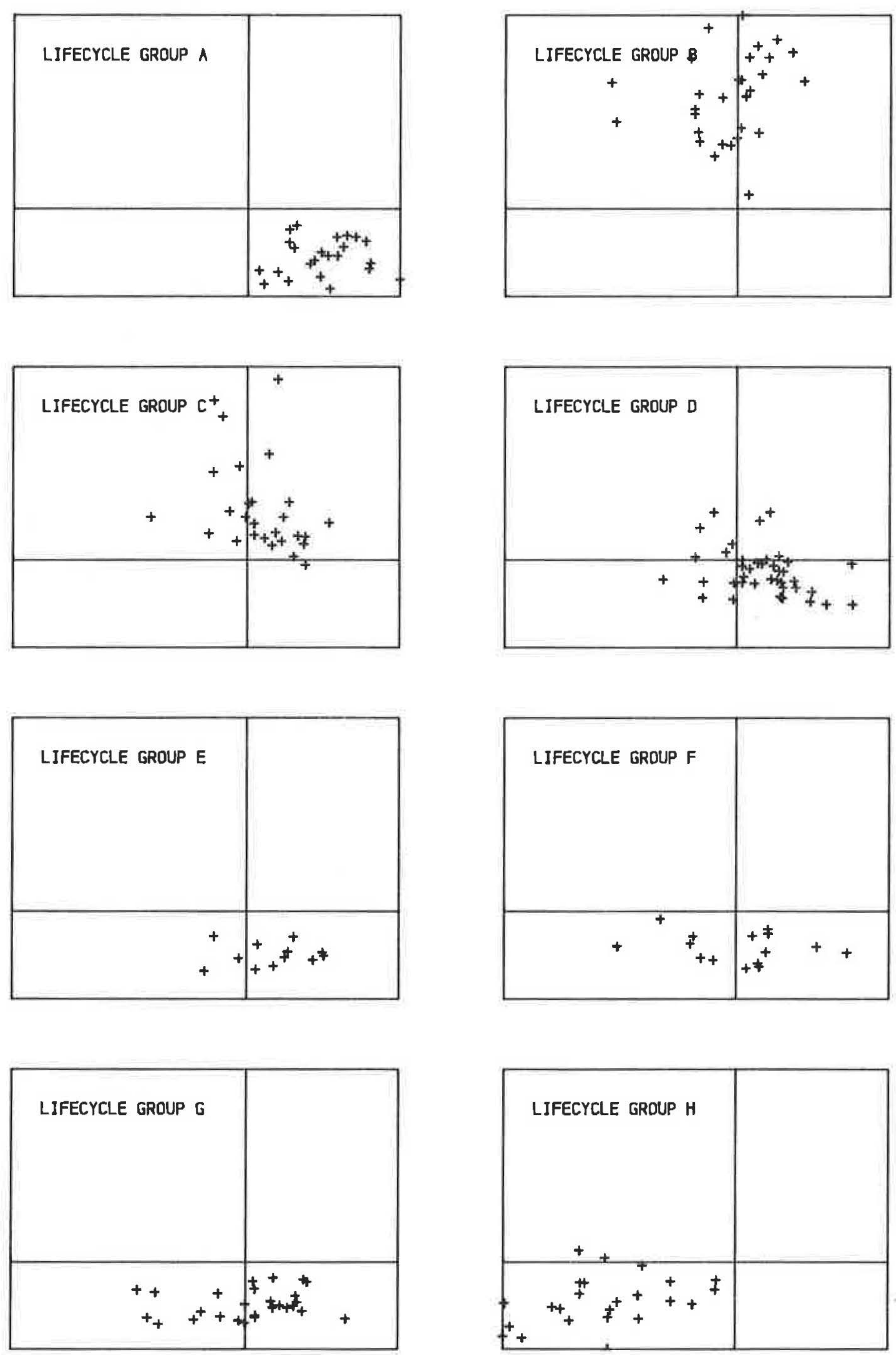
are simply home-shop-home). The husband no longer needs to do so much shopping in conjunction with work, and a marked reduction in their proportion of serve-passenger circuits reflects the reduced opportunity for lift-sharing to and from work.

The major characteristic of group C is the large proportion of circuits that include serve passenger. More than half of the wife's circuits involve this activity, and more than a quarter involve no other. The husband is also heavily involved in lift-giving in conjunction with work and in simple circuits with no other activity. The complexity of the activity patterns among families that have both schoolchildren and infants clearly manifests itself in these figures.

The proportion of circuits that involve providing lifts declines for the wife as the family grows up through groups D, E, and F. For the husband, however, the commitment to providing lifts remains constant as long as the children are in school.

In the final life-cycle group, the retired, almost all of the wife's circuits are simple ones. This is because there is now no need for the complex arrangements required to meet the needs of a family as in earlier groups. The same trend is not apparent for husbands; their simplest travel patterns occur in group G. Both wives and husbands show a local maximum in the proportion of simple circuits at life-cycle group B--after the necessity of fitting in activities around work in group A and before the complications of a growing family set in in later groups.

Figure 3. Surveyed households plotted in terms of activity and time budgets.

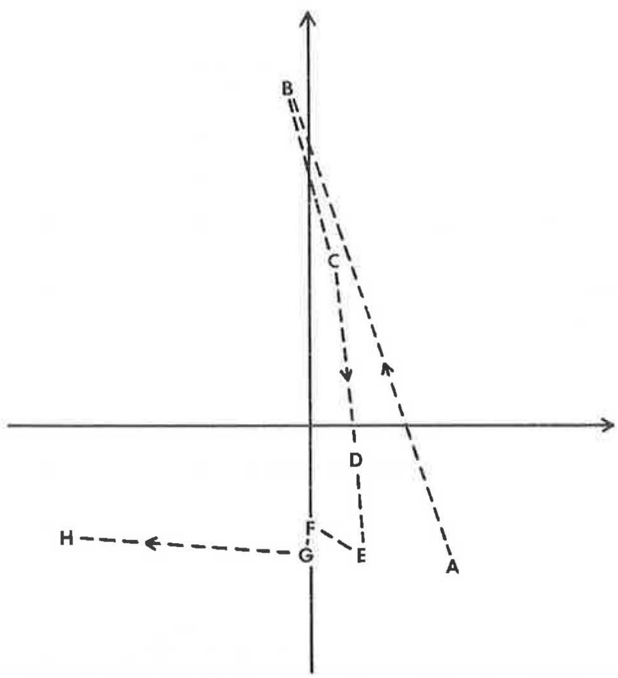


Reanalysis of Conventional Data Sets

Although the above analysis of trip circuits was performed from the detailed activity survey, it could just as easily have used conventional travel data. Whether one thinks of the analysis in terms of trip chains or activity chains is to some extent arbitrary. Travel data are in fact just a special case of activity data, providing no detail on multiple activities at any one location.

It follows that much analysis in terms of activities does not require expensive, detailed activity data, and we have produced activity schedules of the type shown in Figure 2 from conventional travel-data sources (7). Nevertheless, activity data provide an added level of detail that, particularly in a research context, allows examination of the linkages caused by, for example, family meal times.

Figure 4. Typical path of a household through life-cycle stages.



ACTIVITY-BASED BEHAVIORAL MODEL

Most conventional travel models are quite incompatible with the ideas developed in this study. They make little or no provision for the spatial and temporal constraints and linkages between household members that these surveys have suggested are instrumental in shaping the responses of households. We have therefore developed a model structure that takes explicit account of these features and is formulated in terms of activity patterns rather than trips (8,9).

The model is made up of a series of modules, each of which represents a possible response that a household may make when faced by an external stimulus. The model predicts changes in a household's activity schedule; resulting changes in travel patterns follow automatically.

The model is applied to individual households incrementally so that the first module only allows the household to make adjustments to the timing and sequence of the set of activities that they undertook before the application of the stimulus. If this process fails to reveal any feasible options, then other modules are invoked that represent more complex responses, such as changing the activity set or the location of activities.

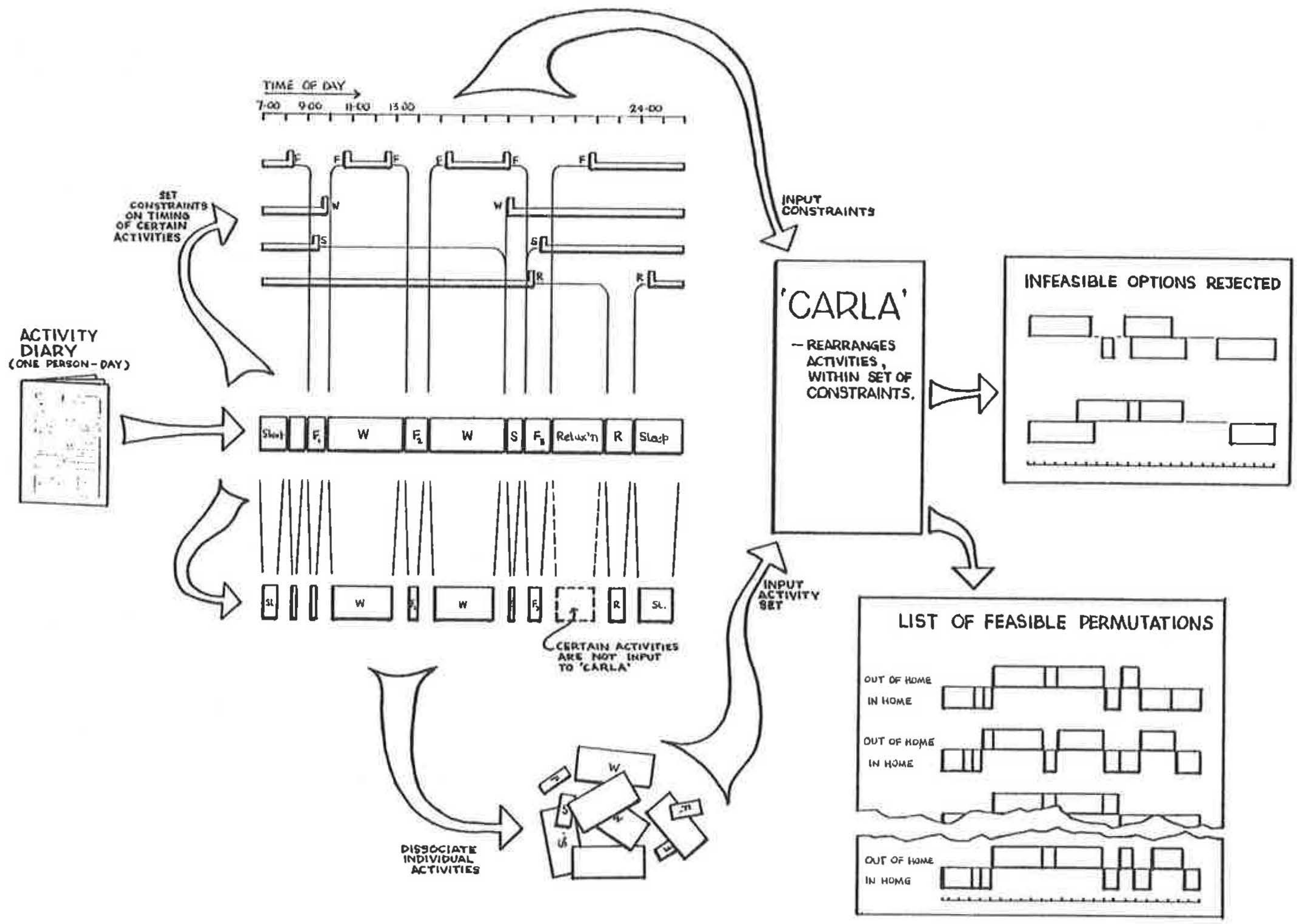
By feasible options we mean activity schedules that obey a particular set of rules. These rules represent logical constraints on activity patterns, land use limitations in both temporal and spatial dimensions, and behavioral aspects such as the existence of linkages between members of the household. Such rules were observed to be in operation when households rearranged their real activity schedule in the course of our surveys.

The core of the model, then, is a submodel

Table 1. Weekday trip circuits of household heads and spouses by family life-cycle group.

Purpose	Household Member	Percentage of Trip Circuits by Life-Cycle Group							
		A	B	C	D	E	F	G	H
Work	Head	56	50	55	45	44	59	48	18
	Spouse	53	8	12	35	45	42	28	8
Shopping	Head	26	24	17	23	23	21	18	39
	Spouse	46	49	40	37	40	45	39	51
Serve passenger	Head	15	6	31	28	32	18	6	7
	Spouse	7	17	52	28	4	4	7	0
Other	Head	39	43	27	29	28	29	37	47
	Spouse	50	50	40	37	29	29	45	51
Work and shop	Head	14	6	4	6	6	7	2	2
	Spouse	31	2	6	11	10	10	9	4
Work and serve passenger	Head	12	3	12	6	12	13	1	0
	Spouse	2	0	7	6	3	0	3	0
Work and other	Head	9	8	9	4	9	5	2	1
	Spouse	18	0	5	5	1	2	1	0
Shop and serve passenger	Head	5	2	5	5	5	1	1	1
	Spouse	0	5	18	9	1	2	2	0
Shop and other	Head	5	9	4	5	6	4	3	10
	Spouse	13	14	12	11	4	5	6	7
Serve passenger and other	Head	5	2	6	5	8	5	2	1
	Spouse	4	6	13	6	1	2	2	0
Simple circuits (one stop)	Head	69	79	72	78	69	67	89	79
	Spouse	58	78	67	66	81	81	81	81

Figure 5. Schematic representation of use of CARLA activity scheduling model to produce feasible activity programs.



(CARLA) that produces rearrangements of a set of activities subject to the various rules. This submodel is shown in Figure 5, where it can be seen that an individual's activity diary gives rise to two sets of information: (a) the individual activities that make up the diary and (b) a set of constraints that represent the times between which each activity may take place.

The constraints are an essential part of the process, since they are the representation of both supply constraints (e.g., shops are only open at certain times) and behavioral rules (e.g., families are unlikely to wish to reschedule their meal times by more than a certain amount of time). These constraints are exogenous to the model itself and may therefore be defined as necessary for a particular application.

The algorithm produces all logical permutations of the activities subject to the temporal constraints, and the resulting set of feasible options corresponds to the household's choice set. The actual choice process is handled by an objective function that is able to point to the "best" option. Study of actual household reactions observed in our surveys showed that a simple function such as "minimizing change" was not sufficient. Rather, it was decided that a two-stage function should be developed to reflect the fact that change will be resisted if at all possible but that, once a change is forced on a household, then a new schedule is chosen so as to maximize some function of free time (measured in various ways) and to minimize travel disutility.

Then there is the question of aggregation. The model necessarily works at a highly disaggregate level, either on surveyed activity data or on hypothetical schedules generated for "prototypical" households of the kind described earlier in this paper in the discussion of daily behavior patterns. It is suggested that study of the modeled reaction of individual prototypical households is a very powerful research and policy tool, but there will of course be occasions when an aggregate prediction is required. For this we propose to use stochastic techniques to attach probabilities of adoption to the various options in the choice set of each of a number of generated households and to bring those probabilities to a gross level to produce a population prediction. We are therefore investigating the integration of the household-level activity model with sample enumeration techniques to provide aggregate prediction capabilities.

The model is still under development, but the rescheduling algorithm has been implemented, tested on real activity data, and found to be practicable. Even in this simple form, the model is capable of being used to investigate simple responses to policies. We have, for example, used it to examine the predicted response of a sample of schoolchildren to various levels of shift in school hours, and the results exhibit just the kind of discontinuous response that was apparent in the HATS interviews. Small changes in school hours can be dealt with by minor retimings of schedules, whereas more severe ones require a major rescheduling of activities and trips.

CONCLUSIONS

The topics discussed in this paper have shown the usefulness of the activity-based study of travel at the data-collection, analysis, and modeling stages of transportation planning. The work also has important implications for other aspects of planning, such as policy generation or evaluation. Although some of these techniques (particularly the modeling) are still in the development stage, others are operational and, most importantly, many can be applied to conventional data sources. Travel-survey data contain much information about the timing, sequencing, and linking of major out-of-home activities rarely used in conventional analyses.

The importance of linkages between household members leads to another immediately practicable theme: use of the stage in the family life cycle as a classificatory variable. That this variable accounts for real differences in travel between households has been demonstrated by our (and other) analyses. Moreover, the variable has a dynamic aspect (one can think of cohorts of the population moving between life-cycle groups over time) that lends itself to predictive modeling applications (6).

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Basic Properties of Urban Time-Space Paths: Empirical Tests

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Temporal and spatial characteristics of urban travel behavior as a time-space path are explored. An abstract model that integrates Hagerstrand's prism, the concept of trip linkage, and the intervening-opportunities concept of trip distribution is developed as a tool for this exploration. Empirical examination of hypotheses derived from the abstract model indicates that the probability of permanently returning home is a function of the time when, and the location where, the trip maker's last sojourn (or stop at an activity site) is completed; that the average duration of a sojourn is negatively correlated with the number of sojourns in the path; and that the spatial distribution of sojourn locations depends on the number of sojourns.

The dominance of the work trip in the development of models aimed at understanding and predicting travel behavior has led to the suppression of the space-time element in these models. The temporal component (time of day) of the work trip is basically constant, as is the spatial aspect in terms of destinations. Travel for other purposes is characterized by countless possibilities of destinations, frequencies, time scheduling, and combinations with other purposes. Only limited research has been devoted to this type of travel behavior because its importance to the planning of roads and highways was not of the highest order and also because it was considered complex.

Recently, however, the importance of considering this type of travel became more obvious when the response to the energy crises of 1973-1974 and the spring of 1979 included travel rescheduling or foregoing discretionary activities and combining trips (1,2). One approach to such aspects of travel behavior is to analyze the behavior in its entirety as a "path" (3) in the time-space dimension. Clearly, an understanding of time-space elements and interactions in travel behavior would be invaluable. Yet currently available analysis methods fail to provide an adequate framework for dealing with the complexity of travel behavior, which is becoming increasingly important.

Research in this field is in the stage of seeking analytic structures, examining alternative hypotheses, and attempting to develop a theoretical framework. Accordingly, the space-time characteristics of travel behavior as a path have been largely unexplored. It appears that the accumulation of relevant empirical observations of the behavior would