Experience, Tendencies, and New Dimensions in the Application of Activity-based Demand Modelling Systems for Metropolitan Planning Organizations in the United States

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Abstract

Regional travel models in the United States are clearly evolving in a shift from conventional models towards a new generation of more behaviourally realistic activity-based models. The new generation of regional travel demand models is characterized by three base features: 1) an activity-based platform, that implies that modelled travel be derived within a general framework of the daily activities undertaken by households and persons, 2) a tour-based structure of travel where the tour is used as the base unit of modelling travel instead of the elemental trip, and 3) micro-simulation modelling techniques that are applied at the fully-disaggregate level of persons and households, which convert activity and travel related choices from fractional-probability model outcomes into a series of "crisp" decisions. While the new generation of model has obvious conceptual advantages over the conventional models, there are still numerous technical issues that have to be addressed before the new generation of models can fully replace conventional models. The paper summarizes the recent successful experience of *PB Consult* in the development and application of activity-based demand models for Metropolitan Planning Organizations in the US, including the New York Metropolitan Transportation Council and the Mid-Ohio Regional Planning Commission.

Keywords

Activity-based models, Tour-based models, Micro-simulation, International Conference on Travel Behaviour Research, IATBR

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1. Introduction

Regional travel demand models in the United States are clearly evolving in a shift from conventional models towards a new generation of more behaviourally realistic activity-based models. There is still ongoing discussion regarding advantages of the new generation of models over the conventional models, especially from the practical perspective. The relative complexity of the new models, and consequently the time-consuming computerized procedures needed to implement them, are often the focus of criticism. In addition, considering the normally limited size and scope of the travel behaviour surveys available to support model development, it is reasonable to expect successful demonstrations of both the practicality and improved forecasting accuracy of the activity-based models before there will be wide-spread acceptance and implementation of these new models.

However, several successful implementations of the new models have already proven that the activity-based concept is workable. Operational models systems at the regional level can be constructed that are practical (reasonable running time, reasonable size and scope of the travel/activity surveys to support the model estimation) and also incorporate the best components from the frontier-line research on activity and travel behaviour.

Overall, when describing the new generation of regional travel demand models, three base features can be highlighted:

1. Activity-based platform, that implies that modelled travel be derived within a general framework of the daily activities undertaken by households and persons (including in-home activities, intra-household interactions, time allocation to activities, and many other aspects pertinent to activity analyses, but typically missing in the conventional travel demand models).
2. Tour-based structure of travel where the tour is used as the base unit of modelling travel instead of the elemental trip; this structure preserves a consistency across trips included into the same tour, by such travel dimensions as destination, mode, and time of day.
3. Micro-simulation modelling techniques that are applied at the fully-disaggregate level of persons and households, which convert activity and travel related choices from fractional-probability model outcomes into a series of "crisp" decisions among the discrete choices; this method of model implementation results in realistic model outcomes, with output files that look very much like a real travel/activity survey data.

While complimentary, these features are essentially independent, and having one of them in place in the modelling system does not automatically require the others. Recognition of the true activity-based nature of travel and modelling attempts to derive travel from the comprehensive analysis of the individual daily activity agenda started long ago without any explicit linkage to the tour-based technique or to micro-simulation – see Bhat and Koppelman, 2000 for a comprehensive survey. Similarly the tour-based concept of travel modelling is rooted in trip-chaining models that were first developed independently of the activity-based paradigm, until it was recognized after the works of Bowman and Ben-Akiva (1999, 2001) that the tour may serve as an effective unit to construct daily activity patterns and schedules. However, the application of the activity-based and tour-based approaches in regional travel models had been long hampered by restrictive structure of fractional-probability models. The micro-simulation technique first opened the way to effectively apply activity-based and tour-based constructs in a real-sized and practical regional modelling setting – see reports of Vovsha *et al*., 2002, Petersen *et al*, 2002, Bradley *et al*, 2001, and Jonnalagadda *et al*, 2001. Thus, in most applications these features do go "hand in hand." This paper summarizes the experience of the Systems Analysis and Forecasting Group of *PB Consult* in developing and applying this type of modelling system for several Metropolitan Planning Organizations in the US.

The paper is organized in the following way. In the 2nd section, the geographic dimension of already developed and expected activity-based models in US is discussed. The next two sections (3, 4) are devoted to a description of the basic structural features of the new model systems. In the 5th section, an important aspect of intra-household interactions is described. The 6th section outlines the model system design. The 7th section gives a list of long-term research directions. The 8th section summarizes practical aspects of application of the new modelling systems. The 9th section draws some conclusions, while the final 10th section contains references.

2. Geography of the New Generation of Models

The majority of the Metropolitan Planning Organizations (MPOs) in the US are still using conventional regional models based on the 4-step modelling paradigm with numerous variations and enhancements. However, a growing number of MPOs either have already developed and applied models of the new type or have at least made a decision to start development of a new model, sometimes in parallel with maintenance and enhancement of the existing 4-step model. Fully developed and applied new generation models can be found in the Portland METRO, San-Francisco County Transportation Authority (SFCTA), New York Metropolitan Planning Council (NYMTC), and Mid-Ohio Regional Planning Commission (MORPC).

MPOs that have started development of new activity-based models include the Atlanta Regional Commission (ARC), the Houston-Galveston Area Council (HGAC), and the Denver Regional Council of Governments (DRCOG) can be mentioned. Several other MPOs, including the Capital Area Metropolitan Planning Organization (CAMPO) of North Caroline and Sacramento Council of Governments (SCOG) are currently considering development of new regional travel demand models in the near future. Additional examples in the US of activity-based and tour-based modelling include the Transportation and Land Use Model Integration Program (TLUMIP) in development for the Oregon Department of Transportation. In addition, the Montreal Mode & Toll Choice Model developed for the Ministry of Transportation of Quebec (MTQ), Canada is also a new model type.

PB Consult has been actively participating in almost all these projects (with the exception of Portland METRO and SCOG) including taking the leading role in the model design and development for NYMTC, MORPC, HGAC, DRCOG, CAMPO, TLUMIP, and MTQ. In several other projects like SFCTA and ARC, *PB Consult* has been closely cooperating with the other leading research and consultancy groups in the area (Cambridge Systematics, J. Bowman, M. Bradley). The current paper is primarily based on the experience of the two successive model developments – NYMTC and MORPC – where the authors comprised the core professional and technical team at all stages of the model design, estimation, and application. Many of the ideas that emerged from these efforts were further extended and incorporated into the proposed model system design for ARC, and have been intensively discussed with J. Bowman and M. Bradley. The authors acknowledge their contribution to many of the aspects described in this paper.

3. Basic Features of the New Modelling Structures

In comparison to the conventional models, the new generation of models is most notably characterized by crucial changes in the modelling structure. Although these new modelling structures are evolving rapidly and are following somewhat different specific paths of developments, it is already possible to summarize the following structural features of the new generation of regional travel demand models with respect to the three salient features identified above – activity-based, tour-based, and micro-simulation:

1. Derivation of travel demand from the general framework of the activities of the household and person that comprise it. This feature leads to the following structural properties of the model:
   1.1. Linking travel choices to underlying decisions regarding activity participation, time allocation, and scheduling activity episodes spanning the entire daily activity/travel

pattern of each individual, including both out-of-home and in-home activities with possible substitution between them – research works in this direction includes Bowman and Ben-Akiva (1999, 2001), Bradley *et al*, 2001, Bhat and Singh, 2000, Wen and Koppelman, 1999, and Miller and Roorda, 2003.

1.2. Linking activity/travel agendas and choices across household members in order to account for intra-household interactions, including explicitly modelling shared/allocated activities and joint travel – examples of modelling constructs can be found in Golob and McNally, 1997, Gliebe and Koppelman, 2002, Zhang *et al*., 2002, Scott and Kanaroglou, 2002, Meka *et al*., 2002, Simma and Axhausen, 2001, Fujii *et al*., 1999, and Vovsha *et al*., 2003.

1.3. Including additional household, personal, and location dimensions, such as household car-ownership or residential choice, as endogenous choices that are modelled together with travel choices, rather than serving as exogenous variables as they are frequently treated in conventional models – the works of Bowman and Ben-Akiva (1999, 2001), as well as Jonnalagadda *et al*, 2001 can be mentioned as examples.

2. Using tour instead of trip as a base unit of modelling. This feature leads to the following structural properties of the model:

2.1. Consistency across mode, destination, and timing choices for individual trips within the same tour; in particular, mode, destination, and time of day choices for non-home-based trips are naturally linked to the corresponding home-based trips from the same tour – an exhaustive analysis of the tour-based model advantages is done by Bowman and Ben-Akiva (1999, 2001), Vovsha *et al*., 2002., and Jonnalagadda *et al*, 2001.

2.2. Linking frequency of activities associated with secondary stops to the travel environment corresponding to the primary destination of the tour; in particular, workplace location and commuting time/distance for work tours can be effectively used as an explanatory variable for frequency and location of additional stops on the way to and from work – the works of Bhat and Singh, 2000, and Wen and Koppelman, 1999 provide good examples.

3. Fully-disaggregate modelling approach that explicitly simulates individual households, persons, as well as activities and travel tours produced by them. This feature leads to the following structural properties of the model:

3.1. Production of disaggregate "crisp" outcomes or true discrete choices by individual households and persons, rather than aggregated fractional probabilities across travel analysis zones and market segments as found in the conventional models; this makes for model outcomes that are much more realistic and compact compared to the conventional models – see Vovsha *et al*., 2002 for analysis of this aspect.

3.2. Explicit micro-simulation of individual persons and households that avoids aggregation biases and virtually removes limitations on multi-dimensional segmentation of the underlying choice models. As a particular example, the developed micro-simulation models reported by Vovsha *et al*., (2002,2003) have 10-20 travel segments (travel purposes/activity types) while most of the conventional large-scale models are limited to 3-5 segments.

3.3. Explicit treatment of time-space constraints on each individual's activity and travel pattern by means of tracking each modelled individual over the course of a day, with necessary temporal resolution and sequential updating of the available time windows and associated locations for activities – the recent work of Miller and Roorda, 2003 provides a good example.

3.4. Wide use of sampling strategies and Monte-Carlo simulations in order to reduce computational complexity, while preserving the variability of important parameters and avoiding aggregation bias. The example reported by Jonnalagadda *et al*, 2001, includes pre-sampling of zones for destination choice, while the model reported in Vovsha *et al*, 2002 incorporates a random variation of the parking cost (from free parking eligibility to the maximum payment).

3.5. Explicit modelling variability of micro-simulation (sometimes referred to as "Monte-Carlo error") that opens a way to explore distributions (in particular, maximum and minimum values) of the statistics of interest rather than just average values – recent paper of Castiglione *et al*., 2003 gives one of the first examples of systematic estimation of the micro-simulation variability.

The modelling structure currently adopted for most of the new regional models represents a sequence of discrete choices, implemented in the manner of individual micro-simulation, in combination with network simulation procedures, typically implemented with standard assignment software and aggregated travel flow matrices. The structure incorporates numerous feedback flows from the network simulation stage to the travel demand modelling stage, and assumes implementation of several global iterations until a sort of equilibrium is reached. One of the future directions of model development relates to a natural extension of the micro-simulation technique to the network simulation stage.

One of the clearest and most important general advantages of the new generation of travel demand models that stems mostly from the micro-simulation technique is that this paradigm leaves significant freedom in the design of the model system in contrast to the restrictions that confront conventional models. Conventional aggregate models have always been structured by travel dimensions with a predetermined sequence of processing (for example, trip generation – time-of-day choice – distribution – modal split). This "dimension-based" concept allows only for the re-ordering of dimensions within each travel segment (for example, modelling modal split before trip distribution or moving time-of-day choice after the distribution or modal split stage, etc). In contrast, the micro-simulation concept makes the modelling design more "object-oriented" where first the order of objects (households, persons, tours) is defined by possible segments (household, person, or tour types), and then travel dimensions are processed in the order appropriate for each object. For example, work commuting tours can be generated first for each worker; then these tours can be processed through destination and scheduling stages; and finally non-work tours can be generated and scheduled for each worker conditional upon the previously scheduled primary work tours.

4. Principal Structural Dimensions

While there are diverse modelling approaches possible, the underlying purpose of the new modelling approach system is the same as conventional models: to predict the entire-day activity and travel agenda for each person. The following four dimensions must therefore be incorporated into the final model design:

1. Generation of activities/episodes of various types,
2. Scheduling of activities, i.e. start and end time (or duration) of each episode,
3. Location of activities (in-home versus out-of-home, and destination for each out-of-home activity),
4. Formation of travel tours to visit out-of-home activities, including consideration of travel modes and routes for each tour.

Despite the many model combinations that can serve this purpose, only a few principal modelling schemes have been proposed that cover all four dimensions. In fact, the majority of academic research concentrates on a particular dimension or sub-set of linked dimensions, while the other dimensions are left out of the research scope. While this intense focus leads to significant advances, it is unacceptable for a practical model which must produce daily tours. The following two principal schemes are the most frequently employed:

- *Activity research* that is primarily aimed at the first two stages, while the spatial dimension and the associated travel formation is left out or greatly simplified; this track includes various research on time allocation, activity episode generation, and activity sequencing/scheduling – a comprehensive survey has been done by Bhat and Koppelman, 2001, while additional examples include works of Miller and Roorda, 2003, Golob and McNally, 1997, Meka *et al*., 2002, Simma and Ahxausen, 2001, and Fujii *et al*., 1999.
- *Daily activity/travel pattern approach* where pattern is defined in terms of a number and structure of travel tours as was originally proposed by Bowman and Ben-Akiva (1999, 2001), and then adopted by Bradley *et al*., 2001, Jonnalagadda *et al*, 2001, and (with several enhancements) by Bhat and Singh, 2000. This approach can be thought of as a mix of stages 1 and 4, while stages 2 and 3 are postponed to be considered conditional upon the daily pattern.

It should be noted that although the second approach has proven so far to be more instrumental and accepted for most of the practical applications that have been implemented, the first line of research should still be considered as theoretically superior in our view. The greatest operational advantage of the second approach is that the whole model system, starting from the activity generation stage is formulated in terms of tours as the travel unit. Through use of this unit, this approach is automatically compatible with the travel demand modelling technique that is focused on the travel dimensions of tour (destinations, modes, etc). The first approach normally produces activity dimensions (time allocation between activities, number of episodes and their sequencing or scheduling) that cannot be directly converted to travel units, thus it is less compatible with travel demand modelling techniques now in use.

Compatibility of the activity generation stages 1-2 with the location and travel stages 3-4, however, is only a technical advantage. From the broader perspective of understanding and modelling activity/travel behaviour, it can be stated that time-allocation and episode-generation/scheduling are of primary importance, and that other travel dimensions should be derived from them. Formulation of the daily activity/travel pattern in terms of travel tours (rather than in terms of activity durations and episodes) has the drawback of prematurely fixing the tour structure, while it should rather be formed conditional upon the activity agenda. However, modelling tour formation conditional upon the set of activities is in itself a complicated combinatorial problem for which only limited research has been done so far – an example is given by Recker, 2001. We believe that a better synthesis of the activity and travel dimensions with the full incorporation of the time-allocation and episode-generation/scheduling technique is the most important direction for the further development of the new generation of travel demand models.

5. Intra-Household Interactions

One of the most important theoretical and practical advantages of the new travel demand modelling framework is that it allows for explicit incorporation of intra-household interactions of various types. The conventional models, as well as standard choice constructs, require unambiguous specification of the decision-making unit (either household, or person, or particular tour/trip) for each choice dimension. However, it has been recognized that a significant share of travel-related decision is made within the complicated framework of the entire-household decision-making process, where each person's preferences are intertwined and consolidated across all household members. As a result some activities are shared among several household members; some other ones are generated at the entire-household level but allocated to particular members to implement; while other activities have a purely individual character. There have been a limited set of attempts to formulate models that incorporate a group-decision mechanism by Gliebe and Koppelman, 2002, Zhang *et al*., 2002, and Scott and Kanaroglou, 2002, which have resulted in interesting, but quite complicated constructs that are not easy to incorporate in the framework of a large-scale regional travel model.

In the design and development of the MORPC modelling system, the following three-part segmentation of household and person activities proved to be effective and practical to implement at the generation stage and in subsequent choice models:

- Individual activities: corresponding tours are generated and scheduled at the person level (with possible inclusion of the household variables, but without direct coordination of choices); the frequency of these activities is modelled for each person either as a part of the daily activity/travel pattern, or by means of the frequency choice model.
- Allocated activities: corresponding tours are generated at the entire-household level because they reflect the collective household needs, however they are implemented and scheduled individually; thus a tour-frequency model is formulated and applied for the household, and then it is followed by an intra-household allocation model that is applied for each generated tour and considers household members as alternatives.
- Joint activities: corresponding tours are generated at the entire-household level and also implemented by several household members travelling together (and frequently sharing the same activity); a tour-frequency model is formulated and applied for the household, and then it is followed by a person participation models that is applied for each generated tour and considers possible travel parties (formed of the household members) as alternatives.

The activity types and trip purposes are grouped into three main segments:

- Mandatory activities (including going to work, university, or school).
- Maintenance activities (including shopping, banking, visiting doctor, etc).
- Discretionary activities (including social and recreational activities, eating out, etc).

Table 1 summarizes the main assumptions made regarding the possible combinations of activity types and settings. Only five out of the nine possible combinations are allowed, which greatly simplifies the modelling system, while preserving behavioural realism and covering most of the observed cases.

Table 1 Modelled Activity/Travel Segments

Activity Type / Travel Purpose	Individual Setting	Allocation Setting	Joint Setting
Mandatory	X		
Maintenance		X	X
Discretionary	X		X

Travel for mandatory activities is always assumed to have an individual character. Frequency of these activities, location, and scheduling are modelled for each person independently. While household-composition variables are used in the utility functions for these individual activities, there is no explicit linkage across all choices made by different individuals with the notable exception of staying at home together or having a non-mandatory travel day together. This assumption is based on the fact that most of the mandatory activities have fixed frequencies and schedules defined exogenously to the household activity framework; however, a realistic activity-based model should be sensitive to the fact that unscheduled at home activity (child at home sick) will negatively impact the frequency of other mandatory travel.

Maintenance activities may be either allocated or joint. It is assumed that the maintenance function is inherently household-based, even if it is implemented individually or related to a need of a particular household member, like visiting doctor. Even in these cases, maintenance activities are characterized by a significant degree of intra-household coordination, substitution, and possibly sharing.

Discretionary activities may be either individual or joint. It is assumed that these activities are not allocated to household members since they do not directly relate to household needs. Thus, these activities are either planned and implemented together by several household members or are planned and implemented individually.

It is assumed that all else being equal, there is a predetermined structure of preferences in the activity generation and scheduling procedure along both dimensions (activity type and setting). Mandatory activities take precedence over maintenance activities, while maintenance activities take precedence over discretionary activities. Joint activities are considered superior to allocated activities, while allocated activities are in turn considered superior to individual activities. Combination of these two preference principles yields the following order of generation and scheduling activities that serves as the main modelling skeleton for many of the developed or proposed model system designs (NYMTC, MORPC, ARC, HGCOG):

1. Individual mandatory activities,
2. Joint maintenance activities,
3. Joint discretionary activities,
4. Allocated maintenance activities,
5. Individual discretionary activities.

6. Models System Design: Order of Choices

With minor variations to the modelling structure adopted for most of the developed or designed model systems, these models incorporate the following basic sequence of choices:

1. Long-term level
    - 1.1. Synthetic population generation
    - 1.2. Base location for each mandatory activity for each relevant household member (workplace/university/school)
    - 1.3. Household car ownership
2. Daily pattern/schedule level
    - 2.1. Daily pattern type for each household member (main activity combination, at home versus on tour) proceeded in a logical sequence with a linkage of choices across various person categories
    - 2.2. Individual mandatory activities/tours for each household member
        - 2.2.1. Frequency of mandatory activities/tours
        - 2.2.2. Primary destination for each mandatory tour
        - 2.2.3. Tour departure/arrival time
    - 2.3. Shared non-mandatory activities/joint travel tours (conditional upon the available time window left for each person after the scheduling of mandatory activities)
        - 2.3.1. Joint tour frequency
        - 2.3.2. Travel party composition (adults, children, mixed)
        - 2.3.3. Person participation in each joint tour
    - 2.4. Allocated and individual non-mandatory activities/tours (conditional upon the available time window left for each person after the scheduling of mandatory and joint non-mandatory activities)
        - 2.4.1. Household frequency of maintenance activities/tours
        - 2.4.2. Allocation of maintenance activities/tours to household members
        - 2.4.3. Person frequency of discretionary activities/tours
        - 2.4.4. Primary destination for each non-mandatory tour
        - 2.4.5. Tour departure/arrival time
3. Tour level
    - 3.1. Entire-tour mode combination
    - 3.2. Frequency of secondary stops on both half-tours
    - 3.3. Location of secondary stops
4. Trip level
    - 4.1. Trip mode choice conditional upon the entire-tour mode combination
    - 4.2. Trip departure/arrival time within the tour time window

One of the most important features of this modelling structure is that the original concept of over-arching daily activity/travel pattern proposed by Bowman and Ben-Akiva (1999, 2001) has been transformed in order to incorporate intra-household interactions. Since the joint and allocated activities are modelled at the entire-household level, it proved to be difficult to preserve the original concept of fully-integrated daily pattern that contains all tours and activities implemented by a person in the course of the day, in a single simultaneous choice model. Instead, we have designed a system with a cascade of conditional choices, with alternating decision-making units (household or person), following the preference rules described in the previous section. The modelling sequence starts with the linked person daily pattern type 2.1, and a list of mandatory activities 2.2, then models joint activities at the household level 2.3 and defines which household members participate in each joint activity (i.e. continues to fill up person schedules with joint activity participations). Finally, it comes to the allocated and individual activities 2.4 that conclude the generation of the full daily activity pattern for each person.

One additional detail that we have found useful in the implementation of this model framework is to place the modelling of the frequency of secondary activities down the hierarchy to the tour level 3.2 (i.e. treated as additional stops on the tours), rather than being considered as a part of the daily pattern level 2. Statistical analysis has shown that stop frequency is a strong function of the tour mode, time of day, and destination, as well as of household composition (especially for pick-ups and drop-offs). Thus, it can be quite effectively modelled at the tour-level, conditional upon the known (modelled) tour mode, time of day, and destination.

7. Long-Term Research Directions

Several challenging issues have emerged after these first recent experiences in the development and application of the activity-based models in practice. In our view, the following topics should be addressed in order to refine and extend the model structure:

- The tour-related dimension should be better linked with the time-allocation and activity-episode dimensions. Although the formulation of the daily activity pattern is operational in terms of travel tours, it obscures to a certain extent the underlying set of activities and time allocation decisions. A modelling structure that starts by generating a set of activities, and then allocates the time spent on each in order to derive travel tours from this set would be preferable – the work of Recker, 2001, represents an interesting attempt to address this objective.
- Since activity/travel decisions are made by individuals, as well as jointly by entire households, new analytical structures must be developed that can incorporate a group-decision making mechanism rather than simply sequentially linking the choices made

by different household members – Gliebe and Koppelman, 2002, and Zhang *et al*., 2002, represent promising attempts in this direction .

- There is an ongoing discussion regarding the variability of micro-simulation and reconsideration of the feedback strategies that can assure reaching an equilibrium state. Several empirical strategies have been tested, and both empirical and theoretical estimates for the Monte-Carlo error have been obtained. However, open questions remain over the interpretation of the Monte-Carlo error, and how to manage, as well as exploit positively the variability of micro-simulation for planning decisions – further research and practical experience in line with reported by Castiglione *et al*., 2003 would be welcome.
- Activity-based travel demand modelling systems lead to a complicated structure of numerous intertwined multi-dimensional choices, with many alternatives, and highly differential degree of similarities between them. Conventional choice models are limited in this respect. More flexible analytical constructs that can treat complex choice situations and exploit the combinatorial nature of choice alternatives represent a challenging direction.
- The sequential modelling of individuals in the micro-simulation framework, in combination with system-wide constraints on mutual resources, has opened up the possibility to explicitly model competition for constrained resources; such as available housing stock in residential choice analysis, or available jobs in context of the workplace choice – the paper presented by Petersen *et al*, 2002 is devoted to this important aspect. Standard choice models that assume only the decision maker is "active," while the choice alternatives are "passive," prove to be too limited in this context. Bid-choice models that allow for interaction of two active choice agents represent a possible solution.
- To ensure behavioural realism, and to reduce all possible aggregation biases and "smoothing up" effects in modelling, a paradigm of direct expansion of observed daily activity/travel patterns across synthetic population segments, rather than constructive modelling of activity/travel patterns by various dimensions, has been introduced and is currently being tested as part of the TRANSIMS project.
- As a result of growing environmental concern, regional modelling procedures must now provide details of vehicle movements by specific vehicle type. This added dimension has to be addressed in all relevant choice models, including household car ownership, mode choice, and car allocation among the household members. This new requirement could be used in a positive way to generate new modelling techniques to keep track of household vehicle usage throughout the day. A prototype of car allocation model has been proposed by Wen and Koppelman, 1999 as a part of the integrated tour-formation system.
- While the first micro-simulation models typically used a breakdown of travel into three or four time-of-day periods, more recent attempts have been made to exploit the micro-simulation framework for a finer temporal resolution – at the level of hour or even less. Changing the temporal resolution has revealed a limitation of discrete choice models in the context of time-related and durational choices. Duration models of hazard-based type comprehensively described by Bhat, 2001, are currently being tested.

8. Acceptance of the New Generation of Travel Demand Models in Practice

Along with the current successes of the new-generation models, and the general sense that this approach represents a major breakthrough in travel demand modelling, it is also important to recognize the problematic side of these models, especially in how practitioners, planners, and final decision-makers may view them. For modellers, the clear and strong advantage of the new generation of models is their behavioural realism and their ability to come closer to an understanding and modelling of individual behaviour. This core concept of a focus on the individual and his or her behaviour may be less appreciated and misunderstood by practical planners, unless they see how it permits the travel demand models they use to better address their needs. Transportation planning decisions are generally based on aggregate forecasts of demand for and performance of transport facilities. In order to see the relevance and importance of micro-simulation of individual travel in the new models, practitioners need to first understand how this new approach leads to more realistic and more policy responsive forecasts – at the aggregate level. Once this is appreciated, there is then an opportunity for practitioners and transportation planners to also see the advantages that the disaggregate approach offers for a more full evaluation of transportation alternatives, such as augmented reporting and analysis capabilities for detailed user benefits and costs assessment.

As part of the development of new regional travel demand models within this emerging framework, for example for NYMTC and MORPC, *PB Consult* has passed through all stages of model development, including numerous discussions with local planners and users of the models, as well as the members of the Advisory / Peer Committee comprised of representatives of both transportation agencies and academia. Intensive discussions in this forum have included such frequent topics as model system design and principal advantages of the new activity-based and tour-based structures, specific estimation requirements and how to support them with travel surveys not specifically designed for the activity based approach, and special programming aspects of the model application system. Attention has been paid to how to achieve reasonable running times, as well as how to deal with the complexity of the computerized model set-up in terms of managing input/output components and user-friendly interface. The following critical points and concerns have been very commonly mentioned in this setting, and, in our view, must be addressed before the new generation of models can replace the conventional travel demand models in common practice:

- The new models are <u>more complicated</u> than the conventional ones; they create new modelling dimensions, as well as intricate linkages across various models that are less easily understood by practitioners and users of the models. All this makes the model output and sensitivity to the network changes less obvious. With the new models, it is important to retain the production of aggregate reports and outputs across the traditional dimensions (zonal tour/trip generation, origin-destination distribution, and modal split) so that make the final model outcomes are compatible with the prevailing modelling "culture" and commonly adopted analyses.

- Some practitioners have voiced a scepticism about the complexity of the model cascade, seeing in it more of an opportunity to introduce new errors, as well as the possibility of "compounding of errors," rather than yielding additional accuracy in the final results. As part of the response to this concern, it is important to demonstrate the real magnitude of hidden aggregation biases pertinent to conventional models, and to explain how these biases can be eliminated in the new model framework, using real numerical examples.
- Many practitioners point out that the new models may not have obvious advantages over conventional ones in terms of replication of traffic counts or other observed statistics for the base year. Moreover, in many respects it is easier to adjust a conventional travel model to fit base condition traffic counts exactly than activity-based micro-simulation model, because aggregate adjustments can be naturally incorporated into the aggregate model structure. In this regard, it is important to distinguish between model accuracy in terms of the replication of the base year observed data, and the responsive properties of the model that are related to the quality of the travel forecasts for future and changed conditions. These two properties of the model are not necessarily parallel. The main reason of the fully-disaggregate modelling of individuals is not that we hope to predict exactly the behaviour of each and every person. It is the desire to ensure realistic aggregate sensitivity of the model to changing transportation and land-use environment that we know cannot be adequately modelled directly at the aggregate level.
- Conventional travel demand models have created a certain modelling culture generally accepted by the transportation planning community. In particular, the behavioural component of the travel demand models has been greatly simplified, sometimes to the point of utilizing trip rates per person and household, while the trip origin-destination distribution, mode choice, and network simulation procedures have received the most attention and staff resources. Traffic engineering has been considered as the best background for travel demand modelling, since it covers the most important issues for network processing, while the trip generation and distribution models have been simple enough to learn quickly. The new generation of travel demand models has changed the proportion between the behavioural aspects of travel modelling versus network processing. Although the last is still as important as ever, the behavioural aspect has come to the foreground. Social science (in particular, understanding the demography, behavioural tendencies, structural shifts in household composition, evolution of activity/travel habits, etc) needs to be added to the transportation planning culture in order to create a more productive dialogue between the model developers and users.
- The variability of micro-simulation is still perceived by many as a drawback that complicates the comparison and unambiguous ranking of transportation alternatives. It is important to introduce into the planning culture an acceptance of handling the probabilistic outcomes of the travel demand models (maximum and minimum values along with averages), and to provide guidance on how to constructively exploit variability of

micro-simulation in order to support the decision-making procedures. It is also important to explore in additional research the magnitude of Monte-Carlo error, both theoretically and empirically in order to have reasonable strategies and application protocols for different types of projects and model applications. It is true that the current regulatory framework in the US is not supportive of variable model results, so strategies must be developed to manage variability, while at the same time proponents of the new generation of models should press regulators to rethink their current stance.

- The content and scope of traditional household travel surveys requires reconsideration in view of the activity-based and tour-based dimensions. The sample size of the survey (typically, 4,000-5,000 households) can impose serious restrictions on the model structure and segmentation. Since, the micro-simulation technique essentially reduces any limitation on model segmentation (number of travel purposes/activity types as well as number of household and person types), it is the sample size of the travel survey used for model estimation that limits the further disaggregation of the model components and level of detail, not the difficulty of accommodating many segments in model application (as is the case of conventional models). It is important to substantiate the necessary sample size and scope of the new travel/activity surveys that are going to be used for the model development, as well as to consider the usefulness of combining standard surveys implemented in different regions.

There are several new modelling components that are especially attractive for practical planners in view of their direct linkage to the actual planning issues and project. These aspects of the new generation of travel demand models should be in the focus of discussions with new potential clients and MPOs that may consider an activity-based micro-simulation model as alternative to their existing conventional model. In particular, there is generally an agreement on the following points that are favourably accepted by practitioners:

- It has been generally relatively easy to explain the advantages of the tour-based modelling technique in terms of the value of models that consistently account for mode, destination, and timing choices for all linked trips. It is more difficult to explain how the tour-based technique actually works, in part because the normal set of dimensions for tour modelling includes seven components (primary destination, entire-tour time of day, entire-tour mode combinations, stop frequency, stop location, trip time of day, and trip mode), while for trip-based modelling, only three components (destination, time of day, and mode) are considered. However, actual visualized examples that appeal to the practical intuition, rather than describing the mathematical structure help. In general, practitioners respond with interest and understanding to examples of how conventional models that treat each trip separately are forced to function with less than full information, and produce conflicting and illogical choices. A constructive discussion normally arises around the common over-sensitivity of the conventional models (a long-standing criticism) that may be well attributed to ignoring linkages across trips within the same tour. In this regard, the argument that a tour-based model has the tendency to exhibit a reasonable conservatism, compared to a conventional model, is generally well accepted.

- A similar appreciation of the improved representation of travel behaviour in the new models is also usually shown with a favourable response to the incorporation of intra-household interactions in the model. This component also normally works in the same direction ensuring a more realistic conservatism of the model, limiting volatility with off-setting interactive components. High-Occupancy-Vehicle (HOV) facilities and differential-by-occupancy toll strategies facilities are commonly a major focus of transport planning in US, thus, the explicit modelling of joint travel that is believed to make forecasts for such projects more realistic, may be presented as a clear advantage of the activity-based models over conventional ones. There is a distinct discrepancy between the conventional planning approach, focused on inter-household work HOV travel, and the reality that upwards of 75% of HOV travel is intra-household based and carried out for non-mandatory purposes as reported by Vovsha *et al.*, 2003. The new generation models can successfully capture the second type of HOV travel and, in doing so, may reorient the discussion of HOV travel and facilities in a more productive direction.
- Conventional travel demand systems rarely have reasonable and sensitive time-of-day models, since it is very difficult to incorporate a time-of-day choice model in the aggregate framework without significant technical difficulties stemming from the required additional segmentation of all matrices by travel segments and person types. It is actually the time-of-day choice dimension that benefits most from the activity-based micro-simulation approach, since it can incorporate advanced duration/scheduling models that are sensitive to all person, household, and zonal characteristics, with virtually unlimited segmentation. It is important to stress that in the new modelling framework tours, trips, and corresponding activities are scheduled in a consistent way for each individual; thus, final time-of-day trip matrices are aggregated from these internally-consistent individual daily schedules, while in the conventional modelling framework time-of-day model operate with abstract aggregate matrices, where control on consistency at the individual level is inevitably lost.

It has been recognized that it would be beneficial to develop a conventional model and a new activity-based model in parallel, for the same region (based on the same surveys and other data sources) in order to compare them in various applications. This type of comparison is planned by *PB Consult* in the framework of the HGCOG model improvement project, where the existing conventional model is being maintained and enhanced for several years, along with the parallel development of a new activity-based model. Another important initiative has also been undertaken by the US Transportation Research Board in the formation of a new Sub-Committee on "Moving Activity-Based Approaches to Practice," a group that will sponsor related research, and coordinate the review and the dissemination of information regarding the growing number of activity-based models found in application.

9. CONCLUSIONS

Several conclusions regarding the experience to date with activity-based modelling in the US can be drawn:

- There is a growing interest and an increasing number of applications of travel demand models of the new generation. These new models are characterized by an activity-based conceptual platform, using the tour as the base unit for the modelling of travel, and the use of a micro-simulation technique that operates on households and persons at the fully-disaggregate level. The new generation of models brings a behavioural realism to the travel demand forecasting process, ensuring an internal logical consistency among the various activity/travel components for each household, person, and tour.
- The new generation of models is characterized by crucial changes in the structure of these models, compared to conventional models. Although these new modelling structures are evolving rapidly, and are following somewhat different specific paths of developments, it is already possible to summarize the basic structural features of the new generation of models. Among them is the explicit incorporation of intra-household interactions, a significant and important new component that has been entirely missing in the conventional travel demand models.
- The new generation of models is based on the detailed classification of activities and travel segmentation. In particular, activities are grouped by type (mandatory, maintenance, discretionary) and setting (individual, allocated, joint) where a special modelling technique is applied for each particular type and setting.
- The skeleton of the new travel demand model can be outlined as a sequence of conditional choices that include long-term level decisions, daily pattern/schedule level, tour level, and trip level.
- The first and recent experiences of development and application of the new generation models has revealed numerous challenging issues that should be addressed in future research. The include a better linkage between the activity generation/scheduling stage and travel stage, exploration of the variability of micro-simulation, incorporation of continuous duration models, and many others.
- Full acceptance of the new generation of travel demand models in practice will be conditional on constructive communication and cooperation among modellers, researchers, practitioners and ultimately regulators. It is important to effectively promote the development and application activity-based models and demonstrate their clear advantages to practical planners in a meaningful way. For the larger transportation planning community, the most compelling aspects of activity based models may be their conceptual consistency, added policy responsiveness, and their inherent realistic conservatism. In contrast, conventional models are over-simplified, are unable to model certain policies, and are frequently oversensitive to forecast inputs. Demonstrating their clear advantages seems the best strategy for the promotion and eventual widespread acceptance of the new generation of models.

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