NEW APPROACHES TO TRAVEL FORECASTING MODELS: A SYNTHESIS OF FOUR RESEARCH PROPOSALS

FINAL REPORT
JANUARY 1994

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Prepared for
U.S. Department of Transportation Federal Highway Administration
Federal Transit Administration Office of the Secretary
U.S. Environmental Protection Agency

Distributed in Cooperation with
Technology Sharing Program
U.S. Department of Transportation
Washington, D.C. 20590

DOT-T-94-15

Sponsored by U.S. Department of Transportation, Federal Highway Administration, Federal Transit Administration, Office of the Secretary, Environmental Protection Agency, Department of Energy, Travel Model Improvement Program

ABSTRACT

In July 1992, the Federal Highway Administration (FHWA) issued a solicitation for proposals to redesign the travel demand forecasting process. The purpose of the solicitation was to enable travel behavior researchers to explain how transportation planning models should and could be improved to meet the new forecasting requirements brought on by recent legislation, to address the impacts of new transportation technology, and to exploit the travel behavior theory and methodology that has developed over the past two decades.

This paper presents a summary and synthesis of the ideas presented in the four research reports. Its purpose is not to evaluate the merits or deficiencies of individual approaches, nor to recommend an overall "winner" among the four proposals. Rather, it is to identify common themes suggested by several of the research reports, to point out what appear to be critical elements missing from some approaches, and to combine the best aspects of the four approaches into a research plan for improving the current

generation of travel demand models. The remainder of this report is divided into three major sections. Section 2 presents brief summaries of each of the four research reports, including underlying behavioral theories, methodological enhancements, and data requirements. Section 3 extracts and discusses the common themes from the four research reports, and identifies certain gaps or areas where further elaboration seems necessary. In Section 4, a preliminary research plan is proposed for activities for which there seems to be general support among the research reports, or for an activity oriented toward a specific approach that seems particularly promising, but requires further elaboration before its potential can be properly evaluated.

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The Department of Transportation, in cooperation with the Environmental Protection Agency and the Department of Energy, has embarked on a research program to respond to the requirements of the Clean Air Act Amendments of 1990 and the Intermodal Surface Transportation Efficiency Act of 1991. This program addresses the linkage of transportation to air quality, energy, economic growth, land use and the overall quality of life. The program addresses both analytic tools and the integration of these tools into the planning process to better support decision makers. The program has the following objectives:

1. To increase the ability of existing travel forecasting procedures to respond to emerging issues including; environmental concerns, growth management, and lifestyle along with traditional transportation issues,
2. To redesign the travel forecasting process to reflect changes in behavior, to respond to greater information needs placed on the forecasting process and to take advantage of changes in data collection technology, and
3. To integrate the forecasting techniques into the decision making process, providing better understanding of the effects of transportation improvements and allowing decisionmakers in state governments, local governments, transit operators, metropolitan planning organizations and environmental agencies the capability of making improved transportation decisions.

This program was funded through the Travel Model Improvement Program.

Further information about the Travel Model Improvement Program may be obtained by writing to:

Planning Support Branch (HEP-22)
Federal Highway Administration
U.S. Department of Transportation
400 Seventh Street, SW
Washington, D.C. 20590

1. INTRODUCTION

In July 1992, the Federal Highway Administration (FHWA) issued a solicitation for proposals to redesign the travel demand forecasting process. The purpose of the solicitation was to enable travel behavior researchers to explain how transportation planning models should and could be improved to meet the new forecasting requirements brought on by recent legislation, to address the impacts of new transportation technology, and to exploit the travel behavior theory and methodology that has developed over the past two decades.

A total of four awards were made to: (1) Resource Decision Consultants, Inc. (RDC); (2) Caliper Corporation (Caliper); (3) the Massachusetts Institute of Technology (MIT); and (4) the Louisiana Transportation Research Center (LTRC). The awards enabled each team to expand their proposals into a study design for additional research needed to develop their approaches into operational transportation planning tools.

This paper presents a summary and synthesis of the ideas presented in the four research reports. Its purpose is not to evaluate the merits or deficiencies of individual approaches, nor to recommend an overall "winner" among the four proposals. Rather, it is to identify common themes suggested by several of the research reports, to point out what appear to be critical elements missing from some approaches, and to combine the best aspects of the four approaches into a research plan for improving the current generation of travel demand models.

The remainder of this report is divided into three major sections. Section 2 presents brief summaries of each of the four research reports, including underlying behavioral theories, methodological enhancements, and data requirements. Section 3 extracts and discusses the common themes from the four research reports, and identifies certain gaps or areas where further elaboration seems necessary. In Section 4,a preliminary research plan is proposed for activities for which there seems to be general support among the research reports, or for an activity oriented toward a specific approach that seems particularly promising, but requires further elaboration before its potential can be properly evaluated.

2. SUMMARY OF RESEARCH REPORTS

This section presents a brief summary of each of the four reports commissioned by FHWA.

2.1 Resource Decision Consultants, Inc. (RDC)

The submission by Resource Decision Consultants, Inc. (RDC) proposes a new generation of transportation forecasting models based on three paradigm shifts from the current generation of models. These paradigm shifts are described below.

1. Activity-based vs. trip-based

Current transportation forecasting models use trips as the unit of analysis. The next generation of forecasting models should focus on activities, with travel being one of several options for satisfying the activity. This shift will enable the models to address issues related to the substitution of non-travel alternatives, the use of non-motorized travel modes, and trip chaining.

Focusing on activities will also permit the incorporation of such constraints as interpersonal dependencies among household members, time constraints related to hours of operation of activity sites, work schedules, expected activity duration, and multi-day scheduling of activities.

2. Stochastic microsimulation vs. deterministic aggregate extrapolation

Current transportation forecasting models use statistical correlations of variables aggregated to some spatial unit (e.g. traffic analysis zones) to develop stable

Parameters which are used for forecasting future travel demand. Simulation techniques should be used on the specific trips made by individual household members to develop stable parameters, and combine them with sample enumeration procedures to produce area-wide traffic patterns. The use of microsimulation will enable the models to retain greater sensitivity to transportation attributes such as congestion by time period, localized parking costs and availability, availability and timeliness of traffic information, etc.

3. Dynamic longitudinal analysis vs. cross-sectional analysis

Current transportation forecasting models rely on cross-sectional survey data to represent the travel demand response to variations in transportation attributes. There should be more extensive use of longitudinal panel surveys to more accurately reflect travelers' responses to specific changes in the transportation system. The analysis of longitudinal data will enable the models to examine the effects of adaptation, including the perception of change and asymmetric responses to the magnitude and direction of change.

These paradigm shifts are seen as necessary in order for the models to respond to new analytical requirements brought about by the Clean Air Act Amendments (CAAA) to assess emissions reductions and the impacts of specific transportation control measures (TCM).

These new analytical requirements include:

- sensitivity to travel by time of day;
- variability in travel patterns for non-work days;
- variability in vehicle fleet composition;
- consistency between socio-demographic forecasts, vehicle ownership, and travel behavior;
- sensitivity to factors which effect mobile emissions -- number of trips, trip speed, time between trips;
- sensitivity to travel behavior options -- time of departure, destination choice, trip chaining, substitution of non-travel options;
- asymmetric responses to the direction and timing of a TCM strategy;
- better socio-demographic and spatial-temporal resolution;
- inclusion of both passenger and goods movements;
- incorporation of macro-level impacts of demographic and economic trends;
- better understanding of vehicle ownership decisions;
- better understanding of the relationship between transportation infrastructure and land use.

The new transportation model framework proposed by RDC is called the Sequenced Activity-Mobility System (SAMS). The key features of SAMS are summarized below:

1. Activity

The model framework is based on the premise that travel is derived from the need to pursue various personal or household activities. Under this premise, an individual's daily pattern of activities is modeled in its entirety, as a function of his/her role in the household, and influenced by various constraints including time availability, access to alternative travel modes, coordination with other household members, etc. In some instances, activities requiring travel may even be replaced by non-travel options (e.g.,work at home). The interaction of activities and constraints also leads to a multi-criteria approach for modeling choice of activities, activity locations, and benefits, beside value-of-time.

2. Incorporation of behavioral dynamics.

The model framework explicitly treats travel behavior as a process of adaptation. Adaptation implies that changes in travel behavior occur only when there is sufficient change in the benefits or costs of engaging in a particular activity to overcome the inertia associated with continuing present behavior. Adaptation also allows for changes in the absence of complete information, whereby the individual may engage in a trail-and-error learning process. Response may also be asymmetric to both the direction and magnitude of change. This implies the need for longitudinal data to examine and develop reasonable models of adaptive travel behavior.

3. Microsimulation Of system dynamics.

The various urban processes that influence travel behavior are treated as endogenous rather than exogenous variables. For example, decisions of land development, employment site and commercial location, and residential location are all explicitly modeled, based on factors that include the results of other decision models and the transportation system.

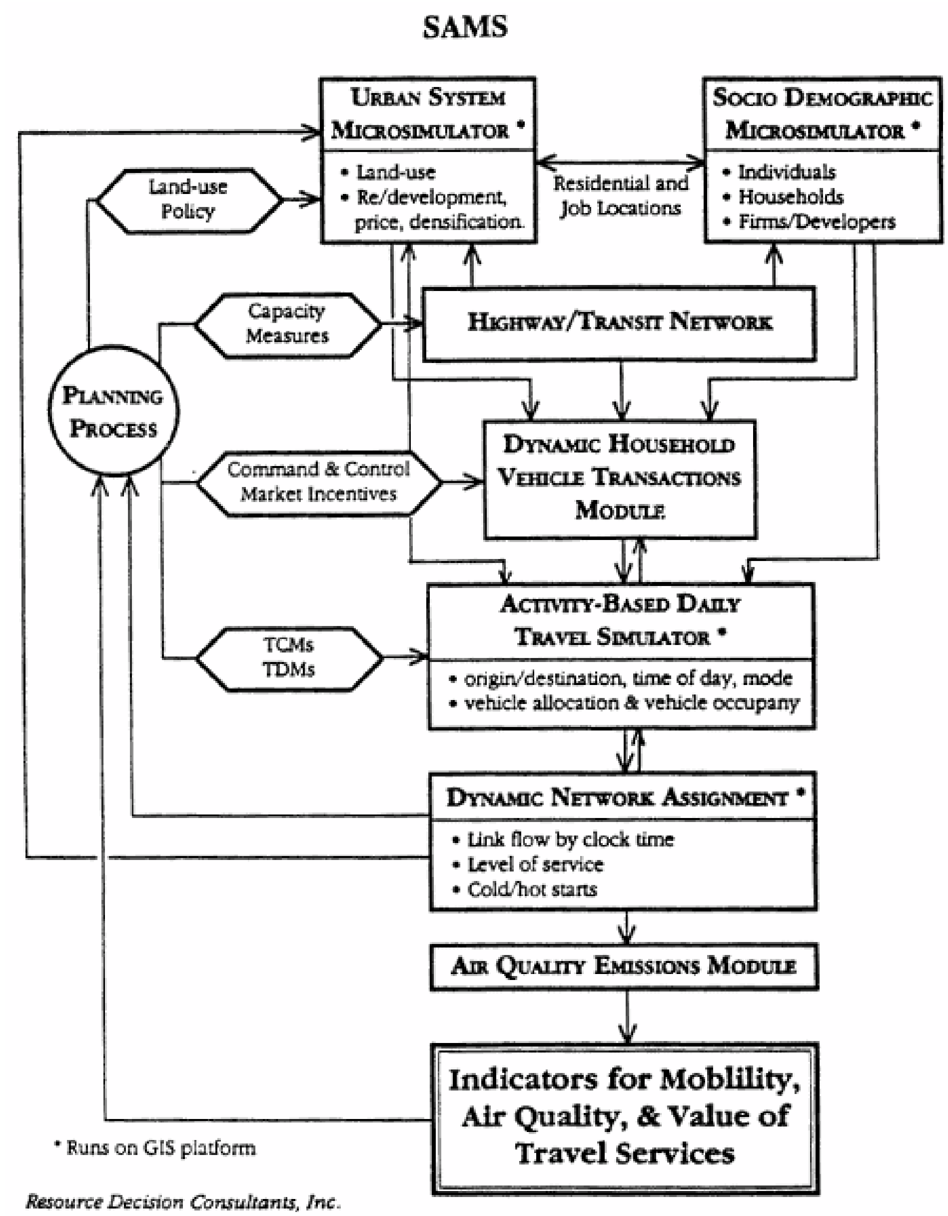
4. Analysis performed on a GIS platform.

Travel is simulated at the level of the individual tripmaker going from specific origins to destinations, rather than from aggregate zone centroid to zone centroid. GIS technology is proposed as a platform for the storage, integration, analysis, and presentation of model results, and the urban transportation network is derived from existing street centerline digital spatial databases, rather than created as an abstract representation of key routes.

5. Dynamic network model.

Trips are loaded incrementally on the transportation network as a function of origin and time of departure, and are removed from the network when they reach their destination. The location of each trip on the network is computed at specified time intervals based on its previous location, current route, and speed. Volume to capacity ratios are recomputed for each link based on current loads, and new link speeds are computed for the next time period. Trips are then rerouted based on the revised link speeds to provide a more dynamic representation of traffic congestion over time.

SAMS consists of several interconnected modules as shown in Figure 1. Each module represents some aspect of the urban travel decision process. The modules are described briefly below:



1. Activity-Mobility Simulator (AMOS)

This module is the heart of SAMS. It consists of an activity-based model of travel behavior that generates a daily travel itinerary for an individual including departure times, travel modes, destinations, chained trips, initial routes, and travel partners. The model receives input in the form of identified activity options, household and mode constraints, and decision parameters from other modules.

2. Dynamic Network Simulator (NET)

This module loads trips from AMOS onto the transportation network based on departure times and continually updates the link speeds and volumes based on link loads. The module provides vehicle speeds and VMT for use in emissions models, detailed system performance measures for use in AMOS, and aggregate performance measures for feedback to the urban system microsimulator.

3. Vehicle Transactions Simulator (VTS)

This module simulates the vehicle acquisition process, including decisions to purchase, dispose, and replace a vehicle, as well as vehicle choice decisions. The model uses input data on household demographics, the transportation network, urban land use, and vehicle marketing policies to generate the number and type of vehicles available to the household. This, in turn, serves as a travel resource in AMOS.

4. Socio-Demographic Simulator (SEDS)

This module simulates the evolution of households and firms in the urban area as functions of general demographic and economic trends, local land use policies, and the urban transportation system. The module generates various parameters and constraints used in AMOS, VTS, and the Urban Systems Simulator.

5. Urban Systems Simulator (USS)

This module simulates urban development, including patterns of land use and price for industrial, commercial and residential sectors, as functions of general economic trends, local land use policies, and the regional transportation system. The module generates parameters for both SEDS and VTS.

The data requirements for developing and validating SAMS are extensive. Since AMOS is based on the premise that travel is derived from the need to satisfy household activities, data from household activity diaries are required. RDC recommends that, to effectively model intra-household activity tradeoffs and multi-.day activity scheduling, diaries should be collected from all household members over several days. In order to model adaption behavior and longer term purchasing decisions such as vehicle transactions and residential choice, there is also a need to conduct longitudinal panel surveys. Panel information can be approximated in the early years of model development using retrospective questions. Stated preference data are also needed to estimate behavioral responses to system changes and new technology that have not yet been implemented. RDC points out that tested survey methodologies exist for all required data, and that the SAMS framework can accommodate evolutionary improvements in the models as more data become available.

RDC also discusses a three stage model validation approach, beginning with a validation of the stated preference approach and models, followed by validation of the individual model components, and finally the entire model system.

2.2 Caliper Corporation (Caliper)

The submission by Caliper proposes a reformulation of the current travel demand modeling process by focusing on four fundamental improvements to traffic assignment models:

1. Modeling joint choices as supernetworks

Many of the travel choices that are currently modeled as sequential decisions (e.g., destination, access and line-haul mode choice) can be more effectively modeled as joint choice decisions using traffic assignment models. Based on the research of Sheffi, et.al., these choices can be represented by pseudo-links in an expanded transportation network and therefore solved in the same way as one would solve for actual routes in a conventional traffic assignment model. By consolidating multiple choices in one model, many of the deficiencies of current sequential models, such as independence of irrelevant alternative (IIA) bias, aggregation issues, and joint versus conditional choice assumptions can be reduced or avoided.

2. Dynamic, stochastic network equilibrium models

Static, one-period traffic assignment models represent a gross simplification in demand modeling that cannot address many of the current issues associated with the build-up and dissipation of highway traffic during peak periods, or model strategies aimed at modifying peaking phenomena. Current traffic assignment models should be replaced by a dynamic assignment process which allows differentiation of network level of service by discrete time periods, and computes flows on downstream links as functions of flows on connecting links in prior time periods.

Dynamic network models should also be linked with a stochastic user equilibrium (SUE) assignment procedure. Unlike more deterministic approaches, SUE does not select a single best path, but assigns flows to alternative paths as a function of their relative generalized costs. SUE allows for variations in user-defined criteria such as route biases, incomplete information or behavioral inertia, and produces a more realistic dispersion of flows on the network. Combining dynamic assignment with SUE is seen as a major methodological challenge, but one that should be feasible given current computer technology.

3. Integration of traffic engineering models

Another deficiency in current assignment models is their reliance on average link speeds as the primary cost criterion when, in fact, intersection delays present a far more significant impact on overall network travel times. More realistic representations of intersection effects can be obtained by integrating traffic simulation models and assignment models.

4. GIS technology for database management and model integration

The above model framework requires much more detailed network data than conventional travel demand models and therefore needs an efficient spatial database management system to manipulate large volumes of spatial data, to integrate data with traffic assignment models, and to present the model results in visually understandable and comparable displays. GIS provides an excellent platform for such data manipulation, model application, and display.

In order to effect the above mentioned improvements, Caliper proposes a list of specific research projects that should be carried out. These projects and specific issues which need to be -addressed are summarized below.

4. Formulation and Implementation of Unified Supernetwork Models.
    1. Determine what level of aggregation is appropriate in representing supernetworks, recognizing that there is a tradeoff between the realism of more detailed networks and the practical limitations of computer processing speed and data requirements.
    2. Develop practical methods for estimating link disutilities in supernetworks, especially for currently non-existing options (e.g., new modes).
    3. Develop more efficient solution techniques for stochastic user equilibrium.
    4. Develop practical calibration techniques for traffic assignment models in general, and for unified, joint choice assignment models in particular.

5. Research on Dynamic Assignment Models.
    1. Investigate alternative formulations of the dynamic assignment problem and alternative solution algorithms for specific formulations.
    2. Examine the tradeoffs between results and computational effort for such parameters as network detail, time granularity, and flow precedence constraints.
    3. Test dynamic assignment models using empirical data and real-world networks.
    4. Investigate the extension of stochastic user equilibrium to dynamic assignment.

6. Traffic and Pollution Model Integration Research.
    1. Determine appropriate network representations for intersections in traffic assignment models.
    2. Modify assignment algorithms to allow consideration of link interactions at intersections and traffic movement under saturated flow conditions.
    3. Develop estimates of speed profiles and vehicle fleet mix by link for use in emissions models.

7. Computational Support for Research.
    1. Establish a computational laboratory and/or set of software tools to facilitate travel demand research. The laboratory should be portable across operating systems and hardware platforms and accessible to all researchers and potential users. The laboratory should also include a library of both synthetic and empirical data for testing new models and algorithms.
    2. Enhance GIS technology to better support travel demand modeling. Potential enhancements include the incorporation of a temporal dimension, development of object-oriented methods, and support for more extensive manipulation of networks.

8. Data Requirements.
    1. Travel demand surveys to support research and local planning should be conducted as soon as possible to maximize compatibility with the journey-to-work data available from the 1990 Census.
    2. Much of the data to support the above research could be obtained using typical home interview surveys, but with greater emphasis on route choice and trip timing. Surveys should also make greater use of stated preference questions.
    3. FHWA should support the collection of several research datasets from different urban environments. Data collected in conjunction with naturally occurring system changes and demonstrations projects should be documented and made available to researchers for developing and validating travel demand models.
    4. New methods for collecting and expanding travel demand data should be explored.

2.3 Massachusetts Institute of Technology (MIT)

The submission by MIT proposes a comprehensive travel demand modeling framework based on the current "best practice" of disaggregate travel demand models. In reviewing the current state-of-the-art in travel demand modeling, MIT concludes that most of the activity-based and trip chaining models developed to date are descriptive and not sufficiently developed to be useful forecasting tools. Similarly, research in the field of information technology (IT) and its impact on travel choices has not yet progressed to the point where empirically validated models have been developed.

MIT identifies the following set of functional requirements for the next generation of travel demand models. The models must:

- be sensitive to changes in transportation and information technology;
- incorporate new travel and no travel options to capture the effects of changes in household and individual activity patterns;
- reflect the effects of changes in family structures, demographics, and activity opportunities;
- accurately evaluate environmental, energy, and economic impacts of governmental policies;
- capture the effects of behavioral adaptation of individuals and households to changing urban and transportation environments;
- incorporate temporal and spatial variations in daily travel patterns as required for dynamic network analyses and air quality models.

The overall model framework proposed by MIT is a hierarchical set of disaggregate choice models based roughly on the temporal duration of the choice decision, with the choice sets for more dynamic choices (e.g., mode or route choice for a specific trip) constrained by prior choice decisions (e.g., residential location or auto ownership). A major enhancement to this "best practice" model framework is the explicit inclusion of IT choices in each of the models.

MIT also identifies two methodological advances that require further research and testing. These are:

9. Dynamic discrete choice models with evolving choice sets.
   The choice set considered by individuals, and the attributes and perceptions of individuals to different alternatives are dynamic, particularly in the presence of IT. Research is needed to:
   1. incorporate individual attitudes and perceptions in the choice process, both in choice set generation and alternative selection;
   2. model the effects of first-hand experience and new information on the attitudes and perceptions of individuals as they affect subsequent choice situations.
10. Fuzzy set theory and approximate reasoning methods to model perceptions and information processing.
   Fuzzy set theory was developed as a tool to deal with problems that are characterized by uncertainty and vagueness. Research is recommended to explore the application of fuzzy set theory to:
   1. model system attributes as perceived by users (e.g., trip duration), and to relate to abstract concepts rather than to exact numerical measures;
   2. model overall decision processes based on fuzzy perceptions or incomplete information.

MIT proposes a multi-year model development program implemented in three stages, with parallel tasks undertaken to develop operational models and to conduct necessary research to support model development effort in subsequent stages. The specific tasks undertaken in each stage include:

11. Stage 1
   1. Select an existing transportation planning model system and enhance it with current state-of-the-art modeling approaches, including the incorporation of activity-based decisions, simplified trip chaining, within-day travel choice dynamics, and interfaces to air quality and transportation control measures prediction modules.
   2. Identify main factors and constraints on household and individual activity decisions. Develop models to analyze: (1) employment decisions, (2) residential location decisions, (3) vehicle ownership; (4) IT equipment ownership; (5) activity time and resource allocation; (6) tele-services subscription; (7) tele-commuting adoption; (8) activity/travel scheduling; and (9) en-route travel choices. Develop analytical tools to capture dynamic and adaptive behavior.
12. Stage 2
   1. Augment the Stage 1 model system to include tele-commuting and other shifts in activity patterns. Incorporate the effects of IVHS (e.g., traveler information systems) on dynamic travel choices; use both revealed preference and stated preference data to estimate activity shifts.
   2. Develop candidate models to analyze the decisions of commercial/industrial developers, firms, and residential developers. Incorporate data collected from IVHS and IT implementation to enhance existing data. Calibrate and test enhanced model system to analyze accuracy of predictions and sensitivity to policy options.
13. Stage 3
   1. Validate and test a preliminary version of the overall model system, including urban activity models and activity shifts.
   2. Make further refinements in urban development decision models.

2.4 Louisiana Transportation Research Center (LTRC)

The submission by LTRC proposes to replace the traditional Urban Transportation Planning System (UTPS) modeling system by an activity-based model of travel named SMART (for Simulation Model for Activities, Resources, and Travel) that integrates household activities, land use patterns, traffic flows, and regional demographics. The core of the proposed model system is a household activity simulator that operates in a GIS environment and determines the locations and travel patterns of household members daily activities in three categories: mandatory, flexible, and optional.

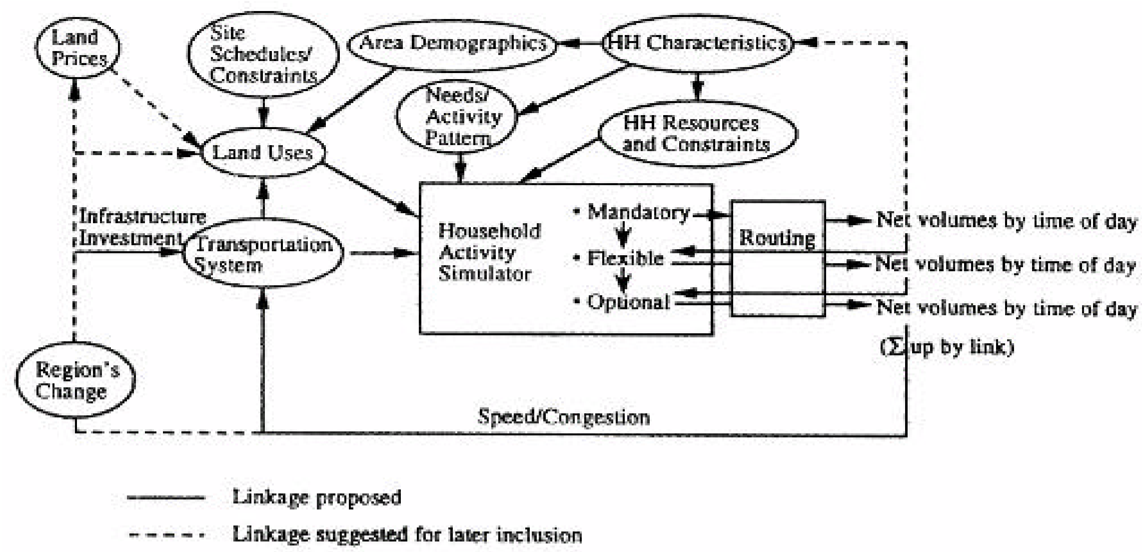
SMART is based on the following assumptions about travel behavior.

- The household is the primary decisionmaking unit. Household members carry out household decisions by engaging in various activities.
- Decisions to participate in activities (as well as who participates) are the result of negotiation and role allocation within households.
- Travel decisions are derived from the pursuit of activities to satisfy household needs.
- Most travel is habitual; travel patterns do not commonly shift from day to day.
- Activities, not travel, should be the focus for understanding travel behavior.
- Households adapt to sufficiently large stimuli by changing activity patterns and consequently, travel within time and money constraints.
- Land use and transportation systems also adapt, over a much longer time frame, to serve changing household activity patterns. Congestion and accessibility represent one, but not the only influence on land use and activity site selection.

SMART consists of several interconnected sub-elements, as shown in Figure 2:

- Land use, defined by the amount of activity participation in sub-areas of the study region.
- Transportation system access, defined by intra-regional separation. System access is influenced by speeds output from the household activity simulator.
- Household characteristics, resources and constraints.
- Household needs, defined as a set of activities that must be performed by one or more household members.
- A household activity simulator which generates a set of activity patterns for a household that meets household needs within household constraints and minimize generalized travel costs.
- A trip routing procedure that assigns trips to routes stochastically, by location.
- Feedbacks between traffic congestion by time of day, and activity specification.
- Macrolevel to microlevel interfaces that permit the simulation of regional effects on household activities and the summation of household activities on regional growth.

In the household activity simulator, individual travel patterns are defined by first assigning mandatory activities (i.e., work, school, and some pre-arranged appointments) to fixed locations in space and time, and then adding flexible and optional activities around them, based on remaining time availability, activity location, and travel times to and from the activity. Mode choice is conditional on the household vehicle allocation decision; it is assumed that transit use is limited to household members without access to a



vehicle, or to those situations where transit has a generalized lower cost.

Calibration of the household activity simulator is based on a closure rule that minimizes the variations between actual (observed) and estimated activity patterns for mandatory activities. For flexible and optional activities, a minimum generalized cost criterion is used which minimizes the disruption to mandatory activity patterns subject to time and household cost constraints.

SMART uses a "random sample enumeration" method of forecasting. Under this procedure, the model operates sequentially on each household record and expands the resulting household trip pattern by factoring it up to the projected regional total households. The impacts of transportation system changes are forecast by simulating household activity patterns under the changed transportation system, identifying those households whose patterns change and then factoring up those households residing in the affected target areas. The impacts of demographic changes are forecast by changing the expansion factors for household categories to reflected the projected population shifts (e.g., more single parent households).

LTRC proposes a two phased research and development program to implement SMART as an operational transportation planning tool. The first phase is to validate certain key assumptions on which SMART is based. The second phase is to develop operational procedures for implementing SMART in an urban area.

Three key assumptions underlying SMART are: (1) that all household activities can be stratified into three categories -- mandatory, flexible, and optional -- based on their criticality in fulfilling the household's needs; (2) that the activities in which a household engages are determined by a relatively small set of forecastable household characteristics; and (3) that differences in the selection, location, and frequency of flexible activities can be estimated from knowledge about the locations where these activities can be performed and about the generalized costs of travel to the activity locations. These assumptions need to be validated through a behavioral research project involving a time-use survey of a set of households having diverse demographic characteristics and different activity and transportation options. The survey would result in a new travel behavior research database that could be used not only to validate the assumptions of SMART, but also to develop some prototype models. The survey would be preceded by focus group interviews of households representing specific demographic categories, and by in depth analyses of some existing travel diary databases.

In the second phase of the implementation plan, SMART would be developed and calibrated for a particular urban area. This phase could be implemented prior to completion of the time-use survey by using data collected from a conventional urban household travel survey. The model would be implemented using a GIS to link household trips with activity locations and the local transportation network and to fit each household activity pattern, beginning with mandatory activities, and then allocating flexible and optional activities based on available time and travel options.

3. COMPARISON AND SYNTHESIS OF APPROACHES

Although each of the four reports commissioned by the FHWA was prepared independently, with little or no collaboration among the authors, the recommended approaches exhibit a large number of common themes. Table I summarizes the major themes identified in the reports, showing, for each theme, which reports included it as a major component of their recommended model framework and which reports omitted it entirely. In this section, themes common to two or more reports are discussed.

3.1 Common Research Themes

For clarity in discussing the common research themes described in the reports, we have stratified the themes into three categories: behavioral assumptions, model methodology, and data requirements.

3.1.1 Behavioral Assumptions

The themes described in this section all relate to the theoretical assumptions of travel demand behavior which underlie the recommended models, and which, in many ways, direct the structure, methodology, and data requirements of the model.

3.1.1.1 Demand for travel is derived from the demand to engage in various activities.

Current transportation forecasting models use the "trip" (usually a vehicular trip) as the basic unit of analysis and prediction. However, most travel behavior research concludes that the decision to make a trip is really derived from a complex series of decisions including: (1) what activities to engage in; (2) whether the activity can be accomplished without vehicular travel; and (3) whether the activity can be combined with other activities. Consequently, by starting with the trip, current transportation forecasting models are unable to explicitly address issues related to: (1) the substitution of non-travel options (e.g., tele-commuting and tele-shopping), (2) the substitution of non-vehicular trips (e.g., walk trips); (3) trip chaining behavior; and (4) induced demand for travel.

Three of the four reports (RDC, MIT, & LTRC) explicitly recommend that the current "trip-based" model framework be replaced by an "activity-based" framework in which the demand for travel is derived from a more basic demand to engage in various activities. Activities represent various "goal-satisfying behaviors engaged in by household members."[1] Activities can be grouped into various categories (e.g., work, shop, recreation, mandatory, flexible, optional), and can be described in terms of where, when, and how long the activity takes place. However, an activity does not necessarily result in a trip. By modeling activities rather than trips, it should be possible to forecast a number which represents a realistic upper bound on the total number of trips that could be generated under a particular scenario.

Behavioral Assumptions	**RDC**	**Caliper**	**MIT**	**LTRC**
Travel Behavior is Derived from Activity Needs	X		X	X
Travel Behavior is Stochastic	X	X	X	
Travel Behavior is Conditional on Longer Term Choices	X		X	X
Travelers Adapt to Changes in Transportation Service Methodology	X		X	
Use GIS as Platform for Data Management, Model Integration, and Display	X	X		X
Use Dynamic Networks with Tirrie-Sensitive Loading	X	X		X
Expand Use of Disaggregate Choice Models		X	X	X
Use Microsimulation Techniques	X			X
Link Travel Demand Models with Emissions Models	X	X		
Model Joint Choice Decisions Using Supernetworks		X		
Link Travel Demand Models with Traffic Simulation		X		
Use SUE for Traffic Assignment		X		
Use Fuzzy Set Theory to Model User Perceptions			X	

Data Requirements	**RDC**	**Caliper**	**MIT**	**LTRC**

[1] See Section 2.4 (LTRC)

Household Activity Diaries	X		X	X
Stated Preference Surveys (for New Alternatives)	X	X	X	
Longitudinal Panels	X		X	X
Collect Before-After Data from Demonstrations	X	X	X	
Establish a Transportation Research Data Library	X	X		X
Detailed Network Data	X	X		
Household Travel Choice Surveys		X		X
Extensive Use of Census Data		X		
Use Choice-Based Samples			X	
Simulate Choice Situations Using Computer Simulation and Virtual Reality			X	
Use Focus Groups to Better Understand Household Decisionmaking				X

The decision to engage in an activity represents a complex interaction of household and individual roles and responsibilities; time constraints on both the individual and the activity; options on activity type, location, and duration; transportation options; and the perceived benefits versus costs of the activity. Many of the decision parameters are either known (i.e., fixed store hours), or can be grouped into a manageable number of categories for forecasting (e.g., household types). While each of the reports suggest a slightly different approach to modeling activity behavior, all of them rely heavily on the use of constraint parameters to reduce the number of choice options to a manageable size.

3.1.1.2 Travel behavior is stochastic rather than deterministic.

All four reports acknowledge that travel demand should be viewed as stochastic rather than deterministic behavior. This means that two tripmakers, faced with the same set of travel conditions and alternatives, may display different behaviors, and these behaviors will occur with some measurable level of probability. Stochastic models are based on the assumption that differences in individual biases or preferences, unidentified or unmeasured choice parameters, or different levels of information can result in a level of uncertainty in a predicted outcome. This uncertainty is assumed to be distributed according to some known probability function. Thus, while it is impossible to predict with certainty how one specific tripmaker will behave, it is possible to predict how the behavior of a group of tripmakers will be distributed.

Stochastic models are currently used extensively in mode choice, and to a lesser degree in trip distribution. However, while stochastic assignment models exist, they are used infrequently in practice, and trip generation models are almost exclusively deterministic. One report (Caliper) recommends the use of stochastic user equilibrium (SUE) in modeling route choice as a means of replicating actual travel patterns without having to severely distort observed link characteristics.

3.1.1.3 Travel behavior is conditional upon longer term choices of residential and employment location, vehicle ownership, and land use.

Three of the four reports (RDC, MIT, and LTRC) explicitly link daily activity and travel behavior with longer term decisions, including those made by the household/individual (i.e., vehicle acquisition, residential location) and those made by others (e.g., firm or store location, land development and use, zoning policies). These linkages are generally structured as constraints on the travel demand decision process. For example, vehicle availability for a specific trip depends on the number of vehicles owned by the household and their allocation among licensed drivers in the household. In the short term the number of vehicles is considered to be fixed. However, over the medium to long term, a model of household auto acquisition would be used to predict the number (and possibly type) of vehicles available to the household. This model would be driven by various socio-demographic variables (number of drivers, household/personal income), as well as by some aggregate measure of household stress related to the number of times a vehicle was desired but not available.

In each of the three reports, the longer term choices are handled as independent modules, with linkages to the household activity module as described above. In most instances, these modules are less well developed (in terms of identifying and quantifying key parameters) than the activity module. However, the overall structure of the activity model framework permits modules to be developed more or less independently, using default values as proxies for the products of uncompleted modules.

3.1.1.4 Travelers exhibit adaptive behavior in response to transportation system changes.

Current transportation forecasting models assume that travelers make rational economic choices in response to the values of existing transportation system parameters under steadystate, equilibrium conditions. These models cannot address issues related to adaptive behavior such as: (1) lags in response to a transportation price or service change; (2) differential responses depending on the direction of change; or (3) differential responses depending on the magnitude of change.

Two of the four reports (RDC & MIT) explicitly recommend that the new transportation forecasting models should have the ability to address adaptive behavior by analyzing data from longitudinal panels and before-after experiments to study the responses of specific individuals subjected to transportation service changes.

3.1.2 Methodology

The themes described in this section all relate to specific models or analysis methods which the researchers feel should be used to develop, calibrate, or apply the next generation of transportation forecasting models.

3.1.2.1 Geographic information systems (GIS) should be used as the platform for data management, model integration, and display.

GIS technology has advanced to the state where many of the difficult data management problems associated with transportation forecasting models (e.g., network building, creating and extracting data for transportation analysis zones, spatial aggregation of data), can be performed quickly and easily. Moreover, GIS provides a graphical display capability that enables the results of a transportation forecast to be communicated to policy makers and the general public in easily understandable maps.

Three of the four reports (RDC, Caliper, & LTRC) explicitly recommend that the next generation of transportation forecasting models utilize GIS technology as a platform for data management, model integration, and data display and presentation. Implicit in this recommendation is that the current practice of developing and coding separate, abstract transportation networks will be largely eliminated. Future transportation networks will be derived from existing geographically referenced digital databases (e.g., Census TIGER files), thereby minimizing much of the "artistic license" employed in selecting and defining which physical links to include in the abstract network. GIS will also permit greater geographic resolution in tracking trips between specific origins and destinations instead of from zone centroid to zone centroid.

3.1.2.2 The route choice/assignment model should be enhanced to incorporate time-sensitive network loadings and departure time decisions.

Current traffic assignment models assign trips to the network using a single origin-destination matrix that represents either an average daily traffic or average peak period traffic flow. While certain capacity restrained assignment algorithms may load trips incrementally, these incremental loadings bear no relationship to the temporal build-up and dissipation of traffic over the peak period. Consequently, current models are unable to evaluate the impacts of strategies to spread the peak or to divert peak period trips to off-peak times. The models are also unable to provide the necessary vehicle speed profiles needed by air quality models to accurately measure CO emissions.

Three of the four reports (RDC, Caliper, & LTRC) explicitly recommend research to develop an operationally efficient dynamic assignment model that incorporates time-sensitive loading of vehicles. Such a model would load trips onto the transportation network according to some user-specified time interval (e.g., a 3-hour peak might be divided into eighteen 10-minute intervals). After each loading, new link speeds would be computed based on the link volume/capacity ratios attributed to the newly loaded traffic and the progress made by traffic loaded in earlier intervals. New paths would be developed based on these revised speeds, and traffic would be routed along the network to a location commensurate with their speed and the assignment algorithm (e.g., all-or nothing, stochastic user equilibrium) over the specified time interval. These new locations would provide the basis for recomputing link volume/capacity ratios for the next time interval. The procedure requires significantly more computing capacity to keep track of flows over the time intervals, and requires more detailed temporal data on flows for model calibration. However, both requirements are seen as feasible given current computer technology and emerging automated data collection methods.

3.1.2.3 Expand the use of disaggregate choice models.

Three of the four reports (Caliper, MIT, & LTRC) suggest that disaggregate choice models still provide a theoretically sound, methodologically practical structure for analyzing and forecasting travel behavior involving choice decisions. The major issues associated with using; disaggregate choice models relate to: (1) more accurately identifying those travelers who actually have a choice, and (2) expanding the use of disaggregate choice models in current transportation planning practice.

3.1.2.4 Use microsimulation techniques to calibrate and forecast travel behavior.

Two of the four reports (RDC & LTRC) recommend the use of microsimulation techniques as a more efficient way to expand travel decisions based on household activities in representative distributions of urban area travel. Neither report provides sufficient information about microsimulation techniques to address questions of data requirements, calibration and verification, or forecasting, suggesting that this may be an area where significant research and development is needed.

3.1.2.5 Link travel demand models more closely with air quality emissions models.

The current state-of-the-art emissions models (i.e., MOBILES) have been developed largely independent of travel demand forecasting tools. Consequently, as noted in most of the research reports, the input requirements of the emissions models are not compatible with the output of the travel demand forecasts, either in terms of resolution or appropriate parameters. Ideally, emissions models require, in addition to vehicle miles of travel, vehicle speeds by link, trip length distributions, locations and durations of traffic queues, cross-correlated by time period and vehicle type. Much of this detailed, link specific temporal flow data can only be derived from a dynamic traffic assignment (see 3.1.2.2 above).

Two of the four reports (RDC & Caliper) recommend that improved emissions models be developed in closer collaboration with the next generation of transportation forecasting models to more fully take advantage of improved data, and to recognize the limitations of the model outputs. Caliper also recommends that traffic assignment models be more closely linked to traffic simulation models in order to obtain more realistic representations of intersection delays and to be able to address issues related to system-wide impacts of improved traffic management.

3.1.3 Data Requirements

Not surprisingly, most of the model enhancements described above require different or more detailed data than is needed for the current generation of transportation forecasting models. This section describes the types of new data recommended by the reports to support the next generation of models.

3.1.3.1 Household Activity Diaries.

In order to migrate from trip-based to activity-based travel demand forecasting models, it is necessary to collect data on activities, both those that result in a trip (as currently defined) and those that don't. Three of the four reports (RDC, MIT, & LTRC) recommend the collection of activity diaries to support model research and development. The level of effort proposed to collect the activity diaries varies, however. Initially, useful activity data can be obtained from several diaries that have already been collected, including conventional travel diaries and activity diaries collected in support of earlier research activities. Eventually, more extensive household, multi-day diaries will be required to capture interactions and role allocations among household members and consolidation or deferrals of activities over several days.

3.1.3.2 Stated Preference Surveys.

Three of the four reports (RDC, Caliper, & MIT) identify the problem of forecasting use of a new option (e.g., a new transit mode or an electric vehicle) when no one in the study area population has any personal experience with using it. Simple hypothetical questions related to expected use result in serious overestimation; more sophisticated survey methods (e.g., conjoint analysis) are not well understood by transportation planners. Each of the three reports recommends that efforts be devoted to developing practical survey procedures that can be used to obtain valid estimates of market penetration for new travel options.

MIT further recommends that additional research be devoted to the use of computer simulation and emerging concepts in virtual reality to provide survey respondents more realistic representations of choice situations for new travel options.

3.1.3.3 Longitudinal Panels.

Current transportation forecasting models are typically calibrated using cross-sectional data from an area-wide travel survey. Implicit in this calibration is the assumption that variations in traveler responses to geographic differences in transportation service levels at one point in time can be used to approximate traveler responses to changes in transportation service levels over time. At least two of the reports (LTRC & MIT) suggest that this assumption may not be valid due to unresolved questions about adaptation and response lags, and the effects, of macro-level economic and demographic changes that may impact the entire study area.

Three of the four reports (RDC, MIT, & LTRC) recommend that longitudinal panel surveys be conducted to explore changes in the behavior of specific travelers over time in response to changes in demographics and life style, introduction of new transportation options, and changes in transportation service levels. Three reports (RDC, Caliper, & MIT) recommend that before and after surveys should be conducted in conjunction with various transportation service experiments or demonstration projects to better monitor the impacts of the service change, and contribute to the growing knowledge, base on traveler responses.

3.1.3.4 Establish a Transportation Research Database Library.

Household activity diaries, stated preference surveys, and longitudinal panels are major data collection efforts that are both time consuming and costly to conduct. Surveys conducted in support of local transportation planning must often compromise on sample size, number of questions asked, or number of call backs to keep within allowable budgets. Consequently, the value of these data collection activities to other travel behavior researchers is often limited.

Three of the four reports (RDC, Caliper, & LTRC) recommend the establishment of a travel behavior research database and/or data library, supported by Federal funds, to provide the requisite data needed for development of transportation forecasting models. Current travel data collection efforts, such as the Seattle longitudinal panel, should be included, and possibly enhanced by the availability of Federal grants or demonstration funds. The survey data would be available to all researchers along with appropriate documentation and background material.

3.1.3.5 Detailed network information.

Two of the four reports (RDC & Caliper) suggest that more detailed network information is needed to obtain more precise measures of transportation level of service parameters. This information is needed to support more detailed emissions models, and to analyze the impacts of various microscale traffic management strategies. This network information can be derived and utilized through GIS technology which will allow models to be calibrated using point-to-point trip records.

3.2 Missing Elements

While each of the reports provides a reasonable overview of their proposed approach, none of them is complete in terms of fully addressing all of the problems that would have to be overcome to produce an operational set of transportation forecasting models. (Note: The FHWA did not require a complete study design)

The Caliper report focuses on the trip assignment process, discussing in detail the merits of stochastic user equilibrium, dynamic networks with time-sensitive loadings, and the integration of traffic simulation into the assignment process. Extensions of the assignment process to other travel decisions (e.g.,mode choice) would be handled through the use of "supernetworks", or the coding of pseudo network links to represent higher level travel decisions. There is no discussion of the interaction between travel and higher level mobility discussions like residential choice, vehicle acquisition, or even trip generation.

The MIT report provides an overall framework for transportation forecasting models, relying extensively on the use of disaggregate choice models as the primary modeling methodology. The report focuses heavily on the influence of information technology on both mobility and dynamic travel decisions, and discusses how and where information technology variables should included into the various choice models. There is relatively little discussion of issues other than information technology, such as transportation control measures to support air quality attainment, or the introduction of new transportation options. It is not clear from this report what modifications would need to be made to disaggregate choice models to effectively address these other, equally critical transportation planning issues.

The LTRC report proposes a basic change in methodology from disaggregate choice models to a microsimulation of household activities under spatial and temporal constraints. There is some discussion of how a microsimulation approach would be calibrated, but little discussion of how the methodology would expand from individual samples to an entire urban area travel pattern. The proposed approach also relies on a number of fundamental assumptions about activities (e.g., classification into mandatory, flexible, and optional activities) that requires some empirical verification. Finally, the report focuses on household/individual activities that lead to travel; it does not expand the approach to more long-term mobility or urban development decisions.

The RDC report provides the most comprehensive framework for an integrated set of transportation forecasting models. Like LTRC, the RDC approach proposes to shift from disaggregate choice models to a microsimulation approach. This approach is incorporated throughout the model framework, from the activity-mobility decision process, to vehicle acquisition, socio-demographic trends, and urban systems. All of the simulation modules are linked to provide a complete process tying travel decisions back to mobility decisions, which in turn are constrained by urban development and transportation policies, and by longer term demographic trends. The major element missing from this discussion, however, concerns the technical details of calibrating and then applying the microsimulation approach to generate urban travel patterns.

4. RESEARCH STRATEGY

4.1 Overall Research Framework

While each of the four reports provides some useful ideas toward developing a new generation of transportation forecasting models, none of them presents a comprehensive research plan to move from current theories to operational planning tools. Indeed, most of the recommended approaches require additional research simply to determine whether the theories can even be incorporated into a practical model structure.

With no clear cut winners or losers among the research reports, the most fruitful strategy at this time would be to establish a research environment that (1) supports projects which support several different approaches; and (2) supports projects oriented toward a specific approach so long as they continue to make satisfactory progress toward the development of operational planning tools.

Based. on the recommendations of the research reports, there appear to be three principal approaches for improving travel demand forecasting models: (1) the activity analysis/microsimulation model recommended by RDC and LTRC; (2) enhancements to disaggregate choice models recommended by

MIT and Caliper; and (3) modeling of travel choices other than traffic assignment using network models recommended by Caliper.

4.2 Specific Travel Model Projects

The first two projects represent important prerequisites to further activities in the activity analysis/microsimulation and network models. The other three projects are general support activities whose successful completion should benefit all travel demand models.

4.2.1 Flesh out strategies on applying microsimulation to travel demand forecasting.

Of the three model approaches, the activity analysis/microsimulation approach is in the earliest stages of development toward an operational planning tool, and therefore represents a relatively high risk but high potential payoff approach. The approach is appealing in that it incorporates travel behavior theory that has been developed over the past two decades and reflects a new methodological approach that may have certain advantages over both aggregate statistical models and disaggregate choice models.

However, one of the glaring omissions from both the RDC and LTRC reports was any technical discussion on how a microsimulation of individual trip patterns can be expanded to produce aggregate patterns of travel demand for an entire study area. Such a discussion should address issues associated with data requirements for validation and application (e.g., what sample sizes are required to get a representative distribution of all relevant demographic profiles and transportation characteristics?), computer processing requirements (i.e., does microsimulation imply multiple runs to obtain a representative distribution as in a monte carlo simulation?), transferability implications (i.e., can microsimulation be transferred from one study area to another without massive new data collection?).

These questions should be fleshed out more fully in a follow-on technical project. Project funding should be sufficient to enable a thorough discussion of the issues and alternative implementation methodologies as well as limited empirical testing of some of the most promising methodologies. Initial efforts should focus on the simulation of household activities and travel behavior, with potential follow-on extensions to other, longer term mobility decisions as suggested in the RDC framework.

4.2.2 Develop a dynamic assignment model, incorporating time-sensitive network loadings.

A key deficiency in current travel demand models is their inability to address issues associated with departure time choice and temporal distributions of vehicles on the network. The development of an operational dynamic, time-sensitive network model represents a critical step in making transportation forecasting models responsive to these problems.

A project to develop such a model should be initiated. This project should be oriented toward development of efficient algorithms for handling the multiple time period accounting of vehicle loadings, of link volume-to-capacity ratios and link speeds, and incremental assignment of vehicles. Follow-on work would include an operational test and validation of the algorithms using data from a moderate size study area.

4.2.3 Conduct research on the use of GIS as a platform for developing and applying transportation forecasting models.

GIS technology appears well suited to be a unifying platform for data management and integration, model calibration and application, and the presentation of transportation model forecasts. A research element should be included in the overall study design to: (1) increase the visibility of GIS among the transportation planning community; (2) address the near term barriers to implementing transportation planning models on a GIS platform; and (3) suggest operational improvements in spatial database design, GIS analytical functions, and forecasting models to facilitate the development of GIS-based transportation forecasting tools.

4.2.4 Establish a transportation research data repository.

One of the major contributions that FHWA could make to support ongoing research in travel demand research would be to establish a repository for databases developed from innovative surveys such as the Seattle longitudinal panel, or the Boston household activity diary. These databases would be augmented with clear and complete documentation and would be available for use by travel behavior researchers in academia, in transportation consulting, and in public agencies. The availability of such databases could significantly reduce the high front-end costs associated with new data collection for transportation research. The repository could also serve as a clearinghouse for information on current transportation planning research, innovative transportation experiments and demonstrations, and proposed data collection activities that researchers with limited data collection budgets could piggyback onto.

In conjunction with the transportation research data repository, FHWA could also provide seed money or incremental funding to innovative data collection efforts to help expand the sample size, support high risk data collection techniques, or include supplementary questions that would increase the research value of the effort at low incremental cost.

4.2.5 Investigate the required linkages between travel demand and mobile emissions models.

A high priority research element, brought about by assumptions underlying the transportation control measures of the Clean Air Act Amendments, is an investigation of the validity, accuracy and sensitivity of the relationships between travel demand and mobile source emissions. As stated above, emissions models have been developed largely independent of the travel demand models which are expected to provide their input data. There is an immediate need to assess the reasonableness of the input data requirements to emissions models in view of the type and accuracy of data forecast by current transportation planning models. The investigation should identify what data is needed, whether or not these data can be provided by current models, and what additional model enhancements will be needed. Conversely, the investigation should provide feedback to emissions modelers regarding what type of data they can reasonably expect from current and/or future transportation forecasting models and at what level of accuracy.

*U.S. G.P.O.:1994-301-717:80572

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DOT-T-94-15

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