MULTIMODAL TRAVEL DEMAND MODELING: TWO APPLICATIONS OF CONCEPTS FROM THE TRAVEL MODEL IMPROVEMENT PROGRAM IN FLORIDA

Ram M. Pendyala
Department of Civil and Environmental Engineering
University of South Florida, ENB 118
4202 E. Fowler Avenue
Tampa, FL 3362-5350
Ph: (813) 974-1084
Fax: (813) 974-2957
Email: pendyala@eng.usf.edu

Abstract

The Travel Model Improvement Program (TMIP) was initiated several years ago by the United States Department of Transportation with a view to enhance travel demand and air quality modeling and forecasting tools to meet the transportation planning challenges of the next century. Research and model development efforts within TMIP have embraced activity-based approaches to travel demand analysis as the underlying theoretical basis for modeling travel behavior. Activity-based approaches explicitly recognize that travel demand is a derived demand and provide a robust framework for modeling multimodal transportation systems under a wide variety of conditions. In the spirit of federal-state cooperation, the Florida Department of Transportation has embarked on a multiyear research effort to apply TMIP concepts in the development of multimodal travel demand modeling systems. This paper describes two such research efforts and their potential application in the context of transit system modeling.

(*Paper prepared for the Association of Collegiate Schools of Planning Annual Meeting November 6-9, 1997, Ft. Lauderdale, FL*)

Draft - October 1997

INTRODUCTION

The four-step urban transportation modeling system has served the transportation planning community for the past 50 years as the primary tool for forecasting travel demand and making decisions regarding transportation investments. During this period, planning agencies in several urban areas have made refinements to the process to better suit their local planning needs. In general, however, the four-step modeling system has virtually remained unchanged with the following steps being executed in a sequential fashion:

- Trip Generation: How many trips are made?
- Trip Distribution: Where are trips made?
- Modal Split: What modes of transportation are used to make trips?
- Network Assignment: What routes are chosen to make trips?

The four-step process yields estimates of traffic volumes on different modal networks. These estimates can be used to determine transportation improvements needed to maintain desired levels of service.

The four-step travel demand modeling system was developed at a time when the primary focus of transportation planning was highway capacity expansion. While highway capacity expansion continues to be an important and integral part of transportation planning, several new challenges and opportunities have considerably expanded the modeling needs of transportation planning professionals (Spear, 1994). Social and environmental concerns coupled with tight fiscal constraints symbolized by such landmark legislative acts as the 1981 Clean Air Act, the 1988 California Clean Air Act, and the 1990 Clean Air Act Amendments call for the effective management of travel demand using an array of travel demand management (TDM) strategies and transportation control measures (TCM) as opposed to the continued expansion of highways to accommodate an ever-increasing vehicular travel demand. Emphasis on multimodalism as epitomized in the 1991 Intermodal Surface Transportation Efficiency Act calls for the enhancement of alternative travel modes and the interconnectivity among them. Technological advances represented by the entire range of Intelligent Transportation Systems (ITS), alternative fuel vehicles, and computer hardware and software improvements call for the ability to model the effects of such technologies on travel behavior.

As transportation planning professionals increasingly faced new challenges and embraced new opportunities, it became clear that new travel demand modeling and forecasting tools would be needed to address planning issues of the 21st century (Stopher, 1991; Stopher and Lee-Gosselin, 1997). In recognition of this need, the U.S. Department of Transportation and the U.S. Environmental Protection Agency initiated a multiyear Travel Model Improvement Program (TMIP). The program is intended to provide short-term and long-term enhancements to the travel demand forecasting tools available to planning agencies around the country. Specifically, the program is divided into six tracks as follows:

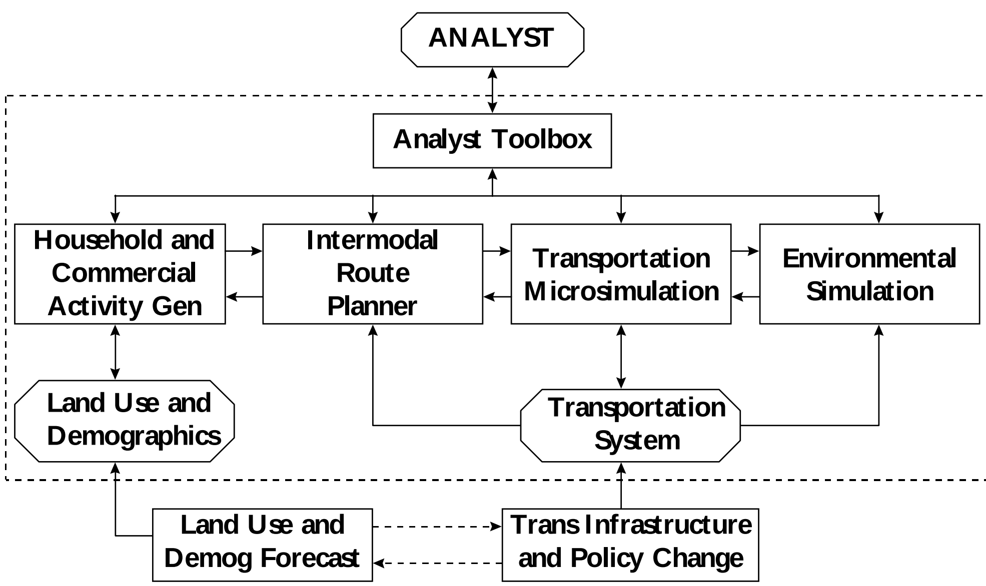
- Track A: Dissemination and Outreach Activities
- Track B: Short-term Improvements within Four-Step Modeling Framework

- Track C: Long-term Development of New Transportation Models
- Track D: Data Needs and Collection Methods
- Track E: Land Use and Transportation Interaction
- Track F: Freight Transportation Modeling and Planning

As such, the Travel Model Improvement Program encompasses a wide range of issues and provides an opportunity for developing modeling tools necessary in the contemporary and future planning contexts.

Track C of the Travel Model Improvement Program is devoted to the long-term development of the next generation of travel demand modeling and forecasting tools. Within this track, TRANSIMS, referring to Transportation Analysis and Simulation System, is being developed by researchers at the Los Alamos National Laboratory under contract to TMIP. TRANSIMS is envisioned to be a comprehensive transportation and air quality forecasting system that is capable of analyzing a wide range of policy, intermodal, and operational conditions. TRANSIMS offers a flexible modular structure that allows users to adapt the model system to their particular needs and context. The TRANSIMS architecture is as shown in the figure below (LANL, 1995):

Figure 1. TRANSIMS Architecture



The analyst's toolbox in TRANSIMS consists of four main modules. The first module determines the activity demand for households and commercial establishments given land use and demographic information for an urban area. The Intermodal Route Planner formulates trip plans (travel patterns) that would meet the activity needs of households and businesses. These trip plans are executed and traffic is loaded on networks in the Transportation Microsimulation module. Finally, air quality analyses is accomplished in the Environmental Simulation module.

Two fundamental concepts distinguish TRANSIMS from traditional travel demand modeling procedures. The first concept is the activity based nature of travel demand. TRANSIMS begins the travel demand modeling process by determining the activities that households and businesses need to accomplish in a specified period of time. Travel demand is thus modeled as a derived demand, i.e., travel is derived from the need to pursue activities that are distributed in time and space. The second concept is the feedback relationships between demand and supply (COMSIS Corporation, 1996). In the TRANSIMS architecture, modules interact through two-way relationships thus recognizing that supply affects demand and in turn, demand affects supply. For example, congestion (delay) encountered in the Transportation Microsimulation module may affect trip plans generated by the Intermodal Route Planner.

The two concepts mentioned above are themes underlying research efforts initiated by the Florida Department of Transportation (FDOT). In an attempt to enhance the state-of-the-art and the state-of-the-practice of travel demand forecasting in a manner that is consistent with the directions taken by the federal TMIP, the FDOT is funding two research projects aimed at developing and testing model systems that utilize activity based approaches and incorporate two-way feedback relationships between travel demand and transportation supply.

This paper is aimed at describing the two research projects in considerable detail. The paper describes the research approach, methodology, input and output data, and model development and testing phases of both projects. The paper also discusses how the research projects are consistent with and utilize interim products and knowledge gained from the federal TMIP to date. First, the paper describes the development an integrated transit demand and supply model that accounts for the two-way relationship between transit ridership and transit service. Second, the paper describes a broader research effort aimed at developing and testing a multimodal activity based travel demand modeling system. Finally, the paper concludes with a summary and discussion on how FDOT's research efforts can converge with those of TMIP in a seamless fashion.

INTEGRATED TRANSIT DEMAND AND SUPPLY MODELING

The research project on integrated transit demand and supply modeling is aimed at incorporating two-way feedback relationships between the demand for transit services and the supply or service configuration of transit system(s) serving the demand. In the next few sections, the research approach and the model framework are described in detail.

Background

Urban transportation modeling procedures have traditionally been applied to forecast highway traffic volumes and as a result, have lacked the ability to accurately predict transit demand and analyze transit system performance. Consequently, transit planners have not been able to rely on model predictions for policy and decision-making purposes. Considering the growing importance of transit in the urban transportation arena, transit modeling procedures need to be enhanced to better represent and capture the unique aspects of transit systems. The integrated transit demand and supply modeling effort is aimed at addressing the feedback relationships

between transit demand and supply, which is an extremely important aspect of transit system performance.
In current travel demand modeling procedures, transit demand is modeled as a function of several transit supply characteristics (service attributes) exogenously specified by the analyst. That is, given a set of transit service characteristics, four-step modeling procedures will predict a certain set of transit demand patterns. However, it is widely recognized that the transportation demand and supply relationship is an interactive one with travel demand affected by capacity and level-of-service and in turn, capacity and level-of-service being affected by demand. This is particularly true and significant in the case of transit systems where capacity, level-of-service, and other service attributes (e.g., headways and service hours) can be altered by a transit agency in short time frames. On the other hand, capacity and level-of-service (supply) attributes associated with roadways do not lend themselves to quick changes and as such, the two-way feedback relationship may not be as crucial for short-term highway planning purposes (but is crucial for long-term planning horizons wherein highway expansion may take place).

Two aspects of the two-way interactive relationship between transit demand and supply merit consideration. One aspect of the relationship is that transit demand is dependent on transit service attributes and in turn, transit service attributes are dependent on transit demand patterns. Transit systems around the country have traditionally followed a path of continuous decline. As transit ridership falls, transit service is cut. As transit service is cut, transit ridership falls further and so on. This leads to a vicious cycle of transit doom where transit ridership and service levels continuously decline over time. Representing this cyclical relationship in the modeling process may provide an avenue for transit agencies to break away from this trend.

A second aspect of the interactive relationship (which is related to the first aspect discussed in the previous paragraph) is that there may be several different transit service configurations that can meet the same demand pattern. In that case, the first set of transit service attributes exogenously input by an analyst may not necessarily be the most efficient and cost-effective configuration that can meet the demand pattern. As most transit modeling procedures do not explicitly capture the two-way relationship through an iterative looping process, a search for the optimal or near-optimal transit service configuration and detailed transit scenario analyses are difficult to conduct.

In order to address the issue of feedback in the transit planning arena, this project is aimed at developing an integrated transit demand and supply model incorporating iterative feedback loops. That is, demand patterns obtained using a certain set of transit attributes will be fed back into a transit supply modeling module. This module will then internally predict the transit supply characteristics that would best (most efficiently) meet the demand patterns. The iterative process is continued until convergence is achieved, i.e., no further changes in transit demand and supply characteristics are obtained from the model. The next section discusses the research approach in greater detail.

Research Approach

The research approach adopted in this project helps accomplish the primary objective of this project, which is to develop an integrated transit demand and supply model that can be interfaced with standard four-step modeling procedures. The research plan calls for the execution of several project tasks which are briefly outlined in the next few paragraphs.

As with most research efforts, the first task involves an in-depth literature review to identify previous research studies that may have a bearing on this project. For example, recent work by Peng, et. al. (1997) in the Portland, Oregon area has been found to be very relevant to this research project. They developed a simultaneous model of transit demand, supply, and inter-route relationships that provided very promising results. This research project will further build on their modeling efforts. In addition, the literature related to transit systems modeling, transit network building and optimization, and transit choice behavior will also be reviewed to ensure that the model system developed in this project reflects current knowledge on transit systems planning and operations.

Model development is at the heart of the research project. The integrated transit demand and supply model will be specified and estimated as a series of simultaneous equations that can predict demand given service attributes, predict service attributes given demand, and analyze competing or complimentary service routes. Within this task, the integrated model and its feedback loop will be specified with respect to the following items:

- Input variables by equation
- Output variables by equation
- Inter-equation relationships
- Model coefficient and parameter estimates
- Algorithm flow of logic within feedback loop

Implementation of the model system will follow model development efforts. This task involves the development of appropriate interfaces that would allow the integrated transit demand and supply model to run in a seamless fashion within a four-step modeling system. First, the integrated transit demand and supply model will be implemented within a geographic information system (GIS). This will facilitate the identification of optimal route structures associated with a transit network given a set of demand patterns. The GIS will also facilitate more detailed modeling suitable for transit systems such as buffer zone analysis, access and egress representation, and intermodal transfer analysis. Second, the GIS-based integrated transit demand and supply model will be interfaced with the four-step modeling system used in the state of Florida. This model system, referred to as the Florida Standard Urban Transportation Model Structure (FSUTMS), is essentially a customized version of the four-step modeling paradigm for the state of Florida. The interface will be developed so as to facilitate a seamless execution of the integrated transit demand and supply model.

Finally, the integrated transit demand and supply model will be tested and assessed. This will be accomplished by applying the model in two urban contexts in Florida. The model will be applied in a large urban area with substantial transit presence and in a smaller urban area with a smaller transit system. In this way, the performance and usefulness of the model can be examined in two different transit environments. The task will involve a comparison of model indications provided by traditional four-step modeling procedures with those provided by enhanced modeling procedures incorporating transit demand-supply feedback loops. More specifically, results obtained from the mode split module, transit assignment module, and transit system evaluation module will be compared between the two modeling methods (i.e., with and without feedback).

Model Framework and Structure

This section consists of two parts. In the first part, the overall model framework is presented in the context of the interface of the integrated transit demand and supply model with the traditional four-step modeling system, FSUTMS. In the second part, the structure of the integrated transit model is presented with a qualitative description of the elements that comprise it. Inputs and outputs associated with the elements are identified and the feedback loop mechanism is discussed.

The integrated transit demand and supply model is intended to predict transit service attributes as a function of demand patterns. The modal split (MODE) module of FSUTMS provides the number of transit trips by origin-destination combinations. The transit network building module of FSUTMS (TNET) provides characteristics of the transit service (headways, schedules, routes, etc.) and the transit path routine (TPATH) provides shortest routes. These are the three crucial modules with which the integrated transit model will interface. The transit assignment module (TASSIGN) and the transit performance evaluation module (TEVAL) will be used to load the transit network and evaluate the performance of the transit system respectively. As such, there is no change in the overall functions of the modules of FSUTMS. Also, TNET will use an exogenously provided transit service configuration as initial conditions.

The integrated transit model will read transit demand patterns by time-of-day and origin-destination pair to develop a new set of transit service attributes that may be able to better serve the demand pattern. These attributes will include headways, schedules, and route configurations. These new configurations will be fed back to the MODE module to account for any possible changes in the demand patterns that may occur as a result of the new service configuration. The new demand patterns are loaded onto the network and the transit system performance under the new configuration is evaluated. Meanwhile, the system will input the new demand patterns into the integrated transit model and generate a new transit service configuration. Once again, demand patterns are predicted and loaded onto the network to evaluate the new transit service configuration. This process is continued until no further changes in demand patterns and service configuration patterns are noticeable. The overall structure of the system may be depicted as shown in Figure 2. The connections between the modules are not exactly as they occur in FSUTMS; the depiction has been considerably simplified to better represent the interface and placement of the integrated model within the overall four-step procedural framework.

It is likely that additional connections will be needed across modules to make the system work in a robust manner. For example, if one were trying to determine modal split based on transit levels-of-service, then TPATH should interface with MODE (as TPATH computes shortest paths for the transit network). In general, however, the structure may be broadly depicted as shown in the figure. At each iteration, the integrated model will provide a new transit service configuration, while MODE will provide a new demand pattern corresponding to the new configuration. The demand and supply are reconciled in the TASSIGN module (see figure). In the future, model development efforts may focus on interfacing the integrated transit model with other four-step modeling modules such as trip generation (GEN) and trip distribution (DISTRIB) and linking it with highway-specific analysis modules.

Figure 2. Simplified Model Structure for FSUTMS Interface of Integrated Transit Demand and Supply Model

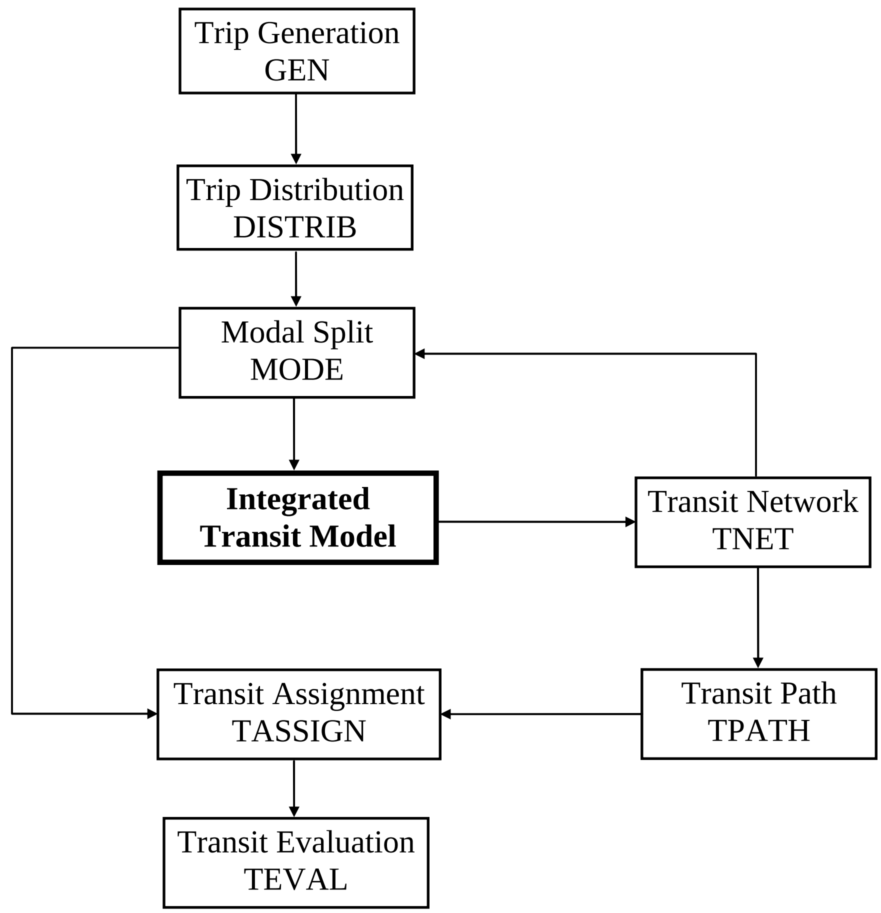
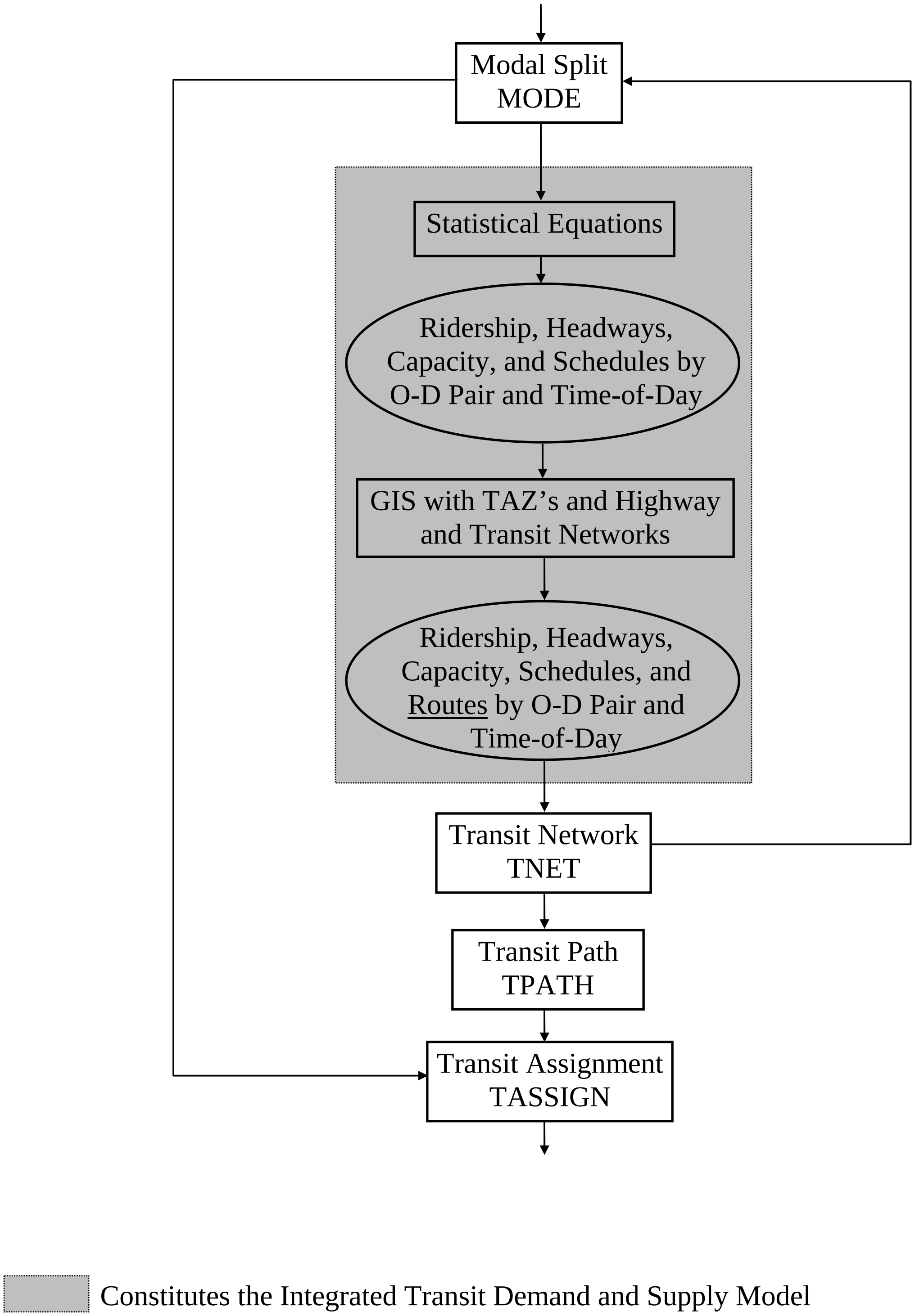


Figure 3 shows the structure of the integrated transit demand and supply model with regard to its various components and output variables. The model consists of two primary components. First, a set of statistical or econometric equations are formulated and applied to local travel behavior and socio-economic/demographic data in order to estimate transit ridership and total transit supply in a simultaneous framework. Results from the statistical equations can be used to deduce the hours of service, total capacity, and headways and schedules of the transit service for a certain level of transit demand.

The second component of the integrated transit model provides the optimal route structures that correspond to a set of transit demand patterns. As optimal route structures are best identified using network optimization algorithms, a GIS is used for this purpose. The GIS will use results provided by the statistical and econometric equations and information on transit demand by origin-destination pair to determine the optimal routing patterns and the schedules along those routes. The GIS has a coded traffic analysis zone (TAZ) structure, transit network, and highway network thus facilitating a linkage across these three entities.

The output of the integrated transit demand and supply model consists of optimal route structures to best meet a certain demand pattern along with the headways and schedules for these routes. This information is then provided to TNET (the transit network building module of the four-step process) continue the iterative demand-supply modeling process.

Figure 3. Integrated Transit Demand and Supply Model Framework



Model Estimation and Application

The previous section provided an overview of the conceptual framework underlying the structure of the integrated transit demand and supply model and its potential interface with a GIS and the four-step modeling process. This section is intended to provide a more detailed discussion on the formulation, estimation, and application of the model system in the context of the ongoing research effort.

Following the discussions by Peng, et. al. (1997), there are three aspects of the simultaneity between transit demand and supply that may be incorporated into an integrated transit model. They are:

- Transit demand model reflecting transit rider and choice behavior
- Transit supply model reflecting the transit operators decision process
- Inter-route model reflecting the effects of complimentary, competing, and independent routes

As transit operators often modify service attributes at the individual route level, the integrated transit demand and supply model may also be formulated to function at that level. Indeed, the model developed by Peng, et. al. (1994) is a route-level transit demand and supply model. However, the ongoing research project is intended to provide a means by which optimal route structures can be identified given a set of origin-destination transit demand patterns. As such, for purposes of this project, the model system will operate at the level of the O-D zone pair as opposed to the specific route. Optimal routing patterns linking O-D zone pairs will be determined within the GIS.

Given the above considerations, the first model is then intended to provide an estimate of transit demand by O-D zone pair given an initial set of transit service attributes. This can easily be accomplished within the current four-step modeling procedures. The mode choice model in most four-step urban transportation planning systems estimates O-D trip tables by mode and in several urban areas, by time-of-day. As such, for purposes of this project, it is envisaged that no new transit demand model will need to be formulated. Using locally available transit service attribute data and socio-economic and demographic data, the transit market share for every O-D zone pair can be determined using probabilistic choice models such as the multinomial logit (MNL) model. Analytically, one may represent the transit demand model as follows:

$$D_{IJ} = p_b Q_{IJ}$$

where D_{IJ} = number of transit trips (demand) from zone I to zone J
p_b = probability of using transit for a trip from zone I to zone J
Q_{IJ} = total number of trips from zone I to zone J

Q_{IJ} may be obtained from the trip distribution modeling step using traditional gravity model formulations. The probability (market share) of using transit, p_b, may be obtained using a multinomial logit model of mode choice as follows (subscript 'b' is used for convenience to denote 'bus'):

$$p_b = \frac{e^{U_b}}{\sum_{k=1}^{m} e^{U_k}}$$

where U_b = utility (or disutility) associated with using transit
m = total number of modes available in the area

The utility (or disutility) associated with using a certain mode may be formulated as a linear function of several modal service attribute variables and socio-economic and demographic variables as follows:

$$U_k = \beta_k + \boldsymbol{\delta}'\mathbf{S_k} + \sum_{\substack{l=1 \\ l \neq k}}^{m} \boldsymbol{\theta}_l' \mathbf{S_l} + \boldsymbol{\gamma}'\mathbf{X} + \varepsilon_k$$

where β_k = alternative specific constant for mode k
$\mathbf{S_k}$ = vector of service attributes for mode k
$\mathbf{X}$ = vector of socio-economic and demographic variables for study area
ε_k = random error term following an extreme value Gumbel distribution
$\boldsymbol{\delta}', \boldsymbol{\theta}', \boldsymbol{\gamma}'$ = vectors of model coefficients to be estimated

As mentioned earlier, the transit demand model can be implemented easily within the scope of most four-step urban transportation modeling systems. The mode choice model may be modified as needed to provide transit ridership estimates by O-D zone pair.

The next step is to determine the service attributes of the transit system by O-D pair and time-of-day. In order to ensure that the model system is as responsive to planning needs as possible, time-of-day modeling will be implemented by breaking the day into homogeneous temporal segments. These segments will be identified by examining transit demand patterns by time-of-day (obtained in the previous step). For example, one may consider three peak periods, AM peak, PM peak, and lunch hour peak, and four off-peak periods, early morning, mid-morning, mid-afternoon, and evening. In each of these time periods, one may determine the frequency of bus service (number of buses per hour) needed to meet the demand patterns in an effective manner. The time periods considered in the model system together with the frequency of bus service estimated for each time period can be used to calculate the headways and transit capacity provisions for each O-D zone pair.

The transit supply model may be formulated as a linear regression equation where the frequency of service in a time period is represented as a linear function of demand patterns (number of transit trips between an O-D pair in that time period), socio-economic and demographic variables, and a set of variables representing the type of transit service being considered in that corridor. The last set of variables are included to account for the potential effects of different types of transit service on frequency. For example, frequency of service may differ depending on whether one is considering a high-speed express bus service or a low-speed local bus service. The model may be represented as follows:

$$F^t_{IJ} = \alpha_0 + \alpha_1 D^t_{IJ} + \boldsymbol{\mu}'\mathbf{X} + \boldsymbol{\zeta}'\mathbf{Z} + \nu$$

where

F^t_{IJ}	=	frequency of bus service between zone pair I and J in time period t (may be represented as buses per hour or directly as headway in minutes)
a_0	=	constant term
D^t_{IJ}	=	transit ridership (demand) from zone I to zone J in time period t
$\mathbf{X}$	=	vector of demographic and socio-economic variables for study area
$\mathbf{Z}$	=	vector of variables representing type of transit service
a_1, $\boldsymbol{\mu}'$, $\boldsymbol{\zeta}'$	=	model coefficients to be estimated
ν	=	random error term distributed normal

At this stage in the integrated transit demand and supply model, transit ridership and service frequency by O-D pair and time-of-day have been obtained. The next step is to determine the optimal or near-optimal route structures that can best serve the demand patterns given the service frequency desired for each corridor (O-D pair). This will be accomplished in the GIS. As such, the inter-route relationships that are considered by Peng, et. al. (1997) will be automatically incorporated into the GIS component of the integrated transit model.

There are several optimal network routing algorithms available in the literature that lend themselves directly to application in this project. The algorithms are based on the traditional traveling salesperson problem that one encounters in the operations research and optimization methods literature. In applying the methods to this research project, one may consider the transit routing problem as one where many origins and many destinations need to be interconnected in an efficient manner. The network routing algorithms not only optimize the connectivity among origins and destinations, but can do so under constrained conditions. For example, if a transit agency would like to provide a certain transit route even if it is not an optimal routing pattern for the given demand patterns, the algorithms can be constrained to include that route.

Dynamic programming approaches may readily be used to determine routes connecting multiple origins and destinations in an optimal framework. These approaches have been implemented in several network optimization software packages. From a transportation perspective, the most appropriate software package in this context would be TRANSCAD, an integrated GIS-based travel demand modeling and transportation network optimization software. In this approach, the origins and destinations are connected in a stepwise fashion using the concept of stages. One or more destinations may constitute a stage and in each stage, the links that need to form a route (such that those destinations are connected) are identified. This process is continued until all origins and destinations are connected. In the proposed model system, the routes will be identified by time-of-day according to the demand patterns by origin-destination pair.

At the end of this step, routes between O-D pairs will be identified together with their associated schedules, headways, hours of service, and travel times. It is to be noted that the network algorithm may identify two or more routes connecting the same O-D pair during the same time period. While the network optimization algorithm may find this optimal from a distance or travel time perspective, it may not be optimal from a transit agency perspective. The interrelationships among competing routes will ultimately be settled in the transit assignment (TASSIGN) module of the four-step modeling process.

The transit assignment module of the four-step modeling system will use the new transit service configuration provided by the integrated model together with the demand patterns (from MODE) to load the transit network. This is done using traditional methods of cost or travel time minimization and equilibrium assignment routines. Competing routes connecting the same O-D pair will compete for the same patronage in each time period. The share of trips obtained by each of the competing routes is determined by equilibrium assignment methods. The loaded transit network is then evaluated in the next module (TEVAL) to assess the performance of the new transit service configuration predicted by the integrated transit demand and supply model.

The integrated transit demand and supply model is an iterative feedback model that allows for feedback between demand and supply. As such, in addition to assigning trips on and evaluating the new transit service configuration in TASSIGN and TEVAL, the integrated model will provide for the new transit service configuration to be rebuilt in TNET. The new transit service attributes will then be fed back to the mode split model (MODE) to estimate new demand patterns that may be brought about by the new transit service configuration. New demand patterns are fed into the supply model to determine new service frequency by time-of-day and new routing structures in the GIS. Once again, trips are loaded onto the new transit network in TASSIGN and the performance of the transit system evaluated in TEVAL. Meanwhile, the iterative feedback mechanism continues as the new transit network configuration is fed back to the modal split model. The process can be allowed to continue until convergence is achieved. That is, when there is no further change in the transit demand patterns and/or the transit service configuration, one may consider the system to have reached a short-term steady state condition and the iterations may be ceased. Alternatively, one may terminate the iterative feedback loop at any time during the process. For example, if a desirable or acceptable transit service configuration has been identified by the model, then the model iterations may be stopped. Thus, the integrated transit demand and supply model is flexible in its potential application in practice.

After the integrated model is interfaced with FSUTMS, it will be applied and tested in two urban area contexts. The urban area test sites chosen for this study are Miami and Volusia County, which represent two different urban contexts. While Miami is a large urban area with substantial multimodal transit presence, Volusia County is a small urban area with a small bus system. The integrated transit demand and supply model will be applied in both of these contexts to investigate the potential benefits of implementing a feedback loop between demand and supply. It may be hypothesized that, in a small urban area with a small transit system, the implementation of a feedback loop between demand and supply will not yield substantially different results simply because the number of alternative transit service configurations that can serve a given demand pattern is going to be small. This hypothesis will be explicitly examined during the pilot-testing task of this project.

It is envisaged that the integrated transit model will serve as a useful tool to transit agencies in the planning and operation of their transit systems. The model can be used for analyzing transit operations both at the system level and at the individual route level. The model will be particularly useful in performing route- and system-based scenario and sensitivity analyses.

MULTIMODAL ACTIVITY-BASED TRAVEL DEMAND MODEL SYSTEM

The Florida Department of Transportation has just embarked on a multiyear effort to develop a comprehensive multimodal activity based travel demand forecasting system. As with the integrated transit demand and supply model, this effort is also motivated by the USDOT's Travel Model Improvement Program where the next generation of travel demand modeling tools is being developed based on activity based approaches to travel demand analysis (Ettema and Timmermans, 1997). In the next few sections, the research approach and the model framework underlying the FDOT research effort are described in detail.

Background

As mentioned earlier in the introductory section of this paper, the USDOT's Travel Model Improvement Program has embarked on a long-term multiyear effort aimed at developing the next generation of multimodal travel demand modeling tools by contracting with the Los Alamos National Laboratory (LANL) to develop the Transportation Analysis and Simulation System (TRANSIMS). While the delivery of TRANSIMS in a form that is ready for implementation is still several years away, it is clear that states and MPO's around the country need to embark on a phased plan that provides for the gradual and seamless implementation of these sophisticated new modeling tools. Indeed, this was the most important message and recommendation that came out of the FDOT TMIP Seminars that were conducted in Fort Lauderdale and Tampa in May of 1996.

A phased implementation plan is necessitated by the fact that transportation planning agencies have used the four-step travel demand modeling procedure for more than 25 years and will undoubtedly continue to use it for several, if not many, years to come. It would be extremely burdensome and near impossible to switch to an entire set of new modeling tools and paradigms overnight. Data availability and collection, model implementation, and training are just some of the issues that would prevent such an abrupt transition. On the other hand, a phased plan would provide for the gradual implementation of new multimodal activity based modeling tools through a step-by-step approach that uses the federal TMIP as its point of convergence.

This research project is intended to serve as a research and development effort providing for the phased implementation of new activity based modeling methods. The federal TMIP and LANL are developing the next generation of travel modeling systems as activity based modeling tools where travel demand is explicitly recognized as being derived from the human and business need to pursue activities that are distributed in time and space (Goulias and Kitamura, 1992; Jones, 1990). As such, FDOT considered it prudent to consider the phased implementation of an activity based modeling system that can interface with the Florida Standard Model, FSUTMS, in the short term and with TRANSIMS in the long term. In this way, the research effort will yield both short-term and long-term benefits while ensuring that Florida proceeds in a multimodal modeling direction set forth by the long term vision of the federal TMIP. Activity-based travel data that would facilitate the development and implementation of multimodal activity based modeling systems will also be collected as part of the research effort.

In light of the above discussion, the specific objectives of the research project may be outlined as follows:

- To collect activity-based travel behavior data that can be used to estimate and validate activity based travel demand models
- To develop an activity based model system that is multimodal in its coverage
- To implement an activity based model system that is practical and user-friendly
- To develop a plan by which model improvements in the state of Florida can converge with national efforts being undertaken as part of the Travel Model Improvement Program

Research Approach

The research project calls for the phased implementation of a multimodal activity based travel demand modeling system in Florida (Kitamura, et. al., 1998). To this end, a phased research plan has been developed so as to provide both short- and long-term deliverables together with results from pilot applications of the activity based model system in selected urban areas of the state. This section describes the phased research plan briefly.

Before the research project could be initiated in earnest, urban areas that would serve as pilot test sites had to be selected. This is because the research plan calls for close coordination with local metropolitan planning organizations (MPO's) and other planning agencies. Such coordination would ensure that the activity based modeling system to be developed and implemented in this project incorporates the needs and desires of local transportation planners. In addition, as activity based data collection would occur in the first phase of the research effort, urban areas in which such data would be collected had to be identified. As with the integrated transit demand and supply modeling project, Miami and Volusia County were chosen as the urban areas to serve as pilot test sites for this project. Both of these areas expressed an interest in cooperating with this research endeavor and as they represent two very different urban contexts, it was felt that they would serve as excellent test sites for the project. By selecting these two areas, it is possible to pilot test the activity based model system in a large urban area (Miami) and a small urban area (Volusia County) context.

The first phase of the research project involves an intensive activity based travel behavior data collection effort. During the last few years, travel behavior research has focused on analyzing activity engagement patterns of individuals in recognition of the derived nature of travel demand. In this context, several urban areas inside and outside the United States have undertaken data collection efforts that collect detailed information on the activity and time use behavior of individuals and households. In the United States, recent surveys in San Francisco, Portland, the Research Triangle area, Dallas-Fort Worth, and Washington D.C. have been activity based (Cambridge Systematics, Inc., 1996b). These surveys differ from traditional travel diary surveys in that they collect detailed information on the activities pursued by an individual and travel is merely reported as a means of getting from one activity to another. By focusing on activity patterns, it is found that activity surveys are able to better capture short, infrequent, and non-motorized trips that would otherwise be forgotten in a traditional travel diary survey. In an effort to develop models that can explain travel behavior in a theoretically robust framework and provide the data needed to estimate and validate activity based model systems, this research project commences with a detailed activity based time use and travel survey effort in Miami and Volusia County.

The second phase of the research project constitutes the short term activity based model development and implementation effort. This phase will commence with a detailed review of activity based model systems that have been or are being developed around the world. Recently, there has been considerable research into the development and implementation of activity based model systems that forecast one or more aspects of travel behavior. This project will draw from past and ongoing research in the field as needed to ensure that the latest know-how is reflected in the model system to be developed in this project. The review of activity based research will be followed by a first level model development and implementation effort. In this phase of the project, an activity-based model of trip generation and trip chaining will be developed and implemented using data collected in the first phase of the project. This first level activity based model will be interfaced with FSUTMS to provide an avenue where trip generation and trip chaining modeling may be done using activity based concepts. The activity based model of trip generation and trip chaining will be provided as an optional item that planners and modelers may access as desired. This first level activity based model system (interfaced with the traditional four-step modeling process) will be pilot tested in Miami and Volusia County to examine its policy sensitivity and relevance in a multimodal environment.

The third phase of the project constitutes the long term activity based model development and implementation effort. This phase of the research project is intended to parallel and converge with the development of TRANSIMS so as to ensure that the state's efforts are in agreement with the federal TMIP. As such, this phase of the project will commence with a detailed review of TRANSIMS and several meetings with the TRANSIMS project team from LANL and officials of TMIP. TRANSIMS modules that have been completed and released to the modeling community will thoroughly reviewed and evaluated. Following this review, a comprehensive activity based travel demand modeling system will be developed while utilizing all of the knowledge and tools gained from TRANSIMS. TRANSIMS modules that may be used in this effort will be interfaced with model components developed as part of this research project. The end result will be an integrated activity based travel demand forecasting system capable of addressing a wide range of multimodal, policy, and operational conditions. As the long term model development effort involves the use of tools unknown at the present time, supplementary data may have to be collected to facilitate the estimation and validation of the activity based modeling system. Such data will be collected in the two pilot test areas, namely Miami and Volusia County. Finally, as in the short term implementation phase of this project, the comprehensive activity based travel demand forecasting system will be pilot tested in Miami and Volusia County to ensure that it meets the needs of transportation planners in Florida.

Activity Based Data Collection

In the first phase of the research project, comprehensive activity based travel behavior data are going to be collected in Miami and Volusia County. This section briefly discusses the data collection effort and the various components of the activity based survey that will be administered in each of these two areas. Surveys are being administered at this time (October and November, 1997) and will be completed before the end of the calendar year.

The data collection effort in this project is intended to serve as a comprehensive source of activity and travel behavior information. As such, the surveys have been designed to collect detailed information about households and their activity and travel behavior (Cambridge Systematics, Inc., 1996a). In addition, the surveys included a stated preference component to investigate how travelers might respond or change their travel behavior if various transportation policies or strategies were implemented. In particular, the surveys being administered in Miami and Volusia County encompass the following types of information:

- Socio-economic characteristics of households and individuals
- Demographic characteristics of households and individuals
- Residential and work/school place information for individuals
- Modal availability and accessibility
- Usual commuting patterns and work/school schedules
- Destination availability and accessibility (land use data)
- Usual trip chaining patterns and constraints
- Transportation system attributes (e.g., parking cost and availability)
- Revealed activity and time use behavior patterns including trip information
- Stated adaptation responses to various hypothetical transportation policy scenarios
- Traveler values, attitudes, and perceptions

In Miami, the entire survey is being administered in stages via a computer-assisted telephone interview (CATI) method together with selected mail-outs of written material. As the demographic, socio-economic, land use, and transportation characteristics of the Miami area are relatively complex, it was felt that a CATI method of survey administration would be the most effective way to collect data in that environment. A survey research firm, NuStats International (based in Austin, Texas), that has extensive experience in the administration of intensive activity based travel surveys using CATI methods has been employed to accomplish this task. A local survey research firm, Behavioral Science Research (based in Miami) has also been brought on the team for providing a local perspective.

It is intended to collect information from a total of 1,300 households. In order to ensure that a sizable transit sample is included in the overall sample, an enriched choice-based sampling method is being adopted. In this method, random sampling techniques will be combined with targeted choice-based sampling of transit riders to constitute the entire sample. Following the random sampling of survey participants, additional survey participants will be recruited through on-board solicitation of transit riders. Through a combination of the random sample and the choice-based transit sample, it is desired to have a total of 450 transit riders reflected in the overall sample. This will ensure that any statistical analysis performed exclusively on the transit sample will be valid.

As it is cumbersome to administer a telephone survey to every member of the household, one adult in each household will be randomly chosen to participate in the survey. As such, the final sample should include activity and travel information for 1,300 individuals. However, socio-economic and demographic information will be collected for the entire household. Each individual will be asked to report activity and travel behavior for a period of two consecutive days (all day pairs except Saturday-Sunday are allowed). All survey participants will be mailed an activity-travel diary in which they can record all of their activities and trips over the two-day period. The activity-travel behavior information is subsequently collected over the phone, the activity diary serving as a handy reminder as the respondent provides the data to the interviewer.

The stated adaptation survey is formulated so that it is customized to each respondent's commute and travel situation. In this way, the hypothetical transportation policy scenarios faced by a respondent are extremely relevant to his or her travel context (Dial, 1995). Such customization of stated adaptation questionnaires has been shown to greatly enhance the credibility of stated responses. In addition, respondents will be asked a series of follow-up questions to ensure that the respondent has put substantial thought into the stated decision-making process. The hypothetical transportation policy scenarios to be administered in the Miami survey are:

- Parking pricing at work locations
- Peak period congestion pricing on all routes
- Exclusive HOV lane provision
- Transit improvements only
- Transit improvements combined with other infrastructure improvements (e.g., pedestrian and bicycle facilities, park-and-ride lots, etc.)
- Intelligent transportation systems scenario

Once again, as in the revealed activity-travel behavior component of the survey, a packet describing the scenarios will be mailed out to respondents and their responses collected over the phone after a few days. In this way, respondents will have the information handy when interviewers call them for retrieving the data.

In Volusia County, a very similar approach is being taken except with regard to the survey administration method. As Volusia County is a smaller urban area with a transportation system that is relatively less complex, it was considered sufficient to adopt a mail-out/mail-back method of survey administration in this context. In addition, the mail-out/mail-back survey administration method would facilitate the collection of revealed activity and travel data from all household members which is crucial to the modeling of household travel behavior in its entirety.

Survey packets will be mailed out to a random sample of addresses in the Volusia County area. It is desired to collect information from a total of 1,000 households and 200 visitors for this survey. As in Miami, the random sampling method will be combined with choice-based sampling methods to obtain a sizable transit user segment. In addition to mailing survey packets to Volusia County residents, survey packets will be distributed on randomly selected bus routes and stops on all days of the week. The goal is to have about 400 households with at least one regular transit user (uses transit at least once a week) within the overall resident sample of 1,000 households. In addition, survey packets are being provided to numerous hotels in the Volusia County area to target visitors and seasonal residents. In the case of visitors and seasonal residents, only one individual per party will be asked to fill the travel survey. This is being done to minimize survey burden (increase response rates).

Survey respondents will be asked to return their activity-travel diaries and completed survey questionnaires via mail to the research team. As in the Miami survey, very detailed information will be collected on socio-economic, demographic, and activity-travel behavior information. Adults in the household will be asked to help children fill their travel diaries. Following the receipt of the completed questionnaires, the research team will code and enter the data into person, household, and activity-trip databases. These databases will be used to generate customized stated adaptation questionnaires for one individual in each household. The stated adaptation questionnaires will be mailed to one commuting adult in each household to minimize survey burden and maximize usefulness of the data. In recognition of the Volusia County travel environment, the following transportation policy scenarios will be included in the stated adaptation questionnaire:

- Selected transit service improvements coupled with other infrastructure improvements
- Parking pricing
- HOV lane provision

Considering the complexity of the stated adaptation questionnaire, respondents will be contacted by phone to retrieve the stated response data. Respondents will be able to use the mail-out as a handy guide as they provide responses over the phone.

The surveys are currently being pre-tested on small samples of 100 respondents to fine-tune the survey instruments and methods of administration. Following the survey pre-test, the actual surveys will be administered in November, 1997 in both Miami and Volusia County. All precautions are being taken to ensure that the survey does not spill over into the holiday season. The research team will code and prepare databases immediately upon receipt of the survey responses. The databases will not only be used for purposes of this project, but will also be provided to the Miami and Volusia County MPO’s for their planning purposes.

Model Framework and Structure

Activity based modeling is an emerging area of research in the areas of travel behavior and travel demand forecasting. As such, there are several ongoing research efforts around the world aimed at developing multimodal activity based travel demand modeling systems. This research effort attempts to utilize as much of the knowledge in this area as possible in developing the short- and long-term activity based model systems. The multiyear time frame of the project allows modeling methods and structures to be modified according to the latest developments in the field and in coordination with TRANSIMS. As such, the model framework and structure described in this section should be regarded as a dynamic entity with the possibility of undergoing several changes before seeing final implementation in practice.

This project is aimed at developing a fully functional multimodal activity based travel demand modeling and forecasting system that transportation planning agencies would be able to use for planning and analysis purposes. To this end, it is envisioned that the modeling system developed in this project will possess three basic and essential characteristics:

- *Flexibility*: The model system should be flexible enough to handle a wide variety of multimodal, operational, and policy scenarios. It should have the capability of addressing a host of planning issues, questions, and needs that are typically faced by a transportation planning agency (such as an MPO) and be sensitive to the socio-economic, demographic, and urban environment in which it may be applied.

- *Explicability*: One should be able to explain the working of the model system, various assumptions made, underlying theoretical and empirical constructs, methodologies employed, input and output variables used, and other aspects of the model to those who may not be directly involved in using the model. In other words, the model system should not be a black box. By ensuring that the model is explicable, planning agencies will also be able to adapt the model system to suit their local needs.

- *Plausibility*: Finally, the model system should be able to provide meaningful and understandable results under a wide range of conditions. The ultimate test of a model is its ability to provide outputs that are credible and do not violate basic common sense and professional judgment.

Given the above considerations, the research team has developed a first-cut step-by-step approach for modeling activity and travel patterns at the level of the individual traveler. The individual traveler is being used as the unit of analysis in order to ensure that the model system operates at the same level as TRANSIMS. The next few paragraphs describe the steps in the same sequence in which they would be executed in the model system.

Step 1: Generation of Activity Set by Time of Day

In the activity based approach to travel demand analysis, trips are recognized as being derived from the activities pursued by individuals. As such, in this approach, one first generates individual activity needs or activity demands and then deduces the trips and travel patterns needed to accomplish the activity needs. In this context, the first step of the model system will determine the activity most likely to be pursued by an individual along the temporal axis of a 24 hour period.

In order to accomplish this step, a daily 24 hour period will be split up into blocks. If each block is one hour long, then there will be 24 time-of-day blocks in which the most likely activity needs to be identified. In order to reduce the magnitude of the problem, one may aggregate certain hourly blocks (say, those in the middle of the night) in which activity engagement may be of a very homogeneous nature. Then, within each time block, the probability of participating in each activity type is determined. These probabilities may then be used to identify the activity most likely to be pursued by an individual in that time period. This process is continued until all of the time periods in a 24 hour period are exhausted. At this time, the model system is limited to 24 hour activity demand generation as data (activity data collected in the first phase of this project) is not available to model weekly or monthly activity engagement behavior.

Step 2: Determination of Activity Durations by Episode

Activity durations tend to influence travel behavior (Mannering, et. al., 1994). When one considers shopping and other non-mandatory (non-work and non-school) type activities, travel behavior tends to vary according to the duration that may be spent at the activity location. One may justify traveling long distances for activities that are of a long duration, but choose to travel to destinations that are nearby for activities that are of a short duration. In addition, time spent at activity locations may influence the amount of time available for traveling. A person who works or goes to school long hours may not be able to spend as much time traveling to destinations as a person who works or goes to school fewer hours. As such, activity duration modeling is an extremely important component of activity based approaches to travel demand analysis.

The second step of the activity based modeling approach is devoted to the estimation of activity durations by episode. Activity durations are likely to be influenced by individual and household characteristics; for example, households with children are likely to differ in their time allocation to different activity types when compared with households that do not have children. As such, activity durations are best modeled as a function of individual and household demographic and socio-economic characteristics.

Step 3: Activity Prioritization and Sequencing

The first two steps of the model system will yield a series of activity episodes with their respective durations. Prior to generating travel patterns associated with these activity episodes, it is necessary to ensure that the activity episodes and durations are constrained to a 24 hour limit and are sequenced in a behaviorally robust manner. This step serves as a mechanism by which the activity episodes, durations, and sequence are reconciled to form a coherent and logically consistent activity demand pattern.

Activities are of various types. Work and school activities are generally considered to be mandatory, shopping and personal business may be considered flexible activities, while social and recreational activities may be considered discretionary in nature. This typology of activities provides a mechanism by which activities can be prioritized over the course of a day. Those activities that are of least priority may be eliminated if time is not available to pursue them. This concept is readily applicable to the modeling approach being adopted in this project. After the completion of the first two steps, the roster of activity episodes and durations will be examined to see whether the activity pattern can be accommodated within a 24 hour period. If a 24 hour period is not sufficient to accommodate all of the activity episodes and their durations, then discretionary activities may be eliminated from the roster thus making more time available to pursue the higher priority activities. If no discretionary activities are present on the roster, then the durations of activities on the list may be modified or adjusted downward, the lower priority activities being adjusted first. This process can be continued until a coherent activity pattern is generated.

In addition to activity prioritization and temporal reconciliation, this step will also perform an activity sequencing check. In the first step of the modeling system, activity episodes are generated by time of day block. The resulting list contains activities in the order (sequence) in which they would be pursued. However, after the activity roster is modified to reflect temporal (24 hour) consistency and activity priorities, the list may need to be adjusted with respect to the sequence in which activities are pursued.

Step 4: Formation of Activity Chains

The first three steps provide a sequenced roster of activities with associated durations. The fourth step in the modeling system is concerned with the concept of activity and trip chaining. Activity and trip chaining is a very important concept in travel behavior modeling (Bhat, 1997). As travelers tend to link their activities and therefore trips, their travel choices are often constrained by the nature of the trip chaining patterns (Strathman, et. al. 1994). For example, if a person drops off a child on the way to work or picks up a child on the way back home from work, then this person may be constrained to drive a personal vehicle even if transit is accessible at both, the home and work locations. Similarly, if a person drives alone to work, then the person is usually constrained to drive back home (unless the person chooses to leave the personal vehicle at work). Similarly, if a person does not take the personal vehicle to work, then it is unlikely that the person can drive alone from work to home. As such, there is a considerable amount of inter-dependence among activities and trips in a chain that is not explicitly represented in the four-step modeling process. This inter-dependence can be explicitly modeled only if the activities and trips are linked into chains.

The sequenced list of activity episodes will be used to form home-based and work-based activity or trip chains. For purposes of practical implementation, all activities are considered to be anchored by either the home location or the work location. Indeed, it has been found that trip chaining is generally home- or work-based. In this step, the activities will be linked together into chains so that inter-dependency among activities and trips can be explicitly captured in the ensuing steps of the model system. Discrete choice modeling methods can be used to determine the type of chain into which an activity will be linked. If a chain consists of several activities (i.e., a multi-stop chain), then they will be arranged in the same order that they appear in the sequenced roster of activities. At this point, the roster of activities is ready to be used for transportation modeling.

Step 5: Destination Choice Modeling

In this step, destination locations that will be chosen for each activity episode are determined. For purposes of practical implementation, the home and work bases are considered to have fixed locations. For all other activities, destination choice models will be estimated to determine the location that will be visited for each activity. The destination choice models will explicitly recognize the inter-dependency among trips and activities linked in the same chain. This step is equivalent to the trip distribution step in the traditional four-step travel demand modeling procedures.

Destination choice models will be estimated for each activity type to reflect possible differences in traveler decision making processes between activities. For example, destination choice decision processes for shopping may be different from those for social/recreational activities. A feasible destination choice set will be considered for each activity type and chain type and the destination most likely to be chosen will be identified using probabilistic modeling methods. At the end of this step, the activity roster is ready for conversion to a trip roster. The activity roster contains a sequenced list of activities together with their associated durations, chain formations, and destination locations. The activity chains are converted to trip chains while utilizing the activity data to generate trip data. For example, activity duration information and destination location information can be used to determine the beginning (departure) time and ending (arrival) time for each trip. The chain information can be used to assign trips to trip chains. The activity locations correspond to trip destinations. As a result, a traditional roster of trips with all necessary attributes is obtained for each individual. This roster of trips is used from here to complete the activity based travel demand modeling process.

Step 6: Mode Choice Modeling

As in the traditional four-step modeling procedures, the destination choice (trip distribution) step will be followed by the mode choice modeling step. Within this step, the mode of transportation used for each trip is determined while explicitly recognizing the inter-dependencies among trips in a chain. Discrete choice modeling methods may be used to determine the probability that a certain mode will be used for a particular trip chain. Characteristics of the trip maker, attributes of the trip chain, and standard modal level-of-service variables will be used as explanatory variables to predict mode choice. In assigning a mode of transportation to a chain, the trip with the highest priority, longest duration, or most constrained mode choice set may be used to most realistically capture the modal split process. If a chain contains an activity to transfer from one mode to another, then a modal transition will occur within the chain.

Identifying the feasible set of modal alternatives is an extremely part of the mode choice modeling process. For example, one may wish to exclude the private automobile as an alternative for individuals in zero-car households. Similarly, public transportation modes may be excluded for trip chains that have destinations not served by transit. It is envisioned that mode choice sets will be generated while recognizing these constraints and limitations.

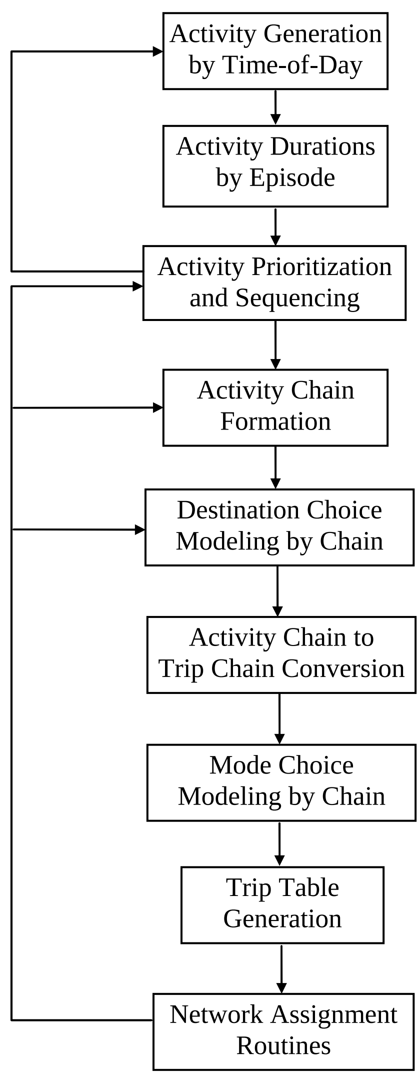
At the end of this step, a sequenced roster of trips by time-of-day and chain affiliation is obtained together with destination and mode information for all trips. The output at this stage corresponds to what one would obtain after executing the first three steps of the four-step modeling process, namely trip generation, trip distribution, and modal split. The trip plans developed for each individual are now ready to be executed on a multimodal transportation network to obtain link volumes, travel times, and other network specific measures. As there are several new and sophisticated assignment algorithms that have been developed in the recent past within and outside the scope of TMIP and TRANSIMS (Hu and Mahmassani, 1995; Dial, 1994), the research effort here will interface with such new assignment algorithms. The next step furnishes such an interface.

Step 7: Trip Table Generation

This step constitutes an interface between the activity based travel demand modeling system and network assignment procedures which expect trip tables as their input. A simple enumeration procedure may be adopted to convert the trip rosters into zonal trip tables by mode and time-of-day. Trips are assigned and new travel time and speed information are fed back to the activity generation module of the modeling system. In this way, the iterative two-way relationship between demand and supply is explicitly incorporated into the model system and the effects of congestion, travel time delays, etc. on activity generation can be captured. The latter is related to the notion of induced, suppressed, and latent travel demand where new activities (travel) may be undertaken (induced) or existing activities (travel) may be eliminated (suppressed and becomes latent) depending on the network performance (Shunk, 1994).

From the above it can be seen that the multimodal activity based travel demand forecasting system to be developed in this project is comprehensive in its scope and is sensitive to a wide variety of socio-economic, land use, modal, and policy conditions (Resource Decision Consultants, Inc., 1995). Figure 4 depicts a conceptual framework for the model system as described in this section.

Figure 4. Simplified Framework of Multimodal Activity Based Travel Model System



Model Estimation and Application

The previous section outlined the various components of the activity based travel demand model system that is envisioned to be developed and implemented within the scope of this project. Estimation of various model components requires the use of activity based travel behavior data that is being collected in the first phase of the project. The second phase of the project will involve the development of the first and fourth steps only. These include the activity generation and activity chaining steps, thus facilitating the implementation of an activity based model of trip chaining within the short-term. Only the first step of the four step process, namely, trip generation, will be accomplished within the short term phase of the project. The entire model system will be completed in the long term so as to facilitate a convergence with TMIP and TRANSIMS.

Model estimation will be accomplished using established and well-known methods that have been implemented in practice. This will ensure that the model system is not a black box and can be implemented in a transportation planning agency environment. This section briefly discusses the estimation methods that may be used in the activity based model system.

Activity generation by time of day may be accomplished using discrete choice modeling methods such as the multinomial logit model. The probability that an individual participates in a certain activity during a specific time period may be computed using this modeling method. The characteristics of the individual and household, certain land use and transportation system variables, and the history of activity engagement (within that day) may be used as input variables to predict activity participation probabilities. That is,

$$P\,[Y_t = a] = f(\mathbf{Y_{-t}}, \mathbf{S}, \mathbf{Z})$$

where

$P\,[Y_t = a]$	=	probability that the activity pursued in time period t is of type a
$\mathbf{Y_{-t}}$	=	vector denoting history of activity engagement upto the period t
$\mathbf{S}$	=	vector of supply variables (land use and transportation system)
$\mathbf{Z}$	=	vector of individual and household characteristics

Activity duration modeling is undertaken in the second step. Activity durations are positive and non-zero for all activities that are pursued and zero for all activities that are not pursued. As such, activity durations constitute censored dependent variables that are best modeled as tobits. Tobit models allow one to define a latent unobserved variable that represents the propensity of activity participation duration. The observed counterpart of this propensity is measured in activity surveys as non-zero (participated) or zero (not participated) values. Explanatory variables that may be used in the tobit model include trip maker characteristics, land use variables, history of activity participation, and type of activity being pursued. The model would then take the following form:

$$D^* = \alpha + \boldsymbol{\beta}'\mathbf{D_{-t}} + \delta Y_t + \boldsymbol{\theta}'\mathbf{Z} + \varepsilon$$

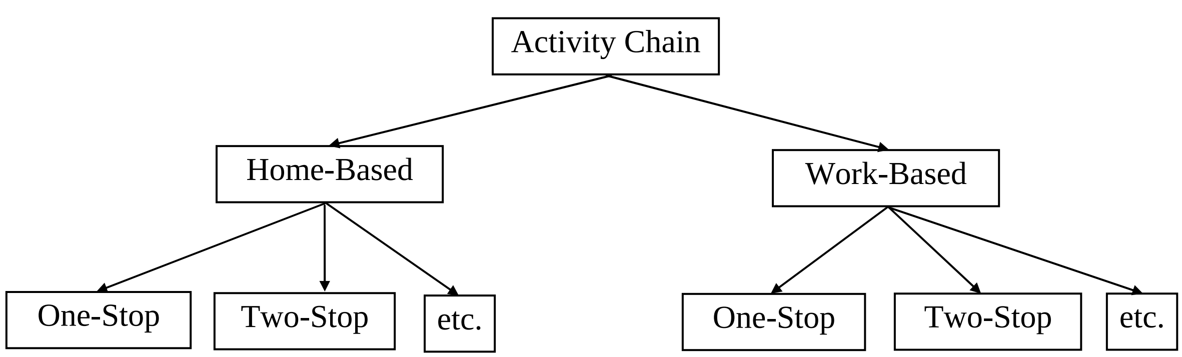
$$D^* = \begin{cases} D & \text{if } D^* > 0 \\ 0 & \text{otherwise} \end{cases}$$

where D^* = latent variable representing propensity for activity participation duration
D = observed variable representing the measured propensity (in survey data)
$\mathbf{D}_{-t}$ = history of activity engagement patterns upto time period t
Y_t = activity episode under consideration
$\mathbf{Z}$ = vector of individual and household characteristics
e = random error term
α, $\boldsymbol{\beta}'$, δ, $\boldsymbol{\theta}'$ = model coefficients to be estimated using survey data

The third step involves the prioritization, sequencing, and reconciliation of activity participation and durations. Using theoretical constructs of travel and activity behavior, this step will be accomplished using heuristics and qualitative approaches that facilitate the manipulation of activity sequences. Program codes that consist of rule-based heuristics will be employed to sequence, prioritize, and temporally reconcile the activity engagement behavior of individuals. These rule-based heuristics are derived from known theories of travel behavior regarding activity prioritization (mandatory, flexible, and discretionary classification), temporal constraints that require all activities to be accomplished within a 24 hour period, and other institutional constraints that preclude certain activities during specific periods of the day (e.g., opening and closing times of stores and businesses).

The fourth step links activities into chains so that the trip linking behavior of individuals can be explicitly captured in the model system. While some of this may be accomplished in a deterministic framework by examining the roster of activity episodes, there may be situations where activities may have to be probabilistically assigned to home-based or work-based chains in a one-stop or multi-stop setup. Discrete choice modeling methods such as the nested logit model may be used to estimate this component of the model system. The choice process for activity chaining may be represented as shown in Figure 5.

Figure 5. Choice Process Representation for Activity Chaining



As in the case of activity type choice modeling (first step), the probability that an activity will be linked into a certain chain can be determined as a function of individual and household characteristics, land use variables, and activities linked in the chain upto that point (history of trip engagement within that chain). Then, the model takes the broad form:

$$P\ [Q_i \in c] = f(\mathbf{Q}_{-i} \in c, \mathbf{S}, \mathbf{Z})$$

where	$P\ [Q_i \in c]$	=	probability that the ith activity is an element of chain c
	$\mathbf{Q}_{-i}$	=	vector denoting activities linked in same chain upto that point
	$\mathbf{S}$	=	vector of land use variables
	$\mathbf{Z}$	=	vector of individual and household characteristics

The fifth and sixth steps are both discrete choice processes. Destination choice (fifth step) and mode choice (sixth step) can both be determined using multinomial or nested logit modeling methods. Choice sets will be generated appropriately using rule-based heuristic algorithms and used to determine probabilities. Explanatory variables for the destination choice model will include individual and household characteristics, land use variables representing the desirability of the destinations, and composite impedance values to represent the disutility associated with traveling to destinations that are further away. In the mode choice model, explanatory variables will include individual and household characteristics, modal level of service variables, and characteristics of the trip chain for which the mode of transportation is being determined.

Numerical enumeration procedures may be employed in the seventh step to develop zonal trip tables. The enumeration procedures will count trips by mode, origin-destination pair, and time-of-day to develop trip tables that are typically used as inputs to network assignment procedures. Research efforts within and outside the scope of TMIP have yielded new network assignment algorithms that reflect route choice behavior of individuals. These network assignment routines will be used to complete the activity based travel forecasting system.

In addition to the above components, there are two additional components that will be included in the activity based travel model system. The first component is a model of human adaptation and learning. This model is intended to forecast human behavioral response to policy options, new technologies, and other new strategies that have not yet been implemented. Stated adaptation data that is being collected as part of the first phase of this project can be used to estimate multinomial logit models of behavioral response. The predicted response can then be used to analyze changes in travel behavior that may take place as a result of the new policy or strategy being implemented. In essence, this tool will provide a mechanism by which the effects of such policies and strategies can be analyzed accurately prior to their actual implementation (which can prove costly and time-consuming).

The second component is a synthetic population generator (Beckman, et. al., 1996). As the model system ultimately intends to operate at the level of the individual traveler, a detailed disaggregate representation of the population would be needed to run the model. A synthetic population generator uses readily available census data to create base year households and then tracks the evolution of households over time. Thus, the generator is capable of providing a disaggregate population forecast for any point in time that serves as an input to the activity based modeling system.

SUMMARY

The research projects described in this paper provide for the phased implementation of new travel modeling tools that are consistent with the federal Travel Model Improvement Program. The Florida Department of Transportation's Office of Public Transportation and Systems Planning Office have been at the forefront in raising the level of travel demand forecasting in the state. Their vision has clearly set the stage for implementing tools that provide for improved analysis of many key travel modeling issues that are undoubtedly going to be faced by transportation planners in the short- and long-term into the next century. A few examples of such issues include:

- Transit scheduling and routing analysis by time-of-day based on how travelers schedule their activities and transfer across modes
- Trip chaining analysis that has far-reaching implications on mode choice, transit service provision to facilitate easy transfers and joint activity engagement, and destination choice
- Incorporating feedback between travel demand and transportation supply (network characteristics)
- Analysis of induced, suppressed, and latent travel demand in conjunction with modeling the effects of travel demand management strategies and transportation control measures
- Computing elasticities of trip making, modal split, and vehicle use with respect to various transportation policies including transit improvements, bicycle and pedestrian improvements, HOV lanes, parking and/or congestion pricing, intermodal developments, and advanced technologies

These research projects will benefit the state by providing the ability to undertake multimodal travel modeling in Florida while ensuring that model improvement efforts in the state proceed in the direction of the federal TMIP. The phased implementation plan will provide for substantial cost and time savings as the burden associated with introducing new tools will be considerably reduced through this effort. The research effort will involve close coordination with MPO's, FDOT district offices, transit agencies, and city/county transportation divisions around the state. In addition, input and review feedback will be solicited from the Statewide Model Task Force, FSUTMS Users Groups, and the modeling community at large to ensure that the modeling tools developed in these projects meet the needs of transportation planners in the state.

ACKNOWLEDGMENTS

The author thanks the project managers, Mr. Ike Ubaka with the Public Transit Office and Mr. Bob McCullough with the Systems Planning Office, for their constant encouragement, support, and technical and policy insights throughout the course of this research. The author is grateful to the Research Center of the Florida Department of Transportation for providing funding for the research efforts described in this paper. The cooperation of participating agencies, namely, the Dade County MPO, FDOT District 6 office, Metro-Dade Transit Agency, Volusia County MPO, Volusia County Transit (VOTRAN), and FDOT District 5, is gratefully acknowledged. The author, however, is solely responsible for all errors and omissions.

REFERENCES

Beckman, R.J., K.A. Baggerly, and M.D. McKay (1996) Creating Synthetic Baseline Populations. *Transportation Research* **30A(6)**, pp. 415-429.

Bhat, C. (1997) Work Travel Mode Choice and Number of Nonwork Commute Stops. *Transportation Research* **31B**, pp. 41-54.

Cambridge Systematics, Inc. (1996a) *Travel Survey Manual*. Prepared for the U.S. Department of Transportation Travel Model Improvement Program.

Cambridge Systematics, Inc. (1996b) *Data Collection in the Portland, Oregon Metropolitan Area: Case Study*. Prepared for U.S. Department of Transportation Travel Model Improvement Program. Report DOT-T-97-09.

COMSIS Corporation (1996) *Incorporating Feedback in Travel Forecasting: Methods, Pitfalls, and Common Concerns*. Prepared for U.S. Department of Transportation Travel Model Improvement Program. Report DOT-T-96-14.

Dial, R.B. (1995) *Network Optimized Congestion Pricing: A Parable, Model, and Algorithm*. Prepared for the U.S. Department of Transportation Travel Model Improvement Program. John A. Volpe National Transportation Systems Center.

Dial, R.B. (1994) *Multi-Criteria Equilibrium Traffic Assignment Basic Theory and Elementary Algorithms: Part I, T2: The Bicriteria Model*. Prepared for the U.S. Department of Transportation Travel Model Improvement Program. John A. Volpe National Transportation Systems Center.

Ettema, D.F. and H.J.P. Timmermans, eds. (1997) *Activity-Based Approaches to Travel Analysis*. Elsevier Science, North Holland, The Netherlands.

Goulias, K.G. and R. Kitamura (1992) Travel Demand Forecasting with Dynamic Microsimulation. *Transportation Research Record* 1357, pp. 8-17.

Hu, T.Y. and H.S. Mahmassani (1995) Evolution of Network Flows Under Real-Time Information: A Day-to-Day Dynamic Simulation-Assignment Framework. *Transportation Research Record* 1493, pp. 46-56.

Jones, P., ed. (1990) *Developments in Dynamic and Activity-Based Approaches to Travel Analysis*. Oxford Studies in Transport. Avebury, Gower Publishing Company, Aldershot, England.

Kitamura, R., C. Chen, and R.M. Pendyala (1998) Generation of Synthetic Daily Activity-Travel Patterns. *Transportation Research Record*, National Research Council, Washington, D.C. (forthcoming).

Los Alamos National Laboratory (1995) *An Operational Description of TRANSIMS*. Prepared for the Federal Highway Administration, Travel Model Improvement Program. Report LA-UR-95-2393.

Mannering, F., E. Murakami, and S.G. Kim (1994) Temporal Stability of Travelers' Activity Choice and Home-Stay Duration: Some Empirical Evidence. *Transportation* **21**, pp. 371-392.

Peng, Z., K. J. Dueker, J. Strathman, and J. Hopper (1997) A Simultaneous Route-Level Transit Patronage Model: Demand, Supply, and Inter-Route Relationship. *Transportation* **24(2)**, pp. 159-181.

Resource Decision Consultants, Inc. (1995) *Activity Based Modeling System for Travel Demand Forecasting*. Prepared for U.S. Department of Transportation Travel Model Improvement Program. Report No. DOT-T-96-02.

Shunk, G.A., ed. (1994) *The Effects of Added Transportation Capacity*. Conference Proceedings Prepared for U.S. Department of Transportation Travel Model Improvement Program. Report DOT-T-94-12.

Spear, B.D. (1994) *New Approaches to Travel Forecasting Models: A Synthesis of Four Research Proposals*. Prepared for U.S. Department of Transportation Travel Model Improvement Program. John A. Volpe National Transportation Systems Center, Report DOT-T-94-15.

Stopher, P.R. (1991) Deficiencies of Travel Forecasting Methods Relative to Mobile Emissions. *ASCE Journal of Transportation Engineering* **119(5)**, pp. 723-741.

Stopher, P.R. and M. Lee-Gosselin (1997) *Understanding Travel Behaviour in an Era of Change*. Elsevier Science, North Holland, The Netherlands.

Strathman, J.G., K.J. Dueker, and J.S. Davis (1994) Effects of Household Structure and Selected Travel Characteristics on Trip Chaining. *Transportation* **21**, pp. 23-45.