AERIS – Applications for the Environment: Real-time Information Synthesis State-of-the-Practice Support

FINAL REPORT
State of the Practice Scan of Behavioral and Activity-Based Models

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7. Author(s)
Balaji Yelchuru

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Booz Allen Hamilton
8283 Greensboro Drive
McLean, Virginia 22102

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16. Abstract

This report has been developed under the Track 1 effort of Phase 1 of the AERIS program and presents the findings of the state-of-the-practice scan of behavioral and activity-based models and their ability to predict traveler choices and behavior in response to implementation of ITS strategies and the suitability to use the behavior changes to quantify air quality impacts. This report presents the sensitivity and validity of a spectrum of models (such as four-step travel demand, tour-based, activity-based and simulation models) in representing traveler behavior choices (such as mode choice, time-of-day choice, trip chaining, number of trips, etc.) in response to implementing ITS strategies. This report also presents the strengths and limitations of four-step, activity-based, and simulation models and identifies modeling gaps related to meeting environmental modeling needs.

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EXECUTIVE SUMMARY

Purpose of the Project

The primary objective of the *Applications for the Environment: Real-time Information Synthesis (AERIS) State-of-the-Practice Support* project is to establish a foundation for the future research work to be conducted as a part of the Connected Vehicle AERIS program by conducting a state-of-the-practice assessment of travel behavior and activity-based models, environmental models, and tools and technology available to enable environmental data acquisition. Conducting the state-of-the-practice scan will help:

- Assess the capabilities of behavioral and activity-based models to predict changes in travel behaviors in response to implementation of intelligent transportation system (ITS) strategies and evaluate whether the behavior changes predicted by the behavior models can be used to estimate environmental impacts
- Understand the capabilities of environmental models to estimate environmental impacts (emissions, fuel consumption, etc.) due to traveler behavior and trip choices and
- Identify technologies that will allow the capture of environmental data needed by environmental models and other data needed to measure environmental impacts.

The AERIS program is delineated into three phases (extending over 5 years) namely:

1. *Foundational Analysis (Phase I)*
2. *Candidate Applications Evaluation (Phase II)*
3. *Research Investment Planning (Phase III).*

*Each phase has six major tracks that span a*cross the entire duration of the AERIS program namely:

1. *Establish Foundation*
2. *Identify Candidate Strategies*
3. *Analyze and Evaluate Candidate Strategies*
4. *Recommend Strategies and Applications*
5. *Policy and Regulatory Research*
6. *Stakeholder Interactions and Technology Transfer.*

This report has been developed under the Track 1 effort of Phase 1 of the AERIS program and presents the findings of the state-of-the-practice scan of behavioral and activity-based models and their ability to predict traveler choices and behavior in response to implementation of ITS strategies and the suitability to use the behavior changes to quantify air quality impacts. The findings of the comprehensive survey conducted as a part of this study will establish the foundation for the future research work to be conducted as a part of the AERIS program and help identify the strengths and limitations of the existing modeling tools to evaluate emissions impacts of candidate strategies to be selected. To complete the state-of-the-practice scan of behavior and activity-based models, the project team:

- Identified the spectrum of travel models including different types of travel behavior models such as four-step travel demand, tour-based, activity-based, simulation, and other hybrid models
- Analyzed and examined the sensitivity and validity of these models in representing traveler behavior choices (such as mode choice, time-of-day choice, trip chaining, number of trips, induced demand, etc.) in response to implementing ITS strategies
- Determined whether the represented traveler behavior changes are suitable to evaluate environmental impacts associated with implementation of ITS strategies
- Identified strengths and limitations of four-step, activity-based, and simulation models
- Considered data needs and issues related to behavioral models
- Identified modeling gaps related to meeting environmental modeling needs.

Note that separate reports that summarize the state-of-the-practice of environmental models and data acquisition technologies have also been prepared as a part of this project.

Background to the Report

The AERIS program vision is to create "Cleaner Air through Smarter Transportation." In order to meet the vision, the AERIS program attempts to generate, capture, and analyze vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) data to create actionable information that allows surface transportation system users and operators to make "green" transportation choices.

The US Department of Transportation (USDOT) and its contractors are in the process of developing Transformative Concepts (TCs) that demonstrate a variety of integrated operational concepts that use vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and other data and communications to change the way transportation systems operate, with an emphasis on combining applications to provide significant environmental benefits to surface transportation networks. The TCs are "modeling scenarios" developed to: determine potential environmental benefits, understand mobility trade-offs, assess data needs and availability of data within a connected vehicle environment, and facilitate development/enhancement of environmental algorithms. There are currently five TCs being evaluated: Eco-Signal Operations, Low-Emissions Zone, Eco-Lanes, Eco-Integrated Corridor, and Alternative Fuel Vehicle Operations Support.

In support of AERIS program, Noblis recently conducted a state of the practice review of existing literature on strategies suited for AERIS program. The strategies identified in this report include:

- **Demand and Access Management** strategies such as electronic toll collection, mileage-based fee, congestion pricing, etc. Demand and access management strategies aim to reduce traffic or travel demand by controlling access to roadways, improving pedestrian and transit options, and encouraging policies that reduce peak-hour congestion

- **Eco-Driving** strategies such as eco-driving assistance, adaptive cruise control (ACC), and eco-routing. These strategies attempt to influence driving behavior and promote driving styles that reduce overall emissions
- **Traffic Management and Control** strategies such as implementation of incident management systems, ramp metering, speed management, adaptive signal control, and signal coordination and optimization. These strategies attempt to dynamically adjust the traffic operations to manage traffic, reduce congestion, and hence reduce the emissions generated
- **Logistics and Fleet Management** strategies such as implementation of automated vehicle location (AVL) systems and idle-off, stop-start systems. These strategies attempt to reduce emissions by optimizing vehicle maintenance, telematics, speed, and fuel management.
- **Freight Management** strategies such as delivery management, platooning, and eco-driving
- **Transit** improvement strategies such as implementing bus rapid transit (BRT) to improve the mode share or reducing transit emissions by implementing transit signal priority (TSP).

Some common traveler behavior changes associated with the above strategies can be broadly classified as behavior changes that reduce the overall VMT (and directly reduce the emissions generated) or behavior changes that do not result in an overall reduction in VMT, but still succeed in emissions reduction. Examples of behavior changes include the following:

Behavior changes that directly result in VMT reduction

- Change in routes (targeted at minimizing travel distance)
- Change in mode of travel (take transit, carpool, non-motorized travel such as walking, biking etc.)
- Change in number of trips
- Change in trip chaining patterns

Behavior changes that do not directly result in VMT reduction but those that can have a positive impact on the environment

- Change in time of travel (for instance, peak spreading or changing the time of departure to avoid congestion and/or toll)
- Compliance with variable speed limits that improves the smoothness of travel
- Change in driving behavior (eco-driving)
- Improved freight planning and operations
- Eco-routing (note that eco-routing sometime can also lead to reduced VMT)
- Change in Fuel choices.

Change in traveler behavior in one or more of the ways listed above is likely to have a direct impact on the environment. For example, if the traveler reduces the amount of auto travel, changes the time of day of travel, or changes the driving style or behavior, then these changes result in reduced VMT or fuel consumption (due to reduction in VMT or improvement in driving style) and hence result in reduced emissions.

Sequencing of Steps to Evaluate Emissions Impacts

Predicting and representing traveler behavior in response to ITS strategies are important to determine the impacts of ITS strategies on the environment. Behavioral or demand models such as the four-step demand models or the activity-based models are used to predict the changes in mode choice, time-of-day choice, route choice, and number of trips. Typically, these behavior changes result in changes in traffic volume or travel during congested times. The outputs of the demand models are the origin-destination (OD) matrices of trips by mode of travel and time of day.

To quantify the emissions impacts of ITS strategies, it is necessary to predict the behavior changes or the updated OD matrices in response to ITS strategies. It is also necessary to estimate the change in network performance (speeds, congestion, volumes, delays, etc.) as a result of change in behavior. For example, the output of behavioral models cannot predict the environmental impact of change in driver characteristics (smooth driving). Traffic assignment procedures or microsimulation tools (mesosocopic and microscopic) are used to model network performance changes resulting from the behavior changes (both pre-trip and while driving). Finally, to quantify the emissions impacts due to the behavior changes, the network performance data (speeds, volumes, etc.) generated by the traffic simulation tools is fed to **emissions** models such as MOtor Vehicles Emissions Simulator (MOVES) or Comprehensive Modal Emissions Model (CMEM). **Figure E-1** shows the modeling capability needed to predict the air quality impacts of ITS strategies.

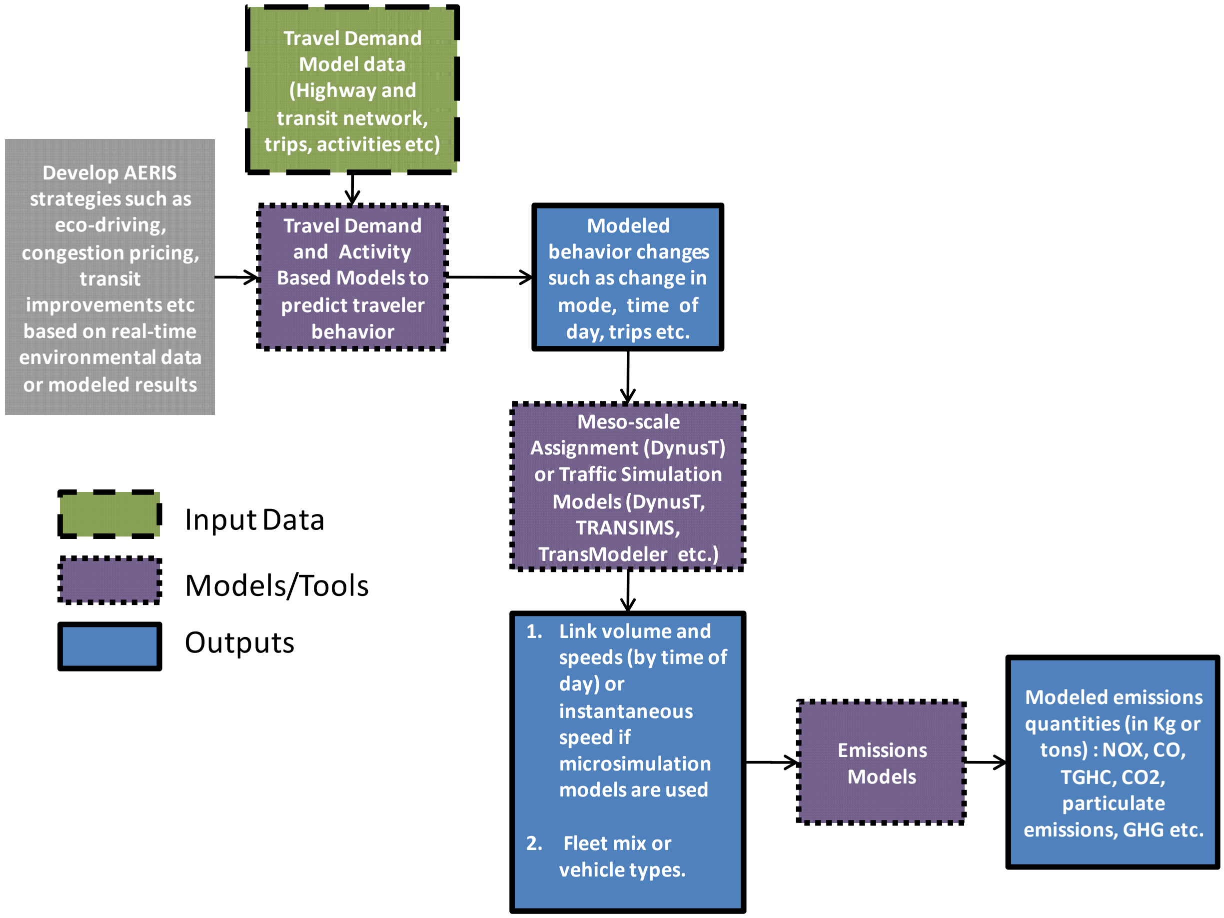

Figure E-1: Sequencing of Steps to Evaluate Emissions Impacts of ITS Strategies

Key Findings on Behavior and Simulation Models

For several decades now, traditional four-step travel demand models have been used as a regional planning tool to quantify the transportation and air quality impacts of proposed highway and transit improvements. The tool is particularly effective in evaluating projects that impact capacity. The four-step travel demand modeling framework includes four steps, namely the trip generation, trip distribution, mode choice, and traffic assignment. The trip generation stage of the travel demand modeling process uses the land-use data to determine the number of people, number of employments, etc. in each traffic analysis zone (TAZ). In the trip distribution stage, the trip attractions and productions determined during the trip generation stage are linked to create the O-D trip patterns. The travel time impacts are considered while pairing the origins and destinations. In the mode choice component, the travel costs are considered to determine the possible mode of transportation (auto, carpool 2, carpool 3, transit, walk, etc.) for each trip in the O-D trip table. Finally, the highway trip tables are assigned to the network to determine the link volumes and speeds. The traffic assignment procedures used in traditional travel demand modeling tools (such as TP+, TransCAD, EMME2, TRANPLAN, etc.) use the volume-to-capacity ratios and the Bureau of Public Roads (BPR) based volume delay functions (VDFs). The outputs from the traffic assignment step (link level volumes and speeds) are then used as an input to emissions models such as Mobile6 and MOVES to determine the emissions.

The following summarizes the findings on four-step models:

- Four-step models are not fully capable of quantifying the behavior changes associated with implementation of strategies such as congestion pricing, changes in land use policy, operational improvements, demand and access management strategies, and other policy changes, especially if the strategy implemented does not directly impact the capacity
- The four-step models' simplistic assumption of modeling travel behavior is not fully capable of predicting traveler choices in response to fine policy changes
- In a four-step model, each person trip is considered separately, and no trip chaining is considered. That is, a person's round trip from home to work and back from work to home is split into two one-way trips, one from home to work and the other from work to home. As a result, the model results are not sensitive to policy changes that are designed to reduce the peak demand such as flexible work schedules and congestion pricing/tolls during peak periods.

As noted above, one of the major shortcomings of traditional four-step, trip-based models is that they do not consider the linkage between individual trips that an individual makes. To overcome this limitation, tour-based models have been used recently. Tour-based models consider travel tours at all stages of demand estimation (generation, distribution, and mode choice), but use a simplified structure for tour generation and scheduling that does not explicitly account for intra-household interactions, joint travel, and individual schedule consistency. Activity-based models take the tour-based models one step forward and consider interaction between members of the household, vehicle ownership, and joint travel, and ensure schedule consistency between individual trips made by every member of the household during the entire course of the day. Activity-based models, which are gaining popularity in recent years, are well positioned to overcome the shortcomings and predict traveler behavior (such as mode choice, route choice, time-of-day choice, induced demand, etc.) in response to implementation of ITS strategies as these models are theoretically sound and model travel behaviors as a series of linked activities or tours.

The following summarizes the findings on activity-based models:

- Activity-based demand models can predict traveler choice in changes in ITS strategies that include travel demand management, transit improvement, policy changes such as fuel price, mileage-based taxes, etc.
- Activity-based models developed by the Mid-Ohio Regional Planning Commission (MORPC) and the DaySim activity-based model recently developed and used by Sacramento Area Council of Governments (SACOG) are two examples of advanced activity-based models that are capable of predicting traveler choice in response to implementation of most demand and access management strategies. It must be noted that these models have not been rigorously tested to model behavior changes in response to dynamic ITS strategies and the full benefits of using activity-based models have not been fully demonstrated
- While activity-based models address travel demand in great detail, the network or the supply side of the model requires enhancements to ensure that improved travel-time estimates (that reflect time-of-day congestion) are available to estimate emissions. The current state-of-practice is to split the highway tours derived from activity-based models into trips aggregated into three or four time periods (AM, midday, PM, night) and a static traffic (TP+, EMME2, TransCAD, etc.) assignment is performed for each period. The actual trip departure time and arrival time within the period are not considered. Also, trips are assumed to be homogeneous within a time period, while in reality a majority of the trips occur (peak) within a certain part of the period, while some of the trips overlap multiple periods.

To support most AERIS and other ITS strategies, in addition to modeling demand (in the context of household activities) and travelers' response to implementation of strategies, the model should capture time-of-day congestion impacts by assigning time-dependent demand tables on a time-dependent network and should consider the operational characteristics (traffic signals, turn lanes, parking lanes, etc.) of the transportation network so that system performance can be evaluated accurately to quantify the air quality impacts. Traditional approaches (traffic assignment procedures in four-step models) to assigning the traffic onto the transportation network produce aggregate measures of volumes and speeds and cannot be used to quantify emissions impacts of implementing ITS strategies. A few MPOs and planning agencies are designing and implementing activity-based models, but fewer agencies have addressed the difficult issue of implementing time-dependent networks to capture time-of-day congestion effects for the entire region. The current state-of-the-practice is to use macroscopic models for regional planning and supplement with simulation studies for intersection-level analyses or for small sub-areas, as traffic simulation tools are not capable of modeling entire regions. Capturing the regional impacts of ITS implementations is difficult in this approach. Mesoscopic and microscopic simulation models are well suited to quantify the air quality impacts associated with implementation of ITS strategies. Mesoscopic simulation tools such as

DynaMIT, DynusT, etc., track vehicles individually in the network to maintain a higher level of detail as compared to macroscopic simulation tools, and they consider traffic signal delays. Microscopic simulation tools consider movements of individual vehicles dynamically on a second-by-second basis using cellular automata or car-following models. Microscopic models require detailed geometric, control, and demand data and a large number of calibrated parameters to accurately model driver behavior in the network. Microscopic and mesoscopic models provide detailed outputs that describe network performance during small time increments (15 minutes or less). Examples of output data generated by these models include link-level travel time, miles traveled, stop times, queue lengths, delays, etc.

The following summarizes the findings on simulation models:

- Microsimulation models simulate traffic at a fine level of time resolution (second-by-second) and hence possess the ability to model peak-hour congestion
- As microsimulation tools provide capability to track different classes of travelers and vehicles, they are ideally suited to support ITS project evaluations
- Mesoscopic and microscopic simulation tools are best suited to generate detailed network performance data that can be fed to emissions models such as MOVES or CMEM to estimate the environmental impacts of ITS strategies
- Activity-based models are not capable of predicting behavior changes such as coordination with adaptive signals, compliance with variable speed limits, adaptive signals, aggressive driving versus eco-driving, etc. Microsimulation tools such as VISSIM, Paramics, etc. are needed to model strategies that do not affect trip choices. The impacts of freight management and logistics and fleet management strategies need to be addressed using microsimulation models, but this is not being carried out by many agencies at this time.

Based on the findings of the state-of-the-practice scan, the table below summarizes the models that are suited for predicting common behavior changes likely to be associated with implementation of ITS strategies.

Table E-1: Capabilities of Models to predict behavior changes

Behavior Change Description	Potential Models or Tools for Predicting Behavior Changes
Behavior Changes that Impact VMT	
Change in routes (targeted at minimizing travel distance)	Traditional four-step models, activity based model, Mesoscopic or Microscopic Simulation Models
Change in mode of travel (take transit, carpool, non-motorized travel such as walking, biking etc.)	Traditional four-step models or activity based models
Change in number of trips	Activity Based Models
Change in trip chaining patterns	Activity Based Models
Behavior Changes that do not directly impact VMT	

Behavior Change Description	Potential Models or Tools for Predicting Behavior Changes
Change in time of travel (for instance, peak spreading or changing the time of departure to avoid congestion and/or toll)	Traditional four-step models in combination with microsimulation tools or Activity based models
Compliance with variable speed limits that improves the smoothness of travel	Microsimulation models
Change in driving behavior (eco-driving)	Microsimulation models
Eco-routing (note that eco-routing sometime can also lead to reduced VMT)	Microsimulation models

Modeling Needs to Support the AERIS Program

To support most AERIS and other ITS strategies, in addition to modeling demand and travelers response (in the context of household activities) to implementation of strategies, the model should simulate individual vehicles and persons on a time-dependent network to evaluate system performance and quantify the air quality impacts accurately. Advanced simulation models are capable of producing detailed vehicle data that can be input to microscopic emissions models such as MOVES and CMEM. Non-simulation approaches to assigning the traffic onto the transportation network produce aggregate measures of volumes and speeds and cannot be used to quantify emissions impacts of implementing ITS strategies accurately. A number of states and metropolitan planning organizations (MPOs) are in the process of designing and implementing activity-based models, but few agencies have addressed the difficult issue of implementing time-dependent networks to capture time-of-day congestion effects for the entire region. The current state-of-the-practice is to use simulation studies for intersection level analyses or for small sub-areas. As the results of the simulation studies are not fed back to demand models, the regional impacts of traffic operational improvements are not fully captured.

Recent modeling studies conducted to support Integrated Corridor Management (ICM) Pioneer Site evaluations attempt to link macroscopic, mesoscopic, and microscopic simulation models to capture the regional impacts of traffic operational improvements. The Test Corridor AMS approach encompasses tools with different traffic analysis resolutions. All three classes of simulation modeling approaches – macroscopic, mesoscopic, and microscopic – are applied for evaluating ICM strategies. This modeling approach provides the greatest degree of flexibility and robustness in supporting subsequent tasks for AMS support of Pioneer Sites.

Over the last 15 years, the Federal Highway Administration (FHWA) has invested in the development of TRansportation ANalysis and SIMulation System (TRANSIMS), an integrated activity-based and simulation-based model. A series of case studies have been carried out to demonstrate the applicability of TRANSIMS to quantify the air quality impacts of traffic operation improvements. While the TRANSIMS case studies demonstrate that they are well suited to support the AERIS program, most TRANSIMS studies to date have been carried out using federal funds and no agency currently uses TRANSIMS as a planning or operational analysis tool.

The Strategic Highway Research Program 2 (SHRP 2) C10 program is currently funding two projects with the objective to develop an Integrated Advanced Travel Demand Model and a Fine-Grained, Time-Sensitive Network. The SHRP 2 C10A project partners are developing an integrated, advanced travel demand model with a fine-grained time-sensitive network simulation for the Jacksonville, Florida, region. This project attempts to integrate the outputs from a detailed activity-based model (DaySim) with a TRANSIMS simulation model to assess regional transportation network performance. The SHRP 2 C10B project partners are developing a framework that integrates the Sacramento Activity-Based Travel Demand with DynusT simulation model. Both the projects are currently ongoing, and the results are likely to be publicly available in 2012. Theoretically, the models developed (that integrate activity-based models with simulation models) as a part of the SHRP 2 C10 program are more capable of quantifying the change in travel behavior in response to implementation of ITS strategies.

The project team concludes that activity-based models are theoretically well suited to predict traveler choices in response to implementation of demand and access management strategies. However, these models are in their infancy and have not been rigorously tested. Also, the current state-of-the-practice is that the activity patterns generated by activity-based models are split into trips, and traditional traffic assignment procedures are used to predict network performance. This is a major limitation, and the outputs from activity-based models need to be interfaced with mesoscopic or microscopic simulation tools to make them fully suitable for supporting the AERIS program and evaluate strategies such as eco-driving, traffic management, and control and transit improvements. The advanced integrated models developed as a part of the SHRP 2 C10 project (or similar models) are likely to be best suited to support the AERIS program.

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1.0 INTRODUCTION

The primary objective of the AERIS State-of-the-Practice Support project is to establish a foundation for the future research work to be conducted as a part of the AERIS program by conducting a state-of-the-practice assessment of travel behavioral and activity-based models, environmental models, and tools and technology available to enable environmental data acquisition. The purpose of this report, in particular, is to document the ability of behavioral and activity-based models to effectively represent actual traveler behavior changes related to ITS strategies and document the ability to use the behavior changes represented by models to quantify the environmental impacts related to AERIS applications.

As a separate but related part of this project, the research team conducted a detailed analysis of current emissions models, their data needs, ease of data availability, and quality of data and determined how to make the existing data more useful and identify additional data needed for emissions models. The research team also conducted a state-of-the-practice scan of technologies for use in capturing environmental data and data needed to measure environmental impacts. In particular, the research team determined the environmental data and data needed by environmental models that can be acquired or derived from in-vehicle and infrastructure-based sensors.

While this report describes the state-of-the-practice assessment of behavioral and activity-based models and their suitability to support the AERIS program, the research team will prepare, as a part of this project, two additional reports that summarize the state-of-the-practice of environmental models and state-of-the-practice of technology to enable environmental data acquisition.

1.1 Research Objectives

The AERIS program's vision is "Cleaner Air through Smarter Transportation." In order to meet the vision, the AERIS program attempts to generate, capture, and analyze vehicle-to-vehicle and vehicle-to-infrastructure data to create actionable information that allows surface transportation system users and operators to make "green" transportation choices. The USDOT and its sub-contractors are in the process of identifying applications that have demonstrated environmental benefits through the use of ITS technologies and looking at opportunities for the AERIS program to use these applications. The preliminary list of applications that have demonstrated to yield environmental benefits includes:

- **Demand and Access Management** or **Transportation Demand Management** (TDM) strategies such as electronic toll collection, mileage-based fee, congestion pricing, en-route or pre-trip traveler information, etc. Demand and access management strategies aim to reduce traffic or travel demand by controlling access to roadways, improving pedestrian and transit options, and encouraging policies that reduce peak-hour congestion
- **Eco-Driving** strategies such as eco-driving assistance, Adaptive Cruise Control (ACC), and eco-routing. These strategies attempt to influence driving behavior and promote driving styles that reduce overall emissions

- **Traffic Management and Control** strategies such as implementation of incident management systems, ramp metering, speed management, adaptive signal control, and signal coordination and optimization. These strategies attempt to dynamically adjust the traffic operations to manage traffic, reduce congestion, and hence reduce the emissions generated
- **Logistics and Fleet Management** strategies such as implementation of Automatic Vehicle Location (AVL) systems and idle-off, stop-start systems. These strategies attempt to reduce emissions by optimizing vehicle maintenance, telematics, speed, and fuel management
- **Freight Management** strategies such as delivery management, platooning, and eco-driving
- **Transit** improvement strategies such as implementing Bus Rapid Transit (BRT) to improve the mode share or reducing transit emissions by implementing Transit Signal Priority (TSP).

Each of the above applications change traveler behavior in one or more ways and is likely to have a direct impact on the environment, either through reduced emissions or reduced fuel consumption. Some common traveler behavior changes associated with the above applications can be broadly classified as behavior changes that reduce the overall VMT (and directly reduce the emissions generated) or behavior changes that do not result in an overall reduction in VMT, but still succeeds in emissions reduction. Examples of behavior changes include:

Behavior changes that directly result in VMT reduction

- Change in routes (targeted at minimizing travel distance)
- Change in mode of travel (take transit, carpool, non-motorized travel such as walking, biking etc.)
- Change in number of trips
- Change in trip chaining patterns

Behavior changes that do not directly result in VMT reduction but those that can have a positive impact on the environment

- Change in time of travel (for instance, peak spreading or changing the time of departure to avoid congestion and/or toll)
- Compliance with variable speed limits that improves the smoothness of travel
- Change in driving behavior (eco-driving)
- Improved freight planning and operations
- Eco-routing (note that eco-routing sometime can also lead to reduced VMT)
- Change in Fuel choices.

To support AERIS and other research programs, it is essential to have modeling tools that are capable of evaluating the benefits of different ITS scenarios or deployment strategies to help agencies determine the best application or bundles of applications that can be deployed. Some of the ITS strategies, such as the demand management and access strategies, tend to influence traveler behavior more directly than other strategies such as eco-driving. For instance, eco-driving strategies tend to indirectly change travel behavior by encouraging the drivers to drive smoothly (using the highest possible gear at low RPM), drive with an increased safety distance (equivalent of about 3 seconds to the car in front) so as to optimize the options to balance speed fluctuations in traffic flow and enable steady driving with constant speed.[1]

For strategies that do not influence the traveler behavior greatly, microsimulation tools such as TRANSIMS, VISSIM, Paramics, AIMSUN, CORSMIM, and SUMO have been successfully used to quantify the air quality impacts. For strategies that tend to change the traveler behavior, such as congestion pricing, it is desirable to have models capable of predicting changes in traveler behavior in response to implementation of ITS strategies. Upon validating the results generated by the models, the represented behavior changes related to AERIS applications potentially can be used to evaluate the environmental impacts.

1.2 Modeling Needs to Support the AERIS Program

The primary objectives of AERIS are to accomplish the following:

1. Generate/capture environmentally-relevant real-time transportation data (from vehicles and the system)
2. Use this environmental data to create actionable information that can be used by system users and operators to support and facilitate "green" transportation choices for all modes
3. Assess whether doing these things yields a good enough environmental benefit to justify further investment by the Department.

As traveler choices impact the VMT or distance traveled, speed, smoothness of travel, and/or driving characteristics, traveler choices have a direct impact on emissions. To quantify the environmental benefits of implementing ITS strategies, it is necessary to accomplish the following:

1. Model traveler response to ITS strategies at a fine level of detail
2. Interface the outputs from travel demand models with traffic assignment models to predict network performance such as speed, volume, delays, vehicle mix, etc.
3. Feed the speed, volume, and vehicle movement data to emissions models to quantify the air quality and fuel consumption impacts of traveler choices.

Typically, outputs from travel demand models (such as speed, volume, fleet mix, etc.) are provided as an input to emissions models to quantify vehicle emissions and fuel consumption. For several years now, transportation planning agencies have input speed estimates from traffic assignment procedures in traditional four-step models (and recently from simulation-based models) to the Mobile6 Emissions model to perform air quality analysis. Mobile6 is a macroscopic emissions model and does not allow much flexibility to change the input parameters and assumptions; however, there have been some recent improvements to emissions models, and the Environmental Protection Agency (EPA) recently released MOVES2010 (Motor Vehicles Emissions Simulator), a next-generation, simulation-based emissions model. The MOVES model is capable of receiving travel demand data inputs at a

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[1] http://www.ecodrive.org/, *Eco-driving concepts and benefits supported by Intelligent Energy, Europe (Accessed on June 17, 2011).*

finer level of detail when compared to Mobile6 (e.g., it can read driving cycles or operating mode distribution of vehicles). Another state-of-the-practice report (*State-of-the-Practice Scan of Environmental Modeling*) provides details about the MOVES model and other emissions models.

1.2.1 Sequencing of Steps to Evaluate Emissions Impacts

Predicting and representing traveler behavior in response to ITS strategies are important to determine the impacts of ITS strategies on the environment. Behavioral or demand models such as the four-step demand models or the activity-based models are used to predict the changes in mode choice, time-of-day choice, route choice, etc., and typically, the behavior changes result in changes in traffic volumes or travel during congested times. The outputs of the demand models are the OD matrices of trips by mode, time of day, etc.

To quantify the emissions impacts of ITS strategies, it is necessary to predict the behavior changes or the updated OD matrices in response to ITS strategies and to estimate the change in network performance (speeds, congestion, volumes, delays, etc.) as a result of change in behavior. For example, the output of behavioral models cannot predict the environmental impact of change in driver characteristics (smooth driving). Traffic assignment procedures or microsimulation tools (mesosocopic and microscopic) are used to model network performance changes resulting from the behavior changes (both pre-trip and while driving). Finally, to quantify the emissions impacts due to the behavior changes, the network performance data (speeds, volumes, etc.) generated by the traffic simulation tools is fed to emissions models such as MOVES or CMEM. **Figure 1** shows the modeling capability needed to predict the air quality impacts of ITS strategies.

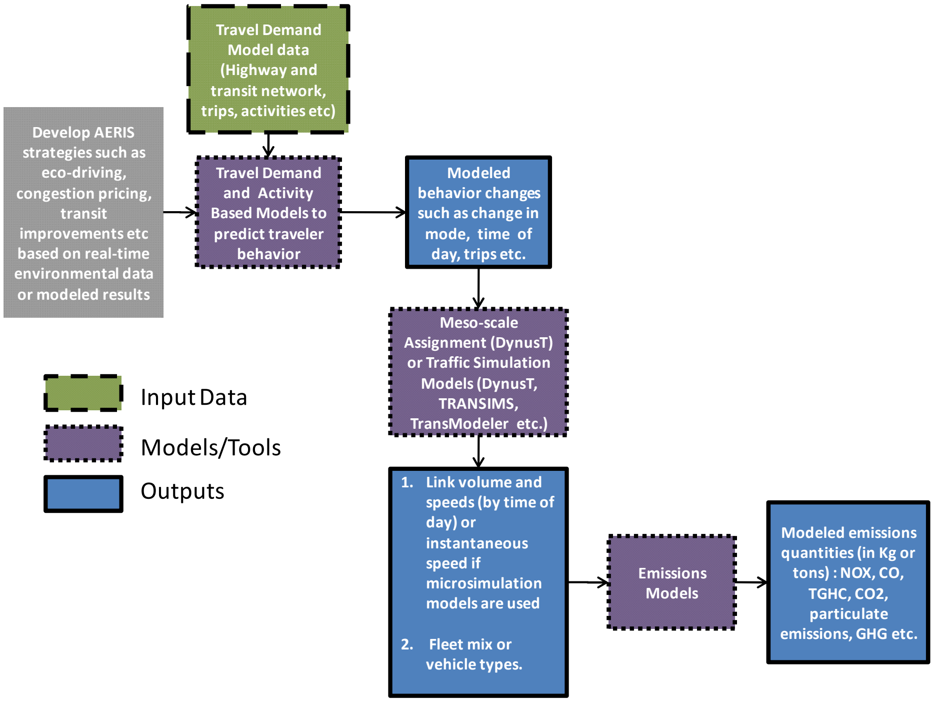

Figure 1: Sequencing of Steps to Evaluate Emissions Impacts of ITS Strategies

Several transportation agencies are implementing TDM techniques and other ITS strategies to influence travel behavior and, hence, reduce emissions. Emission quantities generated from a car depends on the amount of travel (i.e., VMT) and speed with which the travel occurs. Cars and trucks emit significantly higher emissions at lower travel speeds as compared to higher travel speeds (note that certain emissions increase marginally at significantly higher speeds). Also, trucks and other heavy-duty vehicles emit more emissions than cars. Sharp acceleration and deceleration rates also increase the amount of emissions generated by vehicles. As a result, improvement in travel speeds and/or reduction in overall travel volume will help in reducing emissions. Also, smoothing the travel flow and reducing the acceleration and deceleration rates help reduce the emissions.

A preliminary list of desired travel demand modeling capabilities includes the following:

- Evaluate travel behavior changes such as change in route, destination, mode, time of travel (peak-hour spreading), or number of trips due to implementation of high-occupancy-toll (HOT) lanes, managed lanes, high-occupancy-vehicle (HOV) lanes, and other TDM techniques such as reversible lanes, parking charges, etc.
- Evaluate the travel behavior and route changes resulting from traffic operational changes or improvements such as signal progression and/or signal optimization
- Quantify “induced demand” that arises due to implementation of traffic operational and other improvements
- Predict travel behavior changes associated with implementation of transit improvements
- Predict travel behavior changes associated with dissemination of en-route traveler information
- Identify the air quality improvements such as reduction in greenhouse gases accrued from implementing an ITS strategy such as optimized signal timings
- Quantify reduction in fuel consumption.

For several decades now, the traditional four-step (trip generation, trip distribution, mode choice, and traffic assignment) travel demand models have been used for transportation planning purposes and to quantify air quality benefits associated with implementing highway and transit improvements. After many years of relative consistency in the basic approach to travel demand modeling, there now is considerable variety in the structure and capabilities of travel demand forecasting systems and analysis tools in use today. The transportation planning process, especially the project evaluation stage, effectively uses various modeling tools to various degrees. The traffic assignment modules within the four-step travel demand modeling packages use volume-to-capacity ratios to determine the speeds. However, if the operations strategy (e.g., signal timing, incident management, and variable speed limits) does not immediately impact volumes, the speed estimates generated using volume-to-capacity ratios will not be sensitive to the implemented operational improvements and, hence, environmental benefits cannot be determined accurately. To overcome this limitation, several planning agencies are supplementing their regional travel demand model with traffic simulation tools (e.g., VISSIM, Paramics, and CORSIM) to capture the speed variation and to quantify immediate travel-time benefits from traffic operations strategies. Because it is expensive and time consuming to code and simulate large metropolitan areas, it is common to develop a special corridor or subarea model for major projects using some components or information from general-purpose MPO or DOT four-step planning models.

Although developing subarea simulation models works to effectively quantify the transportation benefits of implementing ITS and other operational strategies, this approach does not help quantify the regional impacts of ITS strategies (e.g., changes in trip destination choice, mode choice, time-of-day choice, peak spreading, induced demand) unless the outputs from subarea microsimulation models are fed back into the regional (macroscopic) travel demand models. Integrating macroscopic models with mesoscopic or microscopic subarea models is critical to support new and upcoming DOT research initiatives such as AERIS, Dynamic Mobility Applications (DMA), ICM, and Active Transportation and Demand Management (ATDM) programs. In the current state-of-the-practice, very few agencies have attempted to develop or integrate their micro-scale models with the macroscopic or regional travel demand model; however, recent modeling studies conducted to support ICM Pioneer Site evaluations attempt to link macroscopic, mesoscopic, and microscopic simulation models to capture the regional impacts of traffic operational improvements.

A number of states and MPOs are in the process of designing and implementing activity-based models, but not many agencies have implemented time-dependent networks and dynamic traffic assignment procedures to capture time-of-day congestion effects and validate activity patterns. Without time-dependent networks, the temporal disaggregation created through activity-based models is lost during the process of static traffic assignment. Accurate integration of advanced supply models with demand models is critical to model ITS strategies.

For the past several decades, the outputs from travel behavior models are fed to static assignment procedures to evaluate network performance and quantify the benefits for proposed highway and transit improvement projects. They have also been used for evaluating air quality impacts and to justify policy and project investment decisions. However, static assignment procedures that are based on volume-to-capacity ratios are ineffective in determining the network performance accurately—more so when the demand is likely to exceed the supply significantly in future-year scenarios. The likely result of using static assignment procedures for evaluating strategies is possibly incorrect sensitivities to change in inputs and policies.

1.3 Overview of Travel Models

Public agencies, research organizations, and private vendors and consultants have developed numerous traffic analysis and modeling tools. Although each tool or approach has its own solution domain and resolution characteristics, traffic analysis tools can be grouped into categories with similar characteristics. **Figure 4** shows one categorization with increasing modeling complexity, ranging from sketch planning to detailed microscopic simulation. FHWA's Traffic Analysis Tools program[2] demonstrates a similar tool categorization and progression. Often, the availability of data and resources needed to perform the modeling

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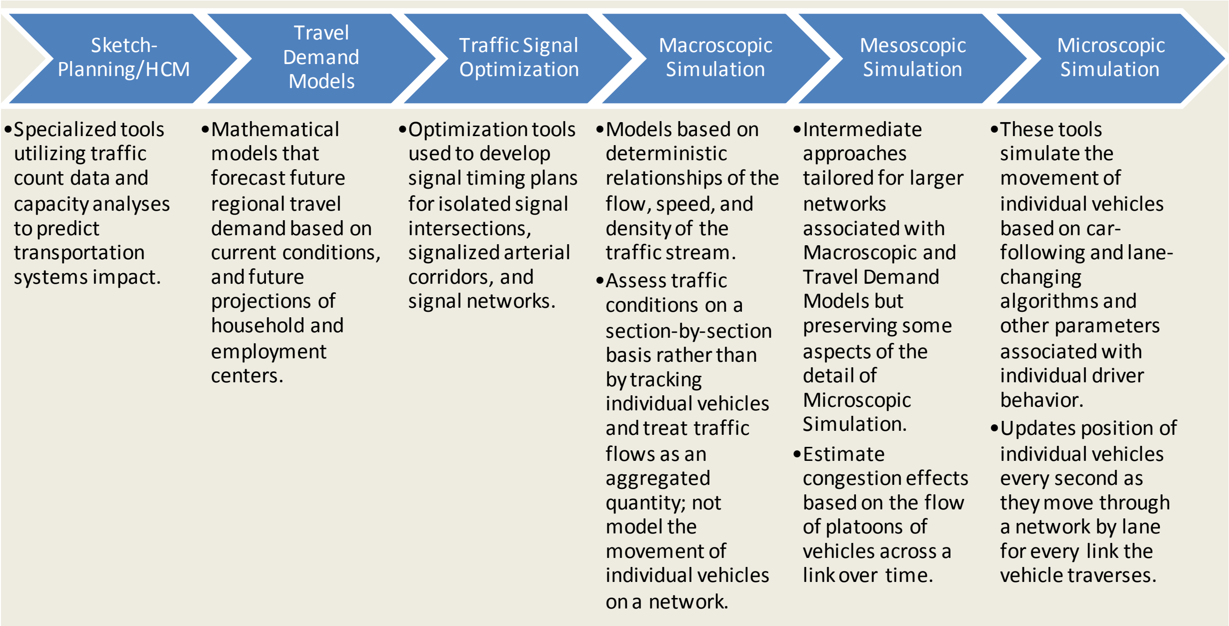
[2] *Traffic Analysis Toolbox Volume I: Traffic Analysis Tools Primer* published by FHWA in July 2004 (http://www.ops.fhwa.dot.gov/trafficanalysistools/index.htm - accessed May 10, 2011).

functions dictates the complexity of the tool and the approach. There is significant risk in developing detailed models with limited data or resources.



Sketch-Planning/HCM	Travel Demand Models	Traffic Signal Optimization	Macroscopic Simulation	Mesoscopic Simulation	Microscopic Simulation
•Specialized tools utilizing traffic count data and capacity analyses to predict transportation systems impact.	•Mathematical models that forecast future regional travel demand based on current conditions, and future projections of household and employment centers.	•Optimization tools used to develop signal timing plans for isolated signal intersections, signalized arterial corridors, and signal networks.	•Models based on deterministic relationships of the flow, speed, and density of the traffic stream. •Assess traffic conditions on a section-by-section basis rather than by tracking individual vehicles and treat traffic flows as an aggregated quantity; not model the movement of individual vehicles on a network.	•Intermediate approaches tailored for larger networks associated with Macroscopic and Travel Demand Models but preserving some aspects of the detail of Microscopic Simulation. •Estimate congestion effects based on the flow of platoons of vehicles across a link over time.	•These tools simulate the movement of individual vehicles based on car-following and lane-changing algorithms and other parameters associated with individual driver behavior. •Updates position of individual vehicles every second as they move through a network by lane for every link the vehicle traverses.

Figure 2: Spectrum of Traffic Analysis Tools

As shown in the above graphic, the analysis tools currently used in practice can be broadly classified into six wide categories. *Traffic Analysis Toolbox Volume I: Traffic Analysis Tools Primer* published by FHWA in July 2004 presents the following definitions for these six categories of tools.

Sketch-Planning Tools: Sketch-planning methodologies and tools produce order-of-magnitude estimates of travel demand and traffic operations in response to transportation changes or improvements. These tools are applicable for quick and cost-effective project evaluation prior to conducting a detailed engineering analysis. Sketch-planning tools use aggregated data, and the results cannot be used to justify policy changes such as eco-driving, congestion pricing, parking restrictions, transit improvements and HOV/HOT lanes that are necessary to implement AERIS strategies. As such, these tools are not “fully” capable of evaluating environmental impacts associated with ITS projects; however, some sketch-level analysis tools can be used for preliminary evaluations of ITS strategies. For example, IDAS (ITS Deployment Analysis Systems) has an environmental module to estimate the benefits. Examples of sketch-level planning tools include IDAS (ITS Deployment Analysis Systems), SMITE (Spreadsheet Model for Induced Travel Estimation), SPASM (Sketch Planning Analysis Spreadsheet Model), and IMPACTS.

Travel Demand Models: Travel demand models are used to forecast travel demand based on current and future predictions of household and employment characteristics. Travel demand models consider destination choice, mode choice, time-of-day travel choice, and route choice, and the representation of traffic flow in the highway network. Travel demand models can be either traditional four-step models or advanced activity-based models. Examples of travel demand models include EMME2, TransCAD, TP+, TRANPLAN, and CUBE. **Section 2.1** and **Section 2.2** present a detailed description of the ability of four-step and activity-based models to predict traveler choices in response to implementation of ITS strategies.

Traffic Signal Optimization Tools: Traffic signal optimization tools are used to develop optimal signal-phasing and timing plans for isolated signal intersections, arterial streets, or signal networks. These tools are typically used to perform capacity calculations; cycle length; splits optimization, including left turns; and coordination/offset plans. Some optimization tools can also be used for optimizing ramp metering rates for freeway ramp control. Traffic signal optimization tools such as Synchro/SimTraffic report environmental MOEs (Measures of Effectiveness) and can be used for ITS evaluation at localized intersections level; however, these tools are not "fully" suited for evaluating environmental impacts of large-scale ITS implementation. Examples of signal optimization tools include tools such as Synchro, PASSER, etc.

Macroscopic Simulation Models: Macroscopic simulation models use deterministic relationships of the flow, speed, and density of the traffic stream to determine system performance. The macroscopic models simulate traffic on a section-by-section basis, rather than by tracking individual vehicles, and have higher fidelity than traditional traffic assignment procedures in travel demand models. While, macroscopic models have considerably fewer demanding computer requirements than microscopic models, they do not have the ability to analyze transportation improvements in as much detail as the microscopic models. These models are not capable of evaluating the environmental impacts of ITS strategies as they do not model network performance at the desired level of detail. Examples of Macroscopic simulation models include FREQ, TRANSYT-7F, SATURN, and VISTA. TRANSYT-7F is a traffic signal optimization tool. It combines a state-of-the-art optimization process (including genetic algorithm, multi-period, and direct CORSIM optimization) with a state-of-the-art macroscopic simulation model (including platoon dispersion, queue spillback, and actuated control simulation).

Mesoscopic Simulation Models: Mesoscopic simulation models combine the properties of both microscopic and macroscopic simulation models. As in microscopic models, the mesoscopic models' unit of traffic flow is the individual vehicle. The vehicle movement, however, follows the approach of the macroscopic models and is governed by the average speed on the travel link. Mesoscopic model travel simulation takes place on an aggregate level and does not consider dynamic speed/volume relationships. As such, mesoscopic models provide less fidelity than the microsimulation tools, but are superior to the typical planning analysis techniques. Mesoscopic simulation models (also referred to as dynamic simulation models) are well suited to support evaluation of the environmental benefits of ITS strategies as they can model large regions of transportation network at relatively high levels of fidelity for much lesser computer resources as compared to microsimulation tools. Examples of mesoscopic simulation tools include CONTRAM, DYNAMIT, DYNASMART-P, DYNUST, VISUM, and AIMSUN.

Microscopic Simulation Models: Microscopic models simulate the movement of individual vehicles based on car-following and lane-changing theories. Typically, vehicles enter a transportation network using a statistical distribution of arrivals (a stochastic process) and are tracked through the network over small time intervals (e.g., 1 second or a fraction of a second). Typically, upon entry, each vehicle is assigned a destination, a vehicle type, and a driver type. Computer time and storage requirements for microscopic models are large, usually limiting the network size and the number of simulation runs that can be completed. These tools develop detailed vehicle movement data that can be directly fed to simulation-based emissions models such as MOVES and CMEM to quantify the air quality impacts of implementing ITS strategies. Examples of microscopic simulation tools include AIMSUN2, CORSIM, INTEGRATION, VISSIM, Paramics, TRANSIMS, and TransModeler.

The above mentioned traffic analysis tools can be broadly classified into two types:

- Travel Behavior or Demand Models
- Network or Supply models.

Travel behavior or demand models predict the travel demand or the OD matrices in a region. The network or supply models assign the OD matrices onto the transportation network and determine the network performance (speed, volumes, queues, delays, etc.). **Table 1** presents an overview of the models reviewed in detail to understand their state-of-the-practice and the suitability to use these models to predict environmental benefits associated with implementing ITS strategies.

Table 1: Overview of Travel Models Reviewed as a Part of This Study

Model Category	Description
Travel Behavior or Demand Models	
Four-Step Travel Demand Models (Traditional Models)	Planning agencies throughout the country have used these models for several decades to support their planning practice and develop long-range plans. Planning agencies also use these models to perform air quality analysis and NEPA analysis. These models use a simplistic representation of travel demand and do not consider interactions between members of household. Examples of these models include TransCAD, EMME2, TP+, and CUBE
Tour-Based/Activity Based Models	Tour-based models consider travel tours at all stages of demand estimation (generation, distribution, and mode choice), but use a simplified structure for tour generation and scheduling that does not explicitly account for intra-household interactions, joint travel, and individual schedule consistency. Activity-based models, on the other hand, are advanced tour-based models and consider interaction between members of the household, vehicle ownership, and joint travel, and ensure schedule consistency between individual trips made by every member of the household during the entire course of the day. MORPC in Columbus, Ohio, uses an activity-based model as a regional planning tool. Other regions such as San Francisco, Atlanta, and Phoenix are in the process of developing a full-fledged, activity-based model
Network or Supply Models	
Macroscopic Simulation tools	Macroscopic simulation models typically are used to model corridors, freeways, and arterials using small or subarea networks. Examples of macroscopic models include PASSER, FREQ, and TRANSYT-7F

Model Category	Description
Mesoscopic Simulation Tools (or Dynamic Traffic Assignment Tools)	Examples of mesoscopic tools include DYNASMART and DYNAMIT, DYNAMEC, and DYNUST. These models typically are used to replace the traffic assignment procedures in the traditional four-step travel demand models to achieve higher accuracy in speed estimates
Microscopic Simulation Tools	Several traffic microsimulation models currently are being used for traffic engineering and traffic operational improvement studies. Examples of traffic simulation models are CORSIM, Paramics, VISSIM, SimTraffic, TransModeler, and TRANSIMS

2.0 STATE-OF-THE-PRACTICE

This section describes the detailed review of behavioral and activity-based models and their suitability to support the AERIS program. The groupings of the models evaluated include:

- Traditional four-step travel behavior models
- Tour/activity-based models
- Traffic simulation models.

The traditional four-step and tour/activity-based models are travel behavior or demand models and the traffic simulation models are the network or supply models. While the behavior models (the traditional four-step and tour/activity-based models) are used to model traveler behavior in response to the implementation of policy changes (such as mode choice, time-of-day travel, trip chaining, change in trip destination, etc.), the supply models (microsimulation models) are used to model the change in network performance as a result of the predicted behavior changes.

2.1 Review of Conventional Four-Step Travel Behavior Models

2.1.1 Overview

Traditional four-step models have been used in the transportation industry for several decades now. A key input to the travel demand modeling process is the land use data and the key output includes traffic volumes on the network links (during different time periods) generated by the traffic assignment procedures. **Figure 3** depicts the typical (simple) four-step modeling framework.

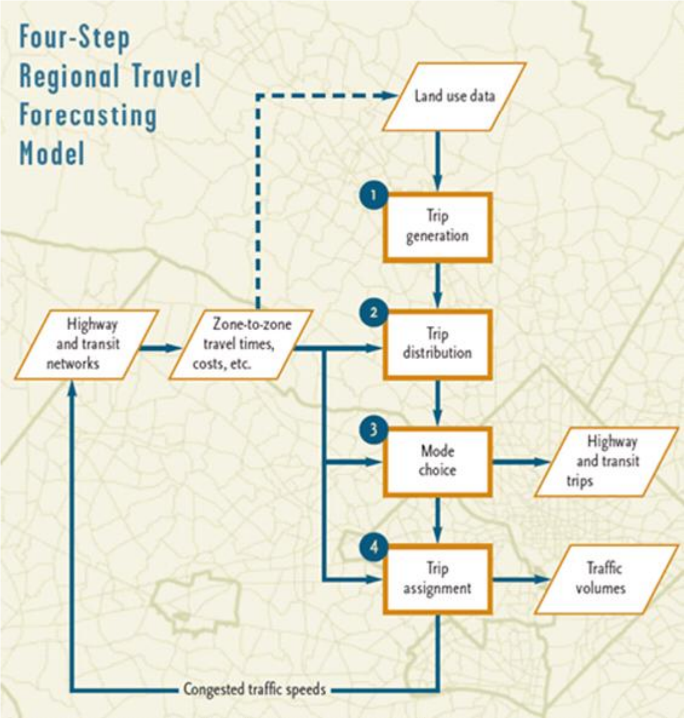


Figure 3: Simple Four-Step Modeling Framework Adopted by Metropolitan Washington Council of Governments (MWCOG)[3]

The Four-Step Model includes the following stages: (1) trip generation, (2) trip distribution, (3) mode choice, and (4) trip assignment. The trip generation stage of the travel demand modeling process uses the land-use data to determine the number of people and number of employments in each traffic analysis zone (TAZ). In the trip distribution stage, the trip attractions and productions determined during the trip generation stage are linked to create the O-D trip patterns. The travel time impacts are considered while pairing the origins and destinations. In the mode choice component, the travel costs are considered to determine the possible mode of transportation (auto, carpool 2, carpool 3, transit, walk, etc.) for each trip in the O-D trip table. Finally, the highway trip tables are assigned to the network to determine the link volumes and speeds. The traffic assignment procedures used in traditional travel demand modeling tools (such as TP+, TransCAD, EMME2, TRANPLAN, etc.) use the volume-to-capacity ratios and the Bureau of Public Roads (BPR) based volume delay functions (VDFs). The outputs from the traffic assignment step (link level volumes and speeds) are then used as an input to emissions models such as Mobile6 and MOVES to determine the emissions.

For several years, single VDFs were used for all facility types in the transportation network (such as freeways, arterials, collectors, etc). As such, the travel times estimated based on loaded volumes were not sensitive to the facility type (restricted, unrestricted, etc.) and the type of intersection control (actuated signals, fixed time signals, stop sign, yield sign, etc.). To improve the speed estimates, several agencies have now started using specific VDFs developed for each

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[3] *Metropolitan Washington Council of Governments (MWCOG) Four Step Travel Demand Model* (http://www.mwcog.org/transportation/activities/models/4_step.asp (accessed May 10, 2011).

facility type and also use different VDFs that attempt to account for delay at signalized intersections.

2.1.2 Data Considerations

Traditional four-step travel demand models are less data intensive as compared to advanced models such as activity-based models and traffic simulation models. The minimum data requirements for a four-step travel demand model include:

- Highway network
- Transit network
- Basic land use data (number of households and employment by TAZ)
- Household travel survey.

To validate the model results, daily or period (AM, PM, off-peak, etc.) based counts are used. The counts are typically collected using loop detectors on major facilities in the transportation network.

2.1.3 Interface with Emissions Models

The traffic assignment procedures used in the four-step models produce average daily volumes and speeds on the network links (by periods), and this data is processed and applied with emissions models such as Mobile6 and more recently MOVES to determine the emissions quantities generated by vehicles (autos and trucks). Both Mobile6 and MOVES emissions models produce an emissions rate look-up table, and the emissions rates are applied to the transportation data (average speeds and associated volumes for each facility type by time period) using custom-made post-processor tools.

2.1.4 State-of-the-Practice of Four-Step Models

As described earlier, planning agencies throughout the country have successfully used four-step models for several decades to support their planning practice and develop long-range plans. These models are also used by planning agencies to perform air quality conformity analysis; develop long-range plans; and conduct transit analysis including justification for New Starts funding, congesting pricing, toll lanes, etc. These models use a simplistic representation of travel demand and are reasonably well suited to evaluate transportation change volumes associated with projects that affect the network capacity. Most planning agencies use commercial packages such as TransCAD, EMME2, TP+, CUBE, or TRANPLAN to build four-step models. Most advanced agencies regularly update their four-step models (at least once every 5 years) to meet their planning needs. Examples of Agencies or MPOs that use well-maintained four-step models include the Virginia Department of Transportation (VDOT), Charlotte Department of Transportation (CDOT), Ohio Department of Transportation (ODOT), MWCOG and Florida Department of Transportation (FDOT) to name a few.

Special Report 288, Metropolitan Travel Forecasting – Current Practice and Future Direction, published by the Transportation Research Board (TRB) in 2007, highlighted the inadequacies of traffic assignment procedures in traditional four-step travel demand models and networks that are period based and not time sensitive to address the impact of management strategies and policy changes. While the new MOVES model is capable of conducting air quality analyses to address different geographic scales of air quality analysis from national, regional, and local to project-level inventories and uses a modal approach for emissions estimation based on second-by-second vehicle performance characteristics, including vehicle-specific power and speed, for different driving modes, traditional traffic assignment are not capable of generating data needed to support advanced air quality analysis.

Strengths

- The simplistic nature of the model makes it affordable for MPOs and other agencies to develop and maintain four-step travel demand models.
- For several decades now, transportation planners have tested and used models to predict behavior changes in response to capacity improvements or changes, and it is relatively easy to understand the sensitivities to changes in input data.
- These models are easy to use and best suited for developing long-range transportation plans and make investment decisions for major highway capacity or transit improvements.

Limitations

- In a four-step model, each person trip is considered separately, and no trip chaining is considered. That is, a person's round trip from home to work and back from work to home is split into two one-way trips, one from home to work and the other from work to home. As a result, the model results are not sensitive to policy changes that are designed to reduce the peak demand such as flexible work schedules and congestion pricing/tolls during peak periods.
- The traffic assignment procedures that are used in the traditional four-step models use volume-to-capacity ratios and are not suited to quantify the air quality impacts associated with implementing traffic operational improvements.
- The model is ineffective in estimating the change in number of trips due to implementation of traffic demand management strategies such as congestion pricing, tolls, HOT lanes, etc.
- Secondary and tertiary changes in a traveler's daily trip pattern (such as a trip to a grocery store, trip to a restaurant, etc.) as a result of change to the primary choice (change in mode, change in time-of-day travel, etc.) is not captured accurately. For example, if a traveler takes transit instead of driving alone, in response to congestion pricing, he is not likely to have flexibility to stop at a grocery store or a coffee shop on his way back from work.
- Typically, the demand is modeled in a traditional model for only two or three time periods (AM peak, PM peak, and/or off peak), and period-based capacities are used to determine the travel speeds. Within the time periods considered, the trip start times are considered to be homogeneous even though in the real world, a majority of the trips occur during the peak period. Also, the models do not account for the fact that some trips are likely to overlap two or more time periods.
- One of the primary limitations of the trip-based models is that they do not consider the interactions between multiple members of the household. As the interaction between trips is not considered, these models do not capture properly the trips that start at a non-work or non-home location (i.e., non home-based trips).

- As the traffic assignment modules within the four-step travel demand modeling packages use volume-to-capacity ratios and VDFs associated with these volume-to-capacity ratios to determine the speed, if the ITS implementation or operations strategy (e.g., signal timing, incident management, variable speed limits, and eco driving) does not immediately impact volumes, the speed estimates generated using volume-to-capacity ratios will not be sensitive to the implemented operational improvements, and hence, environmental benefits cannot be determined accurately. Also, using the VDFs to estimate speeds does not capture the downstream congestion impacts (or queue spillbacks).
- Temporal aggregation (time-period-based analysis) and spatial aggregation (TAZs) limit the ability of these models to predict fine-level changes in traveler choice due to implementation of ITS strategies.
- Because of the aggregate nature of the results generated by the trip-based models (trip start times are period based for individual travelers), interfacing the outputs of traditional trip-based models with microscopic emissions models does not yield accurate results.

2.2 Review of Tour-Based and Activity-Based Models

2.2.1 Overview

Travelers typically respond to demand management and other ITS strategies by changing their activity patterns and/or schedules (e.g. change their departure time, sequence of activities, duration of activities, change mode or defer trips altogether) and instead of performing simpler tours, they combine multiple activities and perform complex tours with multiple stops. To model this complex behavior, it is important to model individuals' travel behavior as a sequence of related activities. As described in **Section 2.1.4**, one of the major shortcomings of traditional four-step, trip-based models is that they do not consider the linkage between individual trips that an individual makes. To overcome this limitation, tour-based models have been used recently. Tour-based models consider travel tours at all stages of demand estimation (generation, distribution, and mode choice), but use a simplified structure for tour generation and scheduling that does not explicitly account for intra-household interactions, joint travel, and individual schedule consistency. Activity-based models take the tour-based models one step forward and consider interaction between members of the household, vehicle ownership, and joint travel, and ensure schedule consistency between individual trips made by every member of the household during the entire course of the day.

Activity-based models permit analysis based on the income and the associated value of time, the willingness of an individual to change his time of departure or deviate from his shortest travel time path in response to a toll. As these models explicitly consider household interactions, they consider facts such as if, in a one-car household, someone uses the car for a work trip, other household members cannot use it for a different trip at the same time—hence, the travel options available to this member of the household include only options such as carpooling, taking an alternative mode (transit, walk, bike, etc.), or not making the trip. Also, since the trips are grouped together as tours, the change in departure time of an outbound trip from home to work (as a result of peak-spreading) also impacts the change in departure time of the return trip from work to home, assuming that the activity duration or the time the individual spends at work remains the same. Also, as the activity-based models do not aggregate travelers and simulate the daily activities of individuals at a fine level (considering interactions between households and time constraints), these models are better suited for testing the impact of policies such as fuel price, gas taxes, vehicle type, fuel type, parking fees, congestion pricing, and transit improvements.

In a trip-based model, a person's daily activities are broken down as individual trips, and these trips are typically classified as home-based work, home-based other, and non-home based. While determining the home location and the work location is relatively straight forward, as it is tied to the home or work location, modeling non-home-based work trips is a challenge and is less accurate, as in this case neither the origin or the destination of the trip is at the home end and hence it is difficult to constrain these trips based on the individuals socioeconomic or other data. However, in a tour-based model, the activities of the individual are considered or simulated throughout the day as a sequence of activities with consideration to their home location, work location, mode availability, socioeconomic characteristics, etc. Travel cost parameters are used to predict changes in response to policy changes. As all trips of an individual are associated to households of known socioeconomic characteristics, the models can be used to evaluate sensitivity or behavior changes in response to changes such as congestion pricing, tolls, fuel price changes, and transit improvements. The activity-based approach requires time-use survey data for analysis and estimation. A time-use survey entails the collection of data regarding all activities (in-home and out-of-home) pursued by individuals over the course of a day (or multiple days). Travel constitutes the medium for transporting oneself between spatially dislocated activity participations. The examination of both in-home and out-of-home activities facilitates an understanding of how individuals substitute out-of-home activities for in-home activities (or vice-versa) in response to changing travel conditions. This, in turn, translates to an understanding of when trips are generated or suppressed. It is important to note that administrating time-use surveys is similar to administrating household travel surveys, except for collection of in-home as well as out-of-home activities. The information elicited from respondents is a little more extensive in time-use surveys compared to travel surveys, but experience suggests that the respondent burden or response rates are not significantly different between time-use and travel surveys.[4]

Different partial and fully operational activity-based microsimulation systems exist in practice today including MIDAS (Micro-analytic Integrated Demographic Accounting System); CEMDAP; PCATS (Prism Constrained Activity-Travel Simulator); SIMAP; ALBATROSS (A Learning-Based Transportation Oriented Simulation System) model; FAMOS (Florida's Activity Mobility Simulator); TASHA (Travel Activity Scheduler for Household agents); and the Best Practice Models of the New York Metropolitan Transportation Council, Columbus and San Francisco County.[5] While the overall concept of the philosophy is the same, each of the above activity-based model systems are slightly different in their approach to predicting or forecasting activities. For example, the CEMDAP modeling framework is used in the development of the North-Central Texas Council of Governments (NCTCOG) activity-based model. **Figure 4** presents an overall activity-based modeling framework.

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[4] *Chandra Bhat and and Frank S. Koppelman, Activity Based Modeling of Travel Demand (http://www.caee.utexas.edu/prof/bhat/ABSTRACTS/TSHANDBK.pdf – last accessed June 20, 2011)*

[5] *Activity-Based Models for Transportation Forecasting* (http://en.wikipedia.org/wiki/Transportation_forecasting - accessed May 10, 2011).

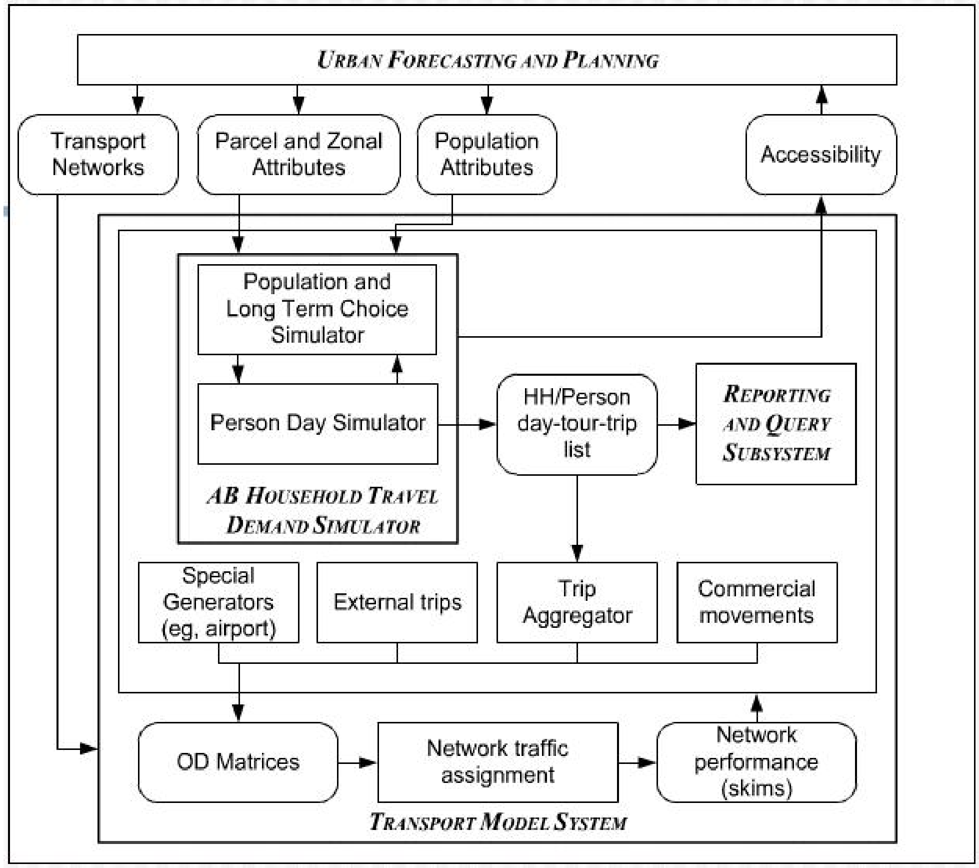

Figure 4: Activity-Based Model Framework[6]

Activity models simulate 24-hour activity and travel itineraries for each synthetic resident of a region. The resulting trips are aggregated into trip matrices, combined with commercial trips and trips of non-residents, and assigned to transit and road networks (as shown in Figure 4). In simulating the itineraries of one person, many dimensions of choice are modeled, including activity participation, timing and location, as well as the mode of associated travel. It is necessary to address the issue of integrating multiple model components because, on the one hand, the outcomes are related to such an extent that it seems appropriate to treat them as a single complex outcome, modeling all dimensions simultaneously and, on the other hand, the outcome is so complex that it is impractical to capture all the needed detail in a single model. Therefore, the models have been implemented as a large number of carefully integrated components. The objective of these models, and hence the objective that guides the selection of integration techniques, is to realistically model travel behavior that can be affected by changes in activity opportunities and travel conditions, especially those that are affected by public policies and programs.[7]

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[6] *John L. Bowman Travel Model Improvement Program (TMIP) webinar, Activity Model Development Experiences, 2009*

[7] *John L. Bowman, Activity-Based Model: Approaches used to achieve Integration among trips and tours throughout the day, http://jbowman.net/papers/2008.Bowman_Bradley.Approaches_to_integration_ETC.pdf (accessed on June 17, 2011)*

Some agencies are in the process of developing activity-based models to meet their modeling needs. Agencies within the United States that have developed a tour-based or an activity-based travel model include:[8]

- Portland Metropolitan Area (METRO)
- New York, New York Metropolitan Transportation Council (NYMTC)
- Columbus, Mid-Ohio Regional Planning Commission (MORPC)
- Sacramento, Sacramento Area Council of Governments (SACOG)
- Los Angeles, Southern California Council of Governments (SCAG)
- Denver, Denver Regional Council of Government (DRCOG)
- San Francisco, San Francisco County Transportation Authority (SFCTA).

Planning agencies that are in the process of either moving towards or considering the move toward the activity-based modeling approach include agencies such as:

- Atlanta, Atlanta Regional Council (ARC)
- Dallas – Fort Worth, NCTCOG
- Chicago, Chicago Metropolitan Agency for Planning (CMAP)
- Seattle, Puget Sound Regional Council (PSRC)
- Phoenix, Maricopa Association of Governments (MAG) El Paso MPO
- Santa Barbara, Santa Barbara County Association of Governments (SBCAG).

Figure 5 shows the timeline of activity-based model implementations in the United States as of 2009.

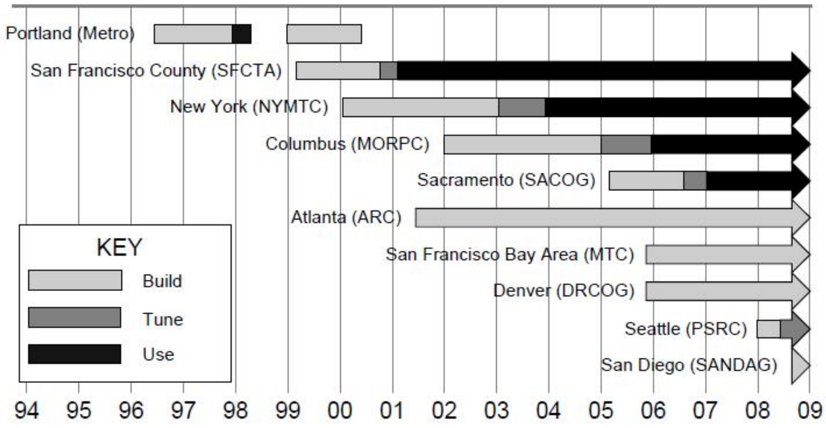

Figure 5: Timeline of Activity-Based Model Implementations in the United States[9]

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[8] *Nazneen Ferdous and Chandra Bhat (Center for Transportation Research, The University of Texas at Austin), Lakshmi Vana and David Schmitt (AECOM Consult), John L. Bowman (Bowman Research and Consulting), Mark Bradley (Mark Bradley Research and Consulting), Ram Pendyala (Arizona State University) - Sensitivity of Four-Step Versus Tour-Based Models to Transportation System, Feb 2011.*

[9] *SCAG PROJECT 09-012: Strategy for Activity-Based Travel Demand Model Development with Travel Survey*, Mark Bradley Research & Consulting in collaboration with John L. Bowman, June 2009.

As the above graphic indicates, only a few agencies have possessed activity-based models for a few years and use activity-based models as a regional planning tool. San Francisco County uses the oldest tour-based model in the country. The Columbus model has been successfully used to conduct air quality analyses and to develop long-range plans over the past few years. Three matured models currently in use are San Francisco, New York, and Columbus. The Sacramento model is in the early stages of application. The Dallas model has been implemented for validation purposes in a laboratory setting. The remaining models are in various stages of development.

The *Historical Development of Activity Based Model Theory and Practice Report* (April 2008) presents the development history of the activity-based models. As described in this report:

- The Portland Metro model (Bowman, et al, 1998) was the first to be implemented and used for policy analysis. It was based directly on the Bowman and Ben-Akiva activity schedule approach developed at the Massachusetts Institute of Technology (MIT), using a full-day activity pattern, conditional tour models, and sensitivity at the day level via logsums from the tour models. It introduced work-based subtours, at-home activities, and detailed activity purposes, and integrated the AB model with the traffic and public transport assignment models. The San Francisco County model used the same basic design. It was the first of the models to be calibrated and then used on an ongoing basis for policy analysis. Along the way, innovative procedures were developed for doing that analysis. In a recent major project, the SFCTA model was enhanced to support road pricing, expand its geography, and add mode and temporal detail. It continues to be enhanced
- In New York, a different approach was used for integrating the tour models (Parsons Brinckerhoff, et al, 2005). Within each household, the simulated tour choices explicitly depended on the purpose of tours already simulated for this and other persons in the household. The NYMTC model has also been used for innovative analyses, some of which would not be possible with a traditional four-step model. The Columbus model (PB Consult, 2005) started with the NYMTC framework and enhanced it substantially, with a strong emphasis on implementing explicit household interactions and detailed time-of-day modeling.
- The Sacramento model (Bradley, et al, 2006) also used the Bowman and Ben-Akiva activity schedule approach. It reformulated the day activity pattern, introduced parcel-level spatial resolution, demonstrated the possibility of rapid development and deployment, and used innovative techniques for rapid equilibration of AB model systems.
- The Lake Tahoe project was the first implementation for a small local authority, and the first to transfer and recalibrate a model built for another region (MORPC). The Oregon model was the first AB model to be implemented for an entire state, and it was also integrated into a land-use model system. Ohio imported the Oregon statewide model and enhanced it to include long-distance inter-regional trips.
- The Atlanta model, which will be based on the MORPC design, has not been fully implemented yet, but they have implemented a flexible population synthesizer, and the design includes other innovations. DRCOG, MTC, and PSRC are the most recent locations where new development projects are under way. PSRC is the first staged implementation in

which the first stage involves integrating a day activity pattern model with the existing trip-based model system.

Most activity-based models developed have been developed either by researchers or consultants and are proprietary in nature. Also, some of these activity-based models are too complex and cannot be easily updated by non-familiar users. So it is likely that developers of the activity based models (researchers) need to be engaged in the near future to enhance these models to support AERIS program. It is likely to be a while before mature activity-based models become available as open source tools.

2.2.2 Data Considerations

The data requirements for an activity-based model are the same as that of a four-step travel demand model, except that it needs a detailed household travel survey that captures the information about trip chains/tours. The basic data needed for developing activity-based models includes:

1. Highway network
2. Transit network
3. Detailed land use data such as Public Use Micro-data Sample (PUMS)
4. Household travel survey data (that captures information of trip chains/tours).

Activity-based models require detailed and accurate input data to estimate the characteristics of each individual and household. Detailed input data is necessary to correctly evaluate accessibility across different modes of transportation. Most of the current activity-based models use the same census PUMS data inputs as conventional models. In addition to the PUMS data, activity-based models also require detailed household and transit surveys. Conducting these surveys and processing these surveys are expensive. Also, activity-based models use parcel-based socioeconomic data instead of TAZ-level data used in four-step models. Most planning agencies currently maintain parcel-level data and should be easily available for modeling purposes.

Just like calibrating traditional four-step travel demand models, daily or period (AM, PM, off-peak, etc.) based counts are used to validate tour-based models. Hourly counts are also desirable. The counts are typically collected using loop detectors on major facilities in the transportation network.

2.2.3 Interface with Emissions Models

Typically, the tour patterns generated by tour-based models are split into individual trips, and traditional traffic assignment procedures are used for assigning the trips to the network. The average daily or period-based volumes and speeds on the network links (by periods) produced by the traffic assignment procedures are post processed and fed into emissions models such as Mobile6 and more recently MOVES to determine the emissions quantities generated by transportation. Both Mobile6 and MOVES emissions models produce an emissions rate look-up table, and the emissions rates are applied to the transportation data (average speeds and associated volumes for each facility type by time period) using custom-made, post-processor tools.

2.2.4 State-of-the-Practice of Tour/Activity-Based Models

As described earlier, three active and matured activity-based models exist, namely:

- San Francisco
- Columbus
- New York City.

These three active US activity-based models have been used to support the full spectrum of MPO planning activities including air quality conformity, analysis, transit, and highway studies, including FTA New Starts analysis and others. The *Review of Current Use of Activity-Based Modeling Report*[10] summarizes the usage of these three models. While, these models have been applied to a wide variety of projects, the total number of applications is relatively low (10 to 20 projects) and not large enough to demonstrate the clear superiority of activity-based models over the traditional four-step models. The following is a brief description of the usage of the activity-based models.

San Francisco SFCTA Model

The SFCTA model has been used to provide forecasts for two major transit projects—the New Central Subway light rail transit (LRT) project and the Geary Corridor Study, which is considering multiple transit options. The SFCTA model has also been used for equity analysis and environmental justice analysis of transportation projects, as well as mobility and accessibility measures and transit service measures, such as vehicle utilization (crowding). While the SFCTA model employs a disaggregate approach to tour generation, tour destination choice, and tour mode choice, it still employs an aggregate network assignment. This greatly lowers the accuracy of model assignments below the corridor level, and since many of the above measures are most useful at the street level or lower, SFCTA commonly re-assigns the model results using Synchro or VISUM to produce the fine-grained measures required for their studies.

Columbus Model

MORPC reports that they use their activity-based model for air quality/conformity analysis, transit alternative analysis, and highway major investment studies. The model was also used for a New Starts analysis.

New York Best Practices Activity-Based Model (NYBPM)

NYMTC reports that the New York Best Practices Activity Based Model (NYBPM) has been used since 2002 to support air quality conformity analysis and a series of single-mode and multimodal transportation studies, including:

- Southern Brooklyn Transportation Improvement Study
- Gowanus Expressway (I-278) Study
- Tappan Zee Bridge/I-287 Corridor Study
- Bruckner Expressway (I-278)/Sheridan Expressway (I-895) Study

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[10] *VHB, Results of FY2006 Travel Forecasting Research, Task 5: Review of Current Use of Activity-Based Modeling, Prepared for Metropolitan Washington Council of Governments (MWCOG), National Capital Region Transportation Planning Board, Washington, DC, 2006.*

- Bronx Arterial Needs Major Investment Study (MIS)
- Kosciuszko Bridge Study
- Goethals Bridge Modernization Environmental Impact Study (EIS).

For several of these studies, the full NYBPM model chain was not always applied. This may be due to the relative instability of the model at the time the studies were conducted.

While there only a few active activity-based models in the United States, researchers generally believe that activity-based models have the potential to overcome the limitations of the four-step travel demand modeling process. Four-step travel demand models attempt to capture the travel behavior and associated traveler choices using four linked model components and do not consider the inter-relationship between these steps (trip generation, trip distribution, mode choice, and route choice). The process is not realistic and the temporal distribution of demand is very coarse. For example, if parking pricing is implemented as a demand and access management strategy, some travelers may choose alternative destinations for discretionary trips (such as shopping, restaurants, etc.), and this is likely to change the trip attraction rates. The four-step procedure does not capture the impact of this strategy as trip attraction is determined in the trip generation phase, which is not sensitive to parking cost. Also, induced trips and suppressed demand are difficult to capture using a four-step procedure as the four-step procedure does not represent the decision mechanisms underlying travel behavior. Activity-based models on the other hand overcome a number of limitations of the traditional four-step modeling process and models the trips an individual makes as a sequence of related activities. Also, as the model keeps track of the socioeconomic characteristics of an individual in every step of the decision-making process, the results are more sensitive to an individual’s response to change in travel cost.

Strengths

Activity-based models are theoretically better suited for modeling the traveler behavior choices associated with implementing TDM and other ITS strategies. The advantages of the activity-based modeling approach include:

- As the activity-based models predict travel behavior at a finer time resolution, it is better suited for modeling behavior that involves changes to trip departure time in response to ITS strategies.
- Activity-based models consider trip chains or tours and hence possess the capability to model non-home-based trips more accurately as compared to traditional four-step models.
- As the activity-based models keep track of the socioeconomic characteristics of the individuals, they are better suited to analyze the travel behavior changes in response to policy changes such as fuel process, mileage-based gas tax, parking fee, improved transit, etc.
- Activity-based models are capable of realistically assessing the impact of TDMs and other ITS strategies on the entire daily travel demand, as they can predict the change in tour patterns in response to changes to the network conditions.

- As the activity-based approach simulates the daily activities for the entire duration of the day, these models are better suited to model the effect of a transportation policy on the entire daily activity, and not just commute trips. The secondary and tertiary choices as a result of change to the primary mode choice, time-of-day choice, etc. are more realistically captured.

Limitations

- Although theoretically sound and best suited to model travel behavior, activity-based models have not been used in the transportation industry to their full potential yet and not rigorously tested to determine the sensitivity or validity. In particular, these models have not been used extensively to model impacts related to ITS strategies.
- As the development of activity-based models requires a significant amount of time and money commitment from the transportation agency, most planning agencies are reluctant to move away from traditional four-step models to activity-based models.
- It will be several years or decades before activity-based models become the most commonly used tool by planning agencies for modeling traveler behavior.

As noted above, the activity-based models theoretically are a very sound method to model person tours. Recently, there has been some research to introduce activity-based modeling concept to model freight movements. For example, “Enhancing Behavioral Realism of Urban Freight Demand Forecasting Models” project executed by University of Wisconsin, Madison will develop a behavior-oriented freight demand model with improved sensitivity to policy variables and system conditions. The model will be implemented and applied to metropolitan areas in East Central Wisconsin. The model will also be evaluated against the conventional trip-based models used in the same study area. The objectives of this research project are to (1) develop analytical methods of enhancing the behavioral realism and policy sensitivity of freight demand forecasting models to better support freight infrastructure investment and policy making; (2) develop a conceptual and analysis framework in which components of an existing three/four-step trip-based model can be logically mapped into and replaced by their counterparts in a behavior-oriented model that considers the complex logistic relationships driving freight movement; and (3) verify and evaluate the proposed behavior-oriented freight demand model against the conventional models.[11]

Although some initial research has been conducted on using activity-based modeling approaches for freight and for travel other than household passenger tours, existing activity-based models typically limit themselves to household travel. As a result, activity-based models are not any better suited to evaluate ITS strategies that attempt to improve freight movements as compared to the four-step models.

While activity models can predict the traveler behavior in response to strategies and policy changes, the assignment step of existing activity-based models is performed by converting person tours to vehicle trips, aggregating those trips into trip tables, and assigning them to the highway and transit networks using traffic assignment procedures available in four-step travel

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[11] *Enhancing Behavioral Realism of Urban Freight Demand Forecasting Models, Project details available at* *http://rip.trb.org/browse/dproject.asp?n=23636 – last accessed on June 17, 2011.*

demand models. In the current approach, the temporal granularity achieved in demand modeling process is lost in the assignment stage. In the last few years, an approach known as dynamic traffic assignment (DTA), which intends to account for congestion effects that evolve over time, is gaining popularity. DTA uses a much more detailed representation of network characteristics, including turn-lane capacities, intersection controls, and time-dependent demand to produce an estimate of travel demand across both space and time.

2.3 Review of Traffic Simulation Tools

2.3.1 Overview

Section 2.2 details the suitability of activity-based models to predict the travel behavior changes in response to implementing ITS strategies. While activity-based models address travel demand in great detail, the network or the supply side of the model requires enhancements so that accurate network performance that reflects time-of-day congestion is available. The current state-of-the-practice is to split the highway tours derived from activity-based models into trips aggregated into three or four time periods (AM, midday, PM, night) and a static traffic (TP+, EMME2, TransCAD, etc.) assignment is performed for each period. The trip departure time and arrival time within the period are not considered. Also, trips are assumed to be homogeneous within a time period; however, in reality, a majority of the trips occur (peak) within a certain part of the period while some of the trips overlap multiple periods.

To support most AERIS and other ITS applications, in addition to modeling demand (in the context of household activities) and travelers' response to implementation of strategies, the model should capture time-of-day congestion impacts by assigning time-dependent demand tables on a time-dependent network and should consider the operational characteristics (traffic signals, turn lanes, parking lanes, etc.) of the transportation network so that system performance can be evaluated accurately to quantify the air quality impacts. Traditional approaches (traffic assignment procedures in four-step models) to assigning the traffic onto the transportation network produce aggregate measures of volumes and speeds and cannot be used to quantify emissions impacts of implementing ITS strategies. A few MPOs and planning agencies are designing and implementing activity-based models, but fewer agencies have addressed the difficult issue of implementing time-dependent networks to capture time-of-day congestion effects for the entire region. The current state-of-the-practice is to use macroscopic models for regional planning and supplement with simulation studies for intersection-level analyses or for small sub-areas, as traffic simulation tools are not capable of modeling entire regions. Capturing the regional impacts of ITS implementations is difficult in this approach.

As described earlier in **Section 1.3**, only the mesoscopic and microscopic simulation models are well suited to quantify the air quality impacts associated with implementation of ITS strategies. Mesoscopic simulation tools such as DynaMIT and DynusT track vehicles individually in the network to maintain a higher level of detail as compared to macroscopic simulation tools, and they consider traffic signal delays. Microscopic simulation tools consider movements of individual vehicles dynamically on a second-by-second basis using cellular automata or car-following models. Microscopic models use a number of driver behavior parameters (lane changing behavior, car following distance, random slow down, gap acceptance) that can be adjusted to model driving differences resulting from strategies such as eco-driving and compliance to variable speed messages.. Microscopic and mesoscopic models provide detailed outputs that describe network performance during small time increments (15 minutes or less). Examples of output data generated by these models include link-level travel time, miles traveled, stop times, queue lengths and delays.

Mesoscopic and microscopic models are also referred to as Dynamic Traffic Assignment (DTA) models. After several decades of research, DTA models have gained popularity in recent years as tools capable of supporting ITS project evaluations, as these tools enable representing traffic in a realistic way by considering the dynamic nature of the network condition including operational factors (such as queue lengths, signal timing, and phasing plans). Mesoscopic DTA models supplement macroscopic s and microscopic traffic simulation models. Macroscopic models are best suited for regional travel analysis, and microscopic traffic simulation models are best suited for small corridor-level or intersection-level analysis. Mesoscopic tools such as DynusT, on the other hand, are capable of modeling traffic for regions that typically are too big for a microscopic analysis. Mesoscopic and microscopic DTA models can be used to predict time-dependent route choice in response to implementation of traffic operational improvements by loading individual vehicles onto the network and considering the traffic operations and prevailing network performance. **Figure 6** shows a typical DTA modeling framework.

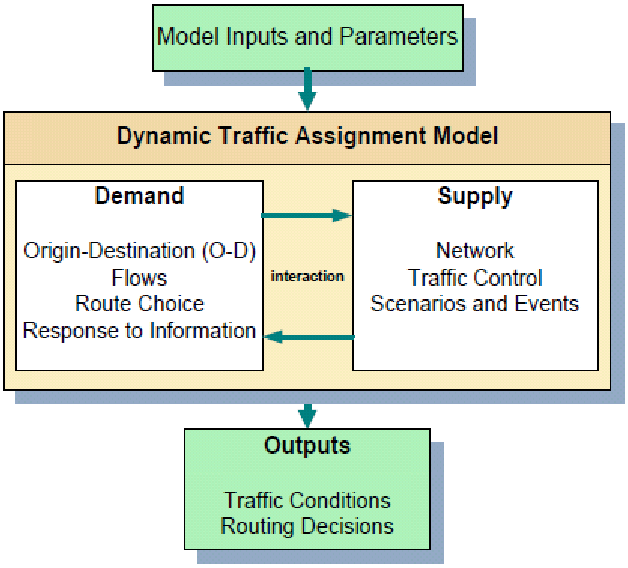

Figure 6: A Typical Dynamic Traffic Assignment Framework[12]

DTA models use a number of input data sets and parameters. These inputs and parameters are used by the various demand and network model components, which interact to predict the spatial and temporal evolution of network-wide traffic conditions. The outputs of large and complex DTA models depend heavily on the input values selected. It is therefore crucial, even mandatory, to ensure that DTA models are adequately calibrated so that their outputs compare favorably with real-world traffic observations made in the study region. If the model can

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[12] *A Primer for Dynamic Traffic Assignment, ADB30 Transportation Network Modeling Committee,* Transportation Research Board (TRB), 2010.

replicate the current (or baseline) conditions well, it instills some confidence in the results generated for future scenarios that obviously lack real-world validation measurements. Before looking at typical model outputs, such as link-based measures of flow, speed and density, there are several global measures that can be used to characterize the model results and put them in context. These are primarily convergence measures and certain network-wide measures that are particularly important when reviewing the initial DTA runs of a model. The most valuable convergence measures are those that quantify how close the current solution is to equilibrium, such as the Relative Gap. This measure reflects the difference between the minimum (best) route cost and the average route costs, relative to (divided by) minimum cost, as a weighted average across all O-D pairs. This measure must be calculated for (and reported by) each departure time interval. [13]

From a travel forecasting perspective, the time and cost of travel are critical factors in quantifying impacts on a regional scale for the purpose of informing policy decisions. Dynamic network analysis models seek to provide another, more detailed means to represent the interaction between travel choices, traffic flows, and time and cost measures in a temporally coherent manner (e.g., further improve upon the existing time-of-day static assignment approach). More specifically, Dynamic Traffic Assignment (DTA) models aim to describe such time-varying network and demand interaction using a behaviorally sound approach.

In the context of real-time operational control, DTA models are relevant for transportation engineers working on large-scale real-time traffic management and/or information provision problems. Real-time DTA models are appropriate to address these types of problems in a systematic manner because they provide capabilities to estimate future network conditions (flow patterns) that will result from a particular traffic management and/or information provision strategy. They are capable of updating the network states and developing new traffic management or information provision strategies based on real-time field data. Although there are advanced real-time DTA models, some important issues still need to be addressed to fully achieve effective deployment. For example, deployable models need to be computationally efficient so as to provide timely solutions. Given the time-dependent nature of demand and network characteristics, DTA models are used primarily to estimate dynamic traffic flow pattern over the vehicular network. That is, DTA models load individual vehicles onto the network and solve for their routes so as to achieve system-wide or traveler class objectives. These objectives are based on the project characteristics. For example, planning studies typically require the estimation of the user equilibrium flow pattern which results when travelers cannot improve their travel times by unilaterally changing routes. Other studies may require the pre-specification of the vehicular routes based on normal conditions or the real-time re-routing of vehicles. This characteristic is particularly important for studies involving Intelligent Transportation Systems (ITS) technologies, the evaluation of the effects of special and short-term events, or the provision of information. Hence, advanced DTA models should provide capabilities to handle different classes of travelers depending on the project characteristics.

DTA models provide a vast array of detailed outputs that describe time-dependent network states. They typically provide time-dependent system-level and link-level statistics. Examples of

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[13] *A Primer for Dynamic Traffic Assignment, ADB30 Transportation Network Modeling Committee,* Transportation Research Board (TRB), 2010.

output files include system-level travel time, miles traveled, and stop times. There are also output files that include time-dependent link-level travel times, speeds, densities, queues, and stop times. In addition, DTA models provide a Graphical User Interface (GUI) to display these network characteristics and statistics graphically. Some GUIs provide capabilities to edit and/or build the project inputs and to handle more than one project/scenario simultaneously. Most DTA models output the trajectories followed by all the vehicles. This information can be used to develop any non-standard statistic that the analyst may need.

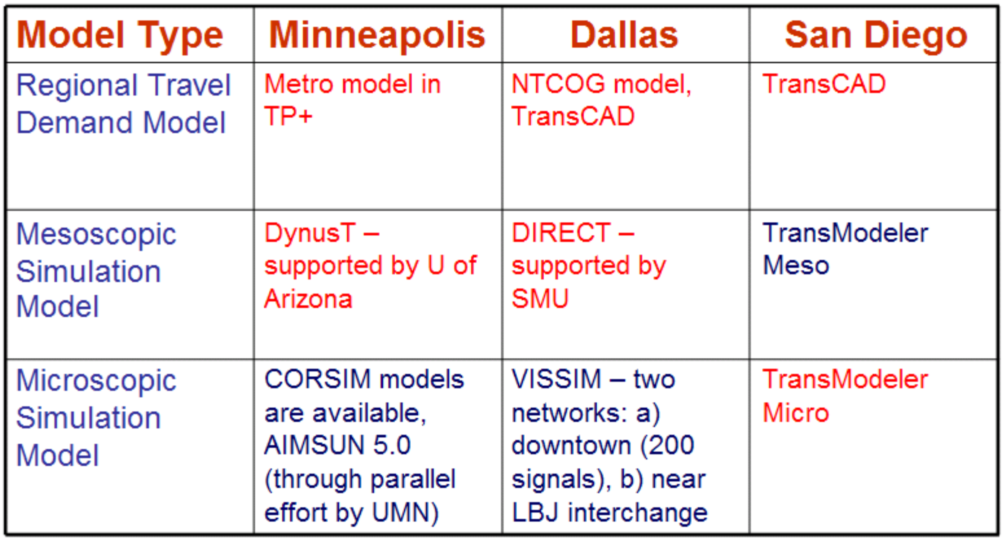
Time-varying demand data may be derived from several sources. The most convenient way is to utilize the existing trip tables associated with travel forecasting models. Most planning agencies have O-D tables for different periods in a day (e.g., a.m. peak, p.m. peak, and off-peak, etc.) with each table spanning several hours. If hourly factors are available for the time of interest, they can be used to derive a temporal profile in order to disaggregate the existing tables into finer time resolutions (e.g., hourly or 15-minute tables). However, one should be warned that simply applying the hourly factors to a 24-hour table to derive the hourly table is a flawed exercise, as the directionality of O-D trips are typically lost when trips are aggregated into the 24-hour table. Factoring a 24-hour table does not retrieve the critical O-D directionality information. The travel pattern would deviate a great deal from reality on the ground. Some planning agencies maintain trip tables representing AM peak, PM peak, or off peak periods. The directionality is more likely to be preserved in these time-of-day tables than the 24-hour table. If DTA is applied only for peak-hour analysis, then a corresponding time-of-day table can be a reasonable starting point. The temporal profile within the period of interest may still need to be specified by the model user, but the trip spatial directionality is generally maintained. For a 24-hour simulation and assignment, one may consider “stitching” these time-of-day tables to form 24-hour demand tables.

From a regional modeling perspective, mesoscopic models are more suitable to address congestion and performance issues within large networks. Also, mesoscopic DTA models are user friendly when it comes to data inputs and network adjustments. Therefore, using such methods would not result in an enormous effort to make an existing regional model ready for a dynamic traffic assignment. On the other hand, microsimulation models such as VISSIM, Paramics, and TransModeler provide users with more details in operational issues such as on/off ramps, lane merge, weaving sections, etc.

The traffic assignment modules within the four-step travel demand modeling packages use volume-to-capacity ratios to determine the speeds. However, if the operations strategy (e.g., signal timing, incident management, and variable speed limits) does not immediately impact volumes, the speed estimates generated using volume-to-capacity ratios will not be sensitive to the implemented operational improvements and hence environmental benefits cannot be determined accurately. To overcome this limitation, several planning agencies are supplementing their regional travel demand model with traffic simulation tools (e.g., VISSIM, Paramics, and CORSIM) to capture the speed variation and quantify immediate travel-time benefits from traffic operations strategies. Because it is expensive and time consuming to code and simulate large metropolitan areas, it is common to develop a special corridor or subarea model for major projects using some components or information from general-purpose MPO or DOT four-step planning models.

Although developing subarea simulation models works to effectively quantify the transportation benefits of implementing ITS and other operational strategies, this approach does not help quantify the regional impacts of ITS strategies (e.g., changes in trip destination choice, mode choice, time-of-day choice, peak spreading, induced demand) unless the outputs from subarea microsimulation models are fed back into the regional (macroscopic) travel demand models. Integrating macroscopic models with mesoscopic or microscopic subarea models is critical to support new and upcoming DOT research initiatives such as AERIS, DMA, ICM, and ATDM programs. However, in the current state-of-the-practice, very few agencies have attempted to develop or integrate their micro-scale models with the macroscopic or regional travel demand model. However, in the last few years, regional travel demand models have been successfully integrated with mesoscopic and macroscopic travel simulation models to capture the regional impacts of implementing ICM strategies such as implementing HOV lanes, tolling, value pricing, BRT and light rail. **Table 2** shows the model linkages that have been tried at three ICM Pioneer Test sites.

Table 2: Model Integration to Perform Analysis for ICM Pioneer Sites[14]



Model Type	Minneapolis	Dallas	San Diego
Regional Travel Demand Model	Metro model in TP+	NTCOG model, TransCAD	TransCAD
Mesoscopic Simulation Model	DynusT – supported by U of Arizona	DIRECT – supported by SMU	TransModeler Meso
Microscopic Simulation Model	CORSIM models are available, AIMSUN 5.0 (through parallel effort by UMN)	VISSIM – two networks: a) downtown (200 signals), b) near LBJ interchange	TransModeler Micro

2.3.2 Data Considerations

The minimum data requirements for a microscopic simulation model are much greater than the data requirements for the macroscopic and mesoscopic models. In particular, microscopic simulation models require the following network details:

- Number of lanes on each link, including turn or pocket lanes
- Real-world speed limits on the network links
- Intersection details such as signalized, un-signalized, no control, etc. For signalized intersections, details of the type of signal (actuated, timed, semi-actuated etc) and the detailed signal timing and phasing plans are needed

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[14] *Steve Mortensen, Integrated Corridor Management (ICM) presentation made at ITS America Annual Meeting 2010,* Session SS24, May 2010 (http://www.its.dot.gov/icms/ppt/ICM_Overview_ITSA2010_Mortensen_files/frame.htm accessed May 12, 2011).

- Time-of-day restrictions such as parking, reversible lanes, lane closures, HOV restrictions, truck restrictions, turn prohibitions, etc.
- If transit is included, detailed bus/rail schedules, assumptions on minimum/maximum dwell time, etc. need to be made
- Input demand with a specific start time (in seconds) for each vehicle that will be entering the system.

In general, the traffic simulation models use a number of model parameters, and these parameters need to be carefully calibrated so that the model predicts the observed conditions closely.

The traffic simulation models also produce detailed outputs as compared to macroscopic models and the outputs need to be post processed to summarize the information. For example, VISSIM can generate the location of every vehicle on the system (with the associated characteristics such as speed of travel, acceleration rates, deceleration rates, etc.) for every second of the day. As more data is available from traffic simulation models, the model results are also validated against detailed data such as:

- Average link speeds in 15 minutes or lesser time increments
- Vehicle speeds at detector locations
- Average link/segment density
- Queue lengths
- Link or sub-route travel times
- Intersection turning movement counts.

2.3.3 Interface with Emissions Models

Microscopic simulation models produce detailed vehicle movement data that can be directly fed to simulation-based emissions models such as CMEM or MOVES. To quantify the air quality impacts, the detailed speeds and volume data are sometimes post-processed and interfaced with emissions models. Some microsimulation tools such as VISSIM also have built-in emissions models that can quantify the emissions generated by the vehicles directly.

2.3.4 State-of-the-Practice of Simulation Models

Large-scale simulation or regional simulation models currently exist for regions such as Baltimore, Chicago, and Knoxville regions to name a few. In addition, work is in progress for the Atlanta, Austin, and San Francisco regions. Agencies across the United States currently use microsimulation tools for traffic engineering and operational improvement studies. In particular, several agencies have successfully used one or more mesoscopic or microscopic simulation tools to evaluate ITS and demand management strategies. The *Best Practices in the Use of Micro Simulation Models* released by the American Association of State Highway and Transportation Officials (AASHTO) Standing Committee on Planning (March 2010) presents case studies across the country where simulation tools have been used based on the unique needs of the project, the objective of the study, or the nature of the proposed measures. Some of the case studies citied in this report include:

- **Caltrans I-5 TDM/TSM Traffic Study:** Caltrans used the VISSIM micro simulation software to evaluate various demand management efforts, capacity improvements, and enhancements to operations on the I-5 corridor in the current year and for a long-range planning horizon. Specifically, it employed a signal optimization tool (Synchro) and a microscopic simulation model (VISSIM) to conduct sensitivity analysis on roadway projects designed to improve travel conditions
- **City of Moreno Valley, CA, TRANSIMS Implementation Study:** The City used the TRANSIMS microscopic simulation model to analyze the impact on the network, especially with respect to commuting patterns and truck traffic, from converting the zoning of more than 4,700 acres from residential and light industrial classifications to warehousing and distribution centers. The study illustrated how truck routes would align themselves to the existing and proposed locations of industrial zones and whether new route alignments would detrimentally impact traffic in existing and future non-industrial areas along their path
- **New York City Department of Transportation (NYCDOT) Broadway Boulevard Project in Midtown Manhattan Study:** The Department used the AIMSUN simulation software to study the effect of removing a major arterial on mobility and the safety of motorists, bicyclists, and pedestrians. In addition, it aimed to determine the impact on air quality of a large-scale diversion of traffic. The simulation focused on 4 to 5 hours during the PM peak period
- **Caltrans I-5 North Coast Traffic Study:** Caltrans combined a signal optimization tool (Synchro) and a meso/microscopic simulation model (TransModeler) to study multiple aspects of peak period traffic. Simulation was chosen because traditional travel demand models did not offer a sufficient level of sensitivity to the variety of scenarios. The objective was to understand how each project alternative would impact traffic operations and travel behavior, provide standardized performance measures to judge each alternative objectively, and define the mobility benefits from each proposed construction phase
- **SACOG Integration of Activity-Based Model with TRANSIMS:** The Sacramento MPO studied the benefits and challenges of integrating its activity-based demand model (DaySim) with the TRANSIMS time-dependent router. The objective was to more accurately model capacity improvements at the regional level and provide better travel time information to the activity-based demand model. The TRANSIMS router generated zone-to-zone travel times for every 15 minutes of the day. This data was then used to generate travel tours between activity parcels. A user equilibrium process was used within the TRANSIMS environment to assign the trips to the network
- **Caltrans I-80 ICM Study:** Caltrans modeled the impacts of ramp metering, active traffic management, and variable speed limits on traffic flow and determined the level of development that would help create optimum traffic flow on one of California’s most heavily used corridors. The study combined the application of a signal optimization tool (Synchro) and a microscopic simulation model (Paramics [Quadstone]) to evaluate demand management scenarios and operational improvements. Modeling traveler behavior and achieving reasonable calibration and validation were reported as the primary difficulties encountered.

- **Minnesota Department of Transportation (MnDOT) I-94 Managed Lane Operations Study:** MnDOT is conducting a high-priority project to study the feasibility of introducing a priced managed lane on the I-94 freeway. This is part of a region-wide effort to evaluate design features and mobility options in Minneapolis after the collapse of the I-35W Bridge in August 2007. The Department applied a mesoscopic simulation model (CORSIM) to determine whether a managed lane would degrade conditions on the general-purpose lanes. Specifically, the software was used to model the likely impact on network conditions resulting from the implementation of initiatives to increase vehicle capacity; improve mobility for transit, pedestrians, and bicyclists; and improve operations
- **MAG I-10 ICM Study:** The MPO used mesoscopic simulation software (DYNASMART-P/DynusT) to perform an elaborate study of a proposed major widening of I-10 in Phoenix, AZ. The model was used to test six interrelated and successive policy questions. The first was to determine the impact on traffic (e.g., route choice, travel time) that would result from a freeway-widening project and then to test the effectiveness of various operational strategies to reduce the congestion caused by construction. In general, planners were to evaluate the realism of the software's DTA procedure in terms of route choice, travel time, departure time, and the practicality of DTA for modeling transit. Finally, tests were made to determine how the resulting changes to route choice and mode choice could be fed back into the long-range planning model to estimate the demand impacts
- **CDOT Downtown Denver Multimodal Access Plan (DMAP) Study:** The study modeled the impact of capacity and operational improvements aimed at reducing congestion from excessive vehicle merging between I-25 and SR 56 in Denver, CO. In addition, the improvements had to minimize the potential for future regional traffic to cut through local streets to connect between the two major roadway channels. Mesoscopic and microscopic simulation (VISUM/VISSIM) software was used to specifically quantify the impact that direct freeway connectors would have on peak-hour traffic operations, which was evaluated according to HCM consistent performance measures
- **Utah Department of Transportation (UDOT) National Environmental Policy Act (NEPA) Study:** The Department turned to a microscopic simulation model (VISSIM) to quantify the amount of environmental pollutants in the region induced by traffic and to model the likely results of mitigation efforts as part of a NEPA analysis. The study evaluated scenarios involving demand management policies, capacity improvements, measures to improve alternative travel modes (transit, bicycle, and pedestrian), and the application of operational improvements. The agency reported that traditional modeling tools lacked sufficient robustness or sensitivity for use in answering these questions
- **Kansas Department of Transportation (KDOT) Johnson County Gateway (I-435/I-35/K-10 Interchanges) Study:** KDOT is redesigning a highly congested interchange that connects two interstates and a limited access state route in Kansas City, KS. The design is extremely complicated from an operations standpoint. The purpose of the study is to model the present and future operations given various design proposals in order to select the option that will eliminate the bottleneck in the long run. The Department had difficulty modeling a large urban network, accurately representing traveler behavior, and achieving a realistic calibration and validation. It was, however, satisfied with the application results given the policy choices presented under the various scenarios

- **San Diego Association of Governments (SANDAG) I-15 ICM Study:** I-15 is the primary artery that commuters and commercial vehicles use to travel from northern San Diego County to downtown San Diego. The MPO leveraged simulation modeling capabilities to estimate detailed traffic flow for making decisions in its traffic management center. The objective was to find approaches that would maximize person-throughput in the face of recurrent and non-recurrent congestion. The agency intended to use the application to prepare messages for the variable message signs on the corridor that advise drivers of an accident's occurrence and to provide temporal and modal options (route-paths) for avoiding the resulting congestion. The agency used a simulation model capable of providing analysis at the macro, meso, and microscopic levels (TransModeler). The modeling scenarios contained proposed demand management initiatives, improvement measures for transit and pedestrian movement, and modifications to advance vehicle-centered operations
- **SFCTA Doyle Drive Project:** The SFCTA faces the challenge of redesigning a 60-year-old thoroughfare that provides direct access to the Golden Gate Bridge. The current design is inadequate to handle the exponential growth in volume on the facility. The purpose of the study was to provide a short-range forecast of route diversion options during the reconstruction phase and prepare the authority for the potential bottlenecks and queues that could result. To that end, it applied a mesoscopic level DTA tool with simulation capability (DynamEQ) to evaluate possible solutions to these issues.

As the above case examples demonstrate, mesoscopic and microscopic simulation tools are currently being used for a variety of transportation studies that focus on evaluating the demand and access management strategies and traffic operational improvement studies and are ideally suited to support ITS programs. Table 3 summarizes the findings from The *Best Practices in the Use of Micro Simulation Models* study released by AASHTO Standing Committee on Planning (March 2010) and a few other ongoing projects that use mesoscopic and microsimulation tools.

Table 3: State-of-the-Practice of Mesoscopic- and Microsimulation-Based Models

Modeling Tool	Agencies Using the Models	Example Transportation Application	Measures of Effectiveness Generated	Study Objectives
AIMSUN	New York City Department of Transportation (NYCDOT)	Capacity improvements, operational improvements	Network-wide: average speed, VMT, VHT, stopped/delay time Link: (time-dependent) volumes, travel times	Determine the effects of removal of one major artery on mobility and safety of vehicular, pedestrian, and bicycle traffic; Determine air quality impacts due to diversion of traffic
DYNASMART, DynusT	Maricopa Association of Governments (MAG)	Variety of applications such as traffic flow studies,	Link: (time-dependent) speeds, volumes,	Study the impact on traffic (e.g., route choice, travel time) due to major freeway widening

Modeling Tool	Agencies Using the Models	Example Transportation Application	Measures of Effectiveness Generated	Study Objectives
		traffic optimization studies or traveler information studies	densities, travel times Path: vehicle trajectories, travel times	project; Test the effectiveness of different operational strategies to reduce the congestion caused by the construction. Determine ways to providing feedback to the long-term planning model for significant route choice and mode choice changes? How much improvement can be achieved with different or combinations of strategies?
Paramics, (with SimTraffic, and SYNCHRO)	Caltrans	Demand management, operational improvements	Network-wide: average speed Link: (time-dependent) speeds, volumes, travel times Path: travel times	Evaluate the impacts of ramp metering, active traffic management, variable speed limits Determine the optimum operational strategy for ramp metering, active traffic management, variable speed limits
TransModeler (with FREQ, SYNCHRO)	Caltrans, District 11	Demand management, capacity improvements, operational improvements	Network-wide: average speed, VMT Link: (time-dependent) speeds, volumes, travel times Path: travel times	Understand traffic operations and behavior of project alternatives; Provide performance measures basis for the alternatives; Evaluate proposed construction phasing and define mobility benefits of each; Develop visual animations of project alternatives for various audiences; Utilize the simulation work as a corridor operations management tool

Modeling Tool	Agencies Using the Models	Example Transportation Application	Measures of Effectiveness Generated	Study Objectives
TRANSIMS	Buffalo	Environmental benefits of lowest fuel consumption Route Guidance in the Buffalo-Niagara Metropolitan Region	Network speeds, volumes, fuel consumption etc.	Conduct an assessment of the likely environmental benefits of a new application for an environmentally-optimized route guidance system for a medium sized metropolitan area
TRANSIMS	City of Moreno Valley	Capacity Improvements, land-use/policy impacts, operational improvements	Still in development as project is still in progress	What link and intersection improvements are required to accommodate the proposed zoning changes while maintaining a given level of service standard? Will the additional truck traffic associated with the proposed zoning changes result in the need to increase the Traffic Index (and resulting structural cross-sections) of the impacted arterials and streets? Will commute patterns be altered so significantly as to require major geometric changes to planned interchange improvements?

Modeling Tool	Agencies Using the Models	Example Transportation Application	Measures of Effectiveness Generated	Study Objectives
VISSIM	Caltrans	Demand management, capacity improvements, operational improvements	Average speed, VMT, VHT, Delay	Determine whether the improvements the legislature funded actually worked Perform an effective cost-benefit analysis of projects Determine what the maximum inputs of TSM/TDM were for the corridor

A number of these tools mentioned are ideally suited to quantify the transportation benefits and generate measures of effectiveness such as improvement in speeds, reduction in delays, improvement of smoothness of travel, and reduction in VMT. Most advanced microscopic simulation models such as Paramics, VISSIM, and TransModeler generate vehicle activity by simulating individual vehicles' trajectories, and this detailed vehicle movement data can be directly used in conjunction with microscopic emissions models such as MOVES or CMEM to quantify the air quality impacts of AERIS strategies.

Strengths

- Microsimulation models simulate traffic at a fine level of time resolution (second-by-second) and, hence, possess the ability to model peak-hour congestion.
- As microsimulation tools provide capability to track different classes of travelers and vehicles, they are ideally suited to support ITS project evaluations.
- Microsimulation tools can be used to effectively capture vehicle movements by mode and by lanes and quantity the impacts of operational changes such as signal priority for transit vehicles, adaptive signals, traffic calming, etc.
- As the fleet mix and associated emissions can be easily captured, microsimulation models provide the ability to model benefits associated with specific classes of vehicles or conditions.
- Detailed vehicle activity data (second-by-second profiles, idling, etc.) can be gathered and fed to advanced microscopic emissions models such as MOVES and CMEM to quantify emissions impacts.
- Microsimulation tools that come with DTA procedures (TRANSIMS) can be effectively used to change the paths of the travelers based on operational improvement changes, real-time traveler information, eco-driving, etc.
- Mesoscopic DTA tools can use the fine grained O-D trip matrices output by activity-based models to determine time-variant network performance.

Limitations

- Microsimulation models are expensive to build and validate. A significant amount of resources are needed both in terms of manpower and computer resources to develop and validate microsimulation models.
- Data needs are very high. Detailed information about number of lanes, turn lanes, parking restrictions, speed limits, road geometry, signal plans, etc. are needed, and not having detailed and/or accurate data will lead to erroneous results. As a result, most agencies resort to conducting a detailed microsimulation for a small sub-region or corridor and use macroscopic or mesoscopic models for regional analysis.
- A number of parameters and assumptions are built into traffic simulation packages, and calibrating the model requires a lot of effort.
- Integrating microscopic models with regional models is difficult and not commonly used in the transportation industry.
- Integrating detailed microsimulation models with regional models is not straight forward and, hence, is usually skipped.

3.0 RECENT ADVANCEMENTS IN THE STATE-OF-THE-PRACTICE

The last section described traditional four-step models, activity-based models, and traffic simulation models. The table below summarizes the models that are suited for predicting common behavior changes likely to be associated with implementation of ITS strategies.

Table 4: Capabilities of Models to predict behavior changes

Behavior Change Description	Potential Models or Tools for Predicting Behavior Changes
Behavior Changes that Impact VMT	
Change in routes (targeted at minimizing travel distance)	Traditional four-step models, activity based model, Mesoscopic or Microscopic Simulation Models
Change in mode of travel (take transit, carpool, non-motorized travel such as walking, biking etc.)	Traditional four-step models or activity based models
Change in number of trips	Activity Based Models
Change in trip chaining patterns	Activity Based Models
Behavior Changes that do not directly impact VMT	
Change in time of travel (for instance, peak spreading or changing the time of departure to avoid congestion and/or toll)	Traditional four-step models in combination with microsimulation tools or Activity based models
Compliance with variable speed limits that improves the smoothness of travel	Microsimulation models
Change in driving behavior (eco-driving)	Microsimulation models
Eco-routing (note that eco-routing sometime can also lead to reduced VMT)	Microsimulation models

While activity-based models are ideally suited to predict changes in traveler behavior in response to implementation of ITS strategies, and microsimulation models are capable of predicting the change in network performance as a result of change in traveler behavior, these models are seldom used in combination for transportation analyses. However, there have been at least three research efforts to develop super-models or modeling systems that can address ITS strategies and other modeling needs. This section provides brief descriptions of the TRANSIMS, SHRP 2, and FHWA Analytics, Modeling, and Simulation (AMS) modeling efforts.

Over the last 15 years, the FHWA has invested in the development of TRANSIMS[15], an integrated activity-based and simulation-based model. The activity-based modeling component of TRANSIMS is not well developed as compared to the network assignment component. A

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[15] TRANSIMS Open Source *portal can be found at* http://www.transims-opensource.net/.

series of case studies have been carried out to demonstrate the applicability of TRANSIMS to quantify the air quality impacts as listed below:

- In 2008, the Georgia Regional Transportation Authority (GRTA) in partnership with the ARC and the Georgia Environmental Protection Division (EPD) implemented TRANSIMS in the Atlanta area. The primary objective of this study included quantifying the potential congestion and emissions impacts of planned transportation projects and integration with the MOVES model[16]
- Work is currently ongoing to interface the outputs from MORPC's activity-based model with the TRANSIMS micro-simulator
- Using TRANSIMS, the University of Buffalo is evaluating the likely environmental benefits of lowest fuel consumption route guidance in the Buffalo-Niagara metropolitan region. This study will conduct an assessment of the likely environmental benefits of a new application for an environmentally optimized route guidance system for a medium-sized metropolitan area. Activities in this project include developing an integrated simulation modeling framework capable of calculating time-dependent fuel consumption factors; using TRANSIMS-MOVES modeling to estimate environmental benefits to be expected from implementing low fuel consumption routing; assessing the impact of market penetration on the likely benefits of the strategy; assessing additional benefits to be expected from taking into account real-time information about traffic disturbances; and assessing modal benefits. Note that this is one of the several FHWA Broad Agency Announcement projects being conducted in support of AERIS program.

The above TRANSIMS case studies demonstrate that they are suited to support the AERIS program; however, it must be noted that most TRANSIMS studies to date have been carried out using federal funds, and no agency currently uses TRANSIMS as a regional planning tool.

The SHRP 2 program is currently supporting two projects[17] (C10 A and C10 B) that attempt to improve modeling and network processes and procedures in order to address policy and investment questions described such as:

- Variable road pricing
- Ramp metering
- ITS strategies—customer information on road conditions, travel time, incidents, etc.
- Reversible lanes
- Policies affecting the time of travel demand such as parking pricing, transit pricing and scheduling flexible work schedules, reversible lanes, HOV lanes, and HOT lanes.
- Work and shop-at-home policies
- Variable speed limits (potentially)

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[16] *The TRANSIMS Wiki Page provides details of the recently concluded and ongoing TRANSIMS Case Studies (http://code.google.com/p/transims/wiki/CaseStudies).*

[17] *Partnership to Develop an Integrated Advanced Travel Demand Model with Mode Choice Capability and Fine-Grained, Time-Sensitive Networks Project Details can be found at (http://144.171.11.40/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=2828 accessed May 10, 2011).*

- Bottleneck improvements (reduction in lane width to add a lane, geometric improvements to ramps, etc.)
- Shift to non-highway mode.

The primary objective of this project is to make operational in two public agencies a dynamic integrated model—an integrated, advanced travel-demand model with a fine-grained, time-dependent network (integrated activities and networks)—and demonstrate the dynamic integrated model set in a real-world environment on selected policies. The SHRP 2 C10 program's objective is to develop an integrated advanced travel demand model and a fine-grained, time-sensitive network. The SHRP 2 C10A project partners are developing an integrated, advanced travel demand model with a fine-grained time-sensitive network simulation for the Jacksonville, Florida, region. This project attempts to integrate the outputs from a detailed activity-based model (DaySim) with a TRANSIMS simulation model to assess regional transportation network performance. The SHRP 2 C10B project partners are developing a framework that integrates the Sacramento Activity-Based Travel Demand with DynusT Simulation Model. Both the projects are currently ongoing, and the results are likely to be publicly available sometime during 2012. Theoretically, these models (that integrate activity based models with simulation models) developed as a part of SHRP 2 C10 program are more capable of quantifying the change in travel behavior in response to implementation of ITS strategies.

Over recent months, there have been a series of FHWA-funded projects related to AMS model systems and developing combinations of models that can address ITS strategies and other modeling needs. This concept started with the ICM project, where FHWA wanted to model the impacts of ICM strategies that called for integrated travel demand models with traffic simulation models. Recent modeling studies conducted to support Integrated Corridor Management (ICM) Pioneer Site evaluations attempt to link macroscopic, mesoscopic, and microscopic simulation models to capture the regional impacts of traffic operational improvements. The approach adopted for the test corridor analysis applies the AMS Methodology framework shown in **Figure 7**. The Test Corridor AMS approach encompasses tools with different traffic analysis resolutions. All three classes of simulation modeling approaches – macroscopic, mesoscopic, and microscopic – may be applied for evaluating ICM strategies. This modeling approach provides the greatest degree of flexibility and robustness in supporting subsequent tasks for AMS support of Pioneer Sites.

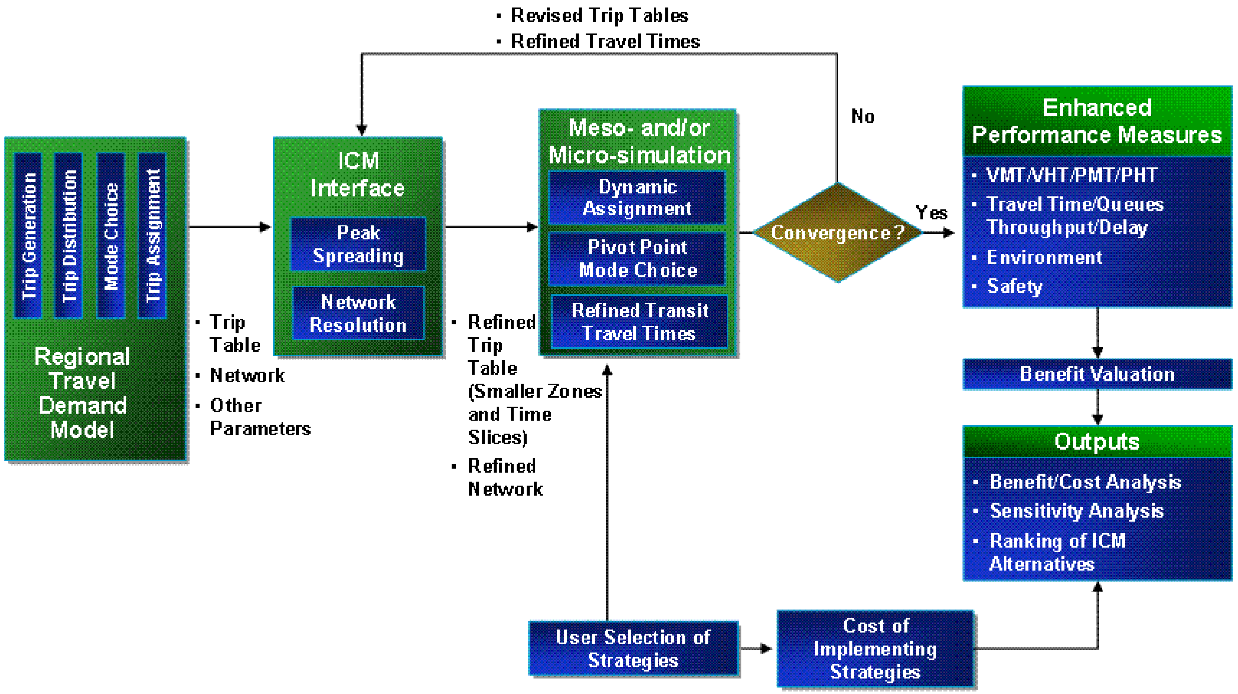

Figure 7: Test Corridor Analysis Modeling and Simulation (AMS) Framework

The AMS methodology for Test Corridor applies macroscopic trip table manipulation for the determination of overall trip patterns, mesoscopic analysis of the impact of driver behavior in reaction to ICM strategies (both within and between modes), and microscopic analysis of the impact of traffic control strategies at roadway junctions (such as arterial intersections or freeway interchanges). The methodology also includes a simple pivot-point mode shift model and a transit travel-time estimation module, the development of interfaces between different tools, and the development of a performance measurement and benefit/cost module. In this AMS framework, macroscopic, mesoscopic, and microscopic traffic analysis tools can interface with each other, passing trip tables and travel times back and forth looking for natural stability within the system. The methodology adopted seeks a natural state for practical convergence between different models, and the iterative process to achieve convergence.[18]

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[18] *Intelligent Transportation Systems, ICM Modeling Approach, http://ntl.bts.gov/lib/jpodocs/repts_te/14415_files/sect02.htm (last accessed June 17, 2011).*

4.0 SUMMARY

Section 2.0 presented the state-of-the-practice in behavioral, tour/activity-based traffic simulation models. Based on the state-of-the-practice assessment, the research team concludes that integrated activity-based and DTA travel demand models are best suited to evaluate environmental impacts of AERIS applications and other ITS strategies.

Activity-based models are best suited to predict the traveler behavior changes associated with the implementation of ITS strategies that include travel demand management; improvement of transit; and change in policies such as fuel price, mileage-based taxes, eco-driving, etc. However, the predicted traveler behavior changes have to be interfaced with DTA and microsimulation tools such as TRANSIMS, DYNASMART, AIMSUN, and Paramics so that the fine resolution of demand generated by the demand models is not lost during the traffic assignment stage and detailed speed and volume data can be generated and fed to advanced emissions models such as MOVES and CMEM to quantify the air quality impacts of ITS strategies.

Activity-based models use significantly advanced modeling structure as compared to traditional four-step travel demand models and explicitly consider the interactions between the travel activities and the associated traveler behavior. By emphasizing participation in activities and focusing on sequences or patterns of activity, the activity-based approach can address complex issues (Bhat and Koppelman 2003). While the model structure of the activity-based model is technically sound, development of activity-based models is very expensive both in terms of time and resources, and most agencies have been attempting to migrate to an activity-based model by replacing certain portions of the four-step model, and they have not been implemented as a comprehensive replacement. Only a few agencies have successfully implemented activity-based models as a regional planning tool (Columbus, San Francisco, New York, etc.) capable of quantifying traveler behavior changes in response to implementing TDM policies such as congestion pricing, fuel taxes, telecommuting options, parking restrictions, etc.

Even for agencies that have implemented activity-based models, the state-of-the-practice is to break the travel tours generated by activity-based models into trips and use the traffic assignment procedure within the traditional modeling tools such as TransCAD, EMME2, TP+ etc. to assign traffic onto the transportation network. However, static assignment procedures used in current MPO models are not very effective in quantifying the air quality impacts associated with implementation of traffic operational improvements and, hence, are not suitable to support the AERIS program. Static assignment procedures need to be replaced with simulation-based assignment approaches to advance the current state-of-the-practice. Mesoscopic simulation tools are best suited for regional assignment, and microscopic simulation tools are best suited for subarea or corridor simulation.

DynusT presents a simple and easy way to integrate macro and micro models and is the most commonly used mesoscopic DTA tool in practice. More than 20 regions use DynusT for a variety of applications. The regions that currently possess DynusT models/tools include El Paso, Pima Association of Governments (PAG), MAG, DRCOG, PSRC, SFCTA, Houston-Galveston Area Council (HGAC), Las Vegas, NC Triangle, Guam, Florida, Southeast Michigan

Council of Governments (SEMCOG), Toronto, SACOG, Mississippi, North Virginia, I-95, US36, New York, Bay Area.[19] DynusT has also been used to demonstrate, through a case study, an integrated, automated modeling framework of MOVES and simulation-based dynamic traffic assignment (SBDTA) model. DynusT and TRANSIMS are two modeling tools that have a good potential to support the AERIS program.

Table **5** shows the models' ability to support the AERIS program by predicting traveler behavior in response to implementation of ITS strategies.

Table 5: Models' Applicability to Support AERIS Program

Model Type	Example Agencies Using the Models	Example Transportation Applications	Linkage between Model Outputs and Emissions Models	Limitations	Applicability for evaluating ITS Strategies
Traditional four-step Models (ex TransCAD, TP+, EMME2, etc.)	Most major MPOs in the US	Long-Range Planning, Regional Travel Impacts of Highway Improvements, Corridor Level Impacts of Highway Improvements, Transit Ridership, Mode Choice Analysis, Air Quality Conformity Analysis, etc.	Traffic Assignment Results are post processed and fed as inputs to emissions models such as Mobile6	Travel demand is not modeled accurately as interrelationship between household members travel activities is not captured, does not capture the network impact accurately as the assignment procedures does not capture signal delays and vehicle interactions	Low
Activity Based Model	San Francisco, Columbus, Sacramento	Full range of MPO planning activities including air quality analysis	Traditional Traffic Assignment Results are post processed and fed as inputs to emissions models such as Mobile6	Travel demand is modeled accurately; however, as traditional traffic assignment procedures are used, these models do not capture the network impact accurately as the assignment procedures do not accurately capture	High – but the traffic assignment procedures should be replaced with DTA tools

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[19] Yi-Chang Chiu, Eric Pihl, Nick Renna, *A Simulation Based Dynamic Traffic Assignment Model for Corridor/Regional Operational Planning Analysis,* Lansing, Michigan, August 2010 (http://www.michigan.gov/documents/mdot/MDOT_DTA_DynusT_Overview_Chiu_8_11_10_334886_7.pdf - accessed May 10, 2011)

Model Type	Example Agencies Using the Models	Example Transportation Applications	Linkage between Model Outputs and Emissions Models	Limitations	Applicability for evaluating ITS Strategies
				signal delays	
Partnership to Develop an Integrated Advanced Travel Demand Model	Two research projects are being carried out as a part of SHRP2 C10 project	Upon completion, will have the capability to support full range of MPO planning activities	Outputs from Simulation model will be fed directly to emissions models such as MOVES	No limitation from a theoretical perspective	High

As explained in earlier sections, activity-based models are technically well suited to model traveler behavior in response to implementation of ITS strategies; however, only a few fully developed activity-based models exist in the country, and these models have not been rigorously tested to model complex TDM or other ITS strategies. Also, as the developing activity-based models are expensive in terms of both time and money, it is likely that most planning agencies will continue to use the existing four-step travel demand models. In addition, the agencies that currently do possess complex activity-based models still use traditional traffic assignment procedures to assign traffic and predict network performance. While there are some projects that attempt to develop integrated activity-based and simulation models such as the SHRP2 C10, it is likely that it will be at least a couple of years before these models are fully operational and thoroughly tested.

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