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Research and Innovative Technology Administration

Active Transportation and Demand Management (ATDM) Foundational Research

Analysis, Modeling, and Simulation (AMS) Capabilities Assessment

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16. Abstract As part of the Federal Highway Administration's (FHWA's) Active Transportation and Demand Management (ATDM) Foundational Research, this publication identifies the AMS needs to support simulated real-time and real-time analysis to evaluate the impact of ATDM strategies, current AMS capabilities that can support ATDM evaluation, and gaps between AMS needs and capabilities and the details the necessity to bridge the gaps to implement ATDM evaluation successfully. This report reviews current and emerging AMS capabilities for modeling ATDM and focuses on reviewing the capabilities that exist to model supply and control aspects as well as demand and travel behavior aspects, both in an offline and online environment. The AMS needs identified in the CONOPS Report are used to develop AMS gaps in this report.		
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Preface/Acknowledgments

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Table of Contents

List of Tables

List of Figures

Executive Summary

During the past several decades, traffic management and operations activities have been reactive in nature. In the recent past, however, the need for effective and more proactive transportation solutions to address mobility and environmental and safety issues as well as to meet the expectations of the transportation system user relative to trip reliability and choices has been recognized. Addressing these needs requires transportation organizations to conduct business in a new way, by proactively managing transportation systems and services to respond to real-time conditions while—at the same time—providing realistic choices for managing travel demand. *Active Transportation and Demand Management* (ATDM) is based on this concept.

ATDM is the dynamic management, control, and influence of travel demand, traffic demand, and traffic flow of transportation facilities. Under an ATDM approach, the transportation system is continuously monitored, and through the use of available tools and assets, traffic flow is managed and traveler behavior influenced in real time to achieve operational objectives. These objectives include preventing or delaying breakdown conditions, improving safety, reducing emissions, and maximizing system efficiency. Using historical data and predictive methods, actions are performed in real time to achieve or preserve system performance.

To test the benefits of ATDM approaches and encourage traffic operators and other public agencies to embrace the ATDM concept, it is necessary to create a suite of modeling tools and methods that enable the user to for evaluate the potential benefits of implementing ATDM strategies in a dynamic and proactive fashion. This set of tools or the Analysis Modeling and Simulation (AMS) system is needed to support agencies in evaluating ATDM at the planning, design, and operational stages. To support the planning and design phases, a “simulated” real-time analysis capability is required to quantify the potential impact of dynamic management using ATDM strategies; to support real-time operations, a real-time analysis capability is needed. The ATDM Foundational Research project’s objectives are to support the development of ATDM program efforts and support the development of an ATDM analysis and modeling framework.

The research undertaken as part of the ATDM Foundation Research project is organized into three reports: Concept of Operations (CONOPS), Capabilities Assessment, and Analysis Plan. This Capability Assessment report is the second in this series. It identifies the AMS needs to support simulated real-time and real-time analysis to evaluate the impact of ATDM strategies, current AMS capabilities that can support ATDM evaluation, and gaps between AMS needs and capabilities and the details the necessity to bridge the gaps to implement ATDM evaluation successfully. This report reviews current and emerging AMS capabilities for modeling ATDM and focuses on reviewing the capabilities that exist to model supply and control aspects as well as demand and travel behavior aspects, both in an offline and online environment. The AMS needs identified in the CONOPS Report are used to develop AMS gaps in this report. Although this report refers to existing applications or/and products, the synthesis has been made using publicly available literature and resources. The report neither endorses a particular commercial tool or product nor intends to present a comparative assessment. It should also be noted that this section references several ongoing research activities that are not fully developed or established.

Chapter 1: Scope

1.1 Identification

For the past several decades, traffic management and operations activities have been reactive in nature. Currently, however, recognition is growing regarding the need for effective and more proactive transportation solutions to address mobility and environmental and safety issues and to meet the expectations of the transportation system user relative to trip reliability and choices. Addressing these needs requires transportation organizations to do business in a new way by proactively managing transportation systems and services to respond to real-time conditions while—at the same time—providing realistic choices for managing travel demand. This is the concept of *Active Transportation and Demand Management* (ATDM).

ATDM is the dynamic management, control, and influence of travel demand, traffic demand, and traffic flow of transportation facilities. Under an ATDM approach, the transportation system is continuously monitored; through the use of available tools and assets, traffic flow is managed and traveler behavior influenced in real time to achieve operational objectives. These objectives include preventing or delaying breakdown conditions, improving safety, reducing emissions, or maximizing system efficiency. Using both archived and real-time data and predictive methods, actions are performed in real time to achieve or maintain system performance.

To test the benefits of ATDM approaches and encourage traffic operators and other public agencies to embrace the ATDM concept, a suite of modeling tools and methods is necessary to evaluate the potential benefits of implementing ATDM strategies in a dynamic and proactive fashion. The ATDM Foundational Research project's objectives are to support the development of ATDM program efforts as well as the development of an ATDM analysis and modeling framework. The Analysis, Modeling, and Simulation (AMS) needed for evaluating ATDM concept is documented in three documents. This report is the second in the series. The two accompanying documents to this report are —

- **ATDM AMS Concept of Operations (CONOPS) Report.** The CONOPS Report describes the ATDM AMS system that can be used to evaluate the benefits of dynamically managing a transportation system. This report, the first in the series, presents limitations of current AMS systems, the AMS needs to support ATDM evaluation, and the description of an ATDM AMS system. The CONOPS Report also provides four illustrative examples of analysis packages for the purpose of developing a detailed Analysis Plan that illustrates how ATDM evaluation can be conducted.
- **ATDM AMS Analysis Plan Report.** This Analysis Plan Report, the third in the series, presents a high-level analysis approach for evaluating the analysis packages described in the AMS CONOPS Report. The Analysis Plan Report can be used to identify the collective modeling requirements for ATDM (specific to individual strategies) to support future test bed development and AMS research using four illustrative examples. T

In particular, this Capabilities Assessment Report provides an assessment of ATDM AMS needs and existing corresponding capabilities to identify gaps between the "what is" and desired states of AMS. AMS is needed to support agencies in evaluating ATDM during the planning, design, and operational stages. To support the planning and design phases, a simulated real-time analysis capability is required to quantify the potential impact of dynamic management using ATDM strategies, while a real-time analysis capability is needed to support real-time operations. *Henceforth in this document, offline analysis refers to simulated real-time analysis conducted at the planning and design stage, and online analysis refers to analysis in real time to support real-time operations.*

The primary purposes of this AMS Capabilities Assessment Report are to —

- Review current and emerging AMS capabilities for modeling ATDM. In particular, review the capabilities that exist to model supply and control aspects as well as demand and travel behavior aspects
- Identify AMS gaps for conducting further research.

This Capabilities Assessment documents the following:

- AMS needs to support simulated real-time analysis to evaluate the impact of ATDM strategies during the planning and design stages
- Current AMS capabilities that can support ATDM evaluation
- Gaps between AMS needs and capabilities and the criticality of bridging the gaps to support successful implementation of ATDM evaluation

1.2 Document Overview

This document includes five main chapters and is organized as follows:

- Chapter 1 provides the scope, presents the ATDM concept, and describes the motivation for AMS.
- Chapter 2 describes the AMS needs for evaluating the benefits the ATDM concept.
- Chapter 3 describes the currently existing or under-development AMS capabilities relevant to the ATDM evaluation.
- Chapter 4 describes the ATDM AMS gaps.
- Chapter 5 lists references.

1.3 ATDM Concept

ATDM is a dynamic way to manage a system that is both active and predictive. The goal is to identify problems ahead of time and use an approach to manage demand and supply to meet the desired network performance. The primary hypothesis of ATDM is that proactive management yields better results than reactive management and will improve a system's reliability, safety, and environment. An agency can implement a single ATDM strategy to achieve the desired benefit, or it can implement multiple strategies to gain benefits across the entire transportation system. ATDM is not confined to a specific set of strategies and represents a shift in the traffic management and operations paradigm from static operations to more active management using a variety of traffic, parking, and demand strategies. Figure 1-1 provides an example of how strategies can evolve from a static to a more active state.

A core principle of the ATDM approach is actively influencing the entire trip chain. The trip chain represents a series of decisions that affect transportation demand and utilization of the network. It also represents the points at which ATDM actions may influence travel activities. There are three forms of transportation network demand:

- **Travel Demand.** The level of person-demand for making a trip at a given time, independent of travel mode

- **Transportation Demand.** The person-demand for making a trip using specific modes
- **Facility Demand.** The demand for facility use; for roads, typically represented by vehicles as opposed to individuals

Figure 1-1: Moving Toward Active Transportation and Demand Management (ATDM) (Examples)

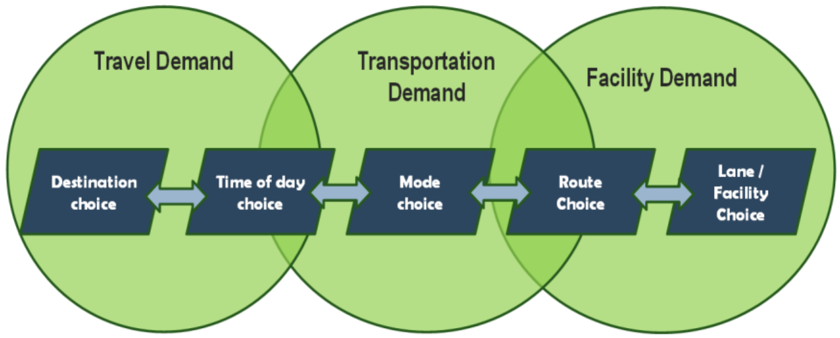
Variable Speed Limits		Manual operation based on identification of conditions	Automated operation based on pre-defined thresholds	Automated operations based on predicted travel conditions
Parking Management		Static parking information with fixed pricing	Real-time availability information, reservation systems	+ Dynamic pricing like SF Park , wayfinding
En-Route Traveler Information	Scheduled Work and Closures (press releases)	+ Incident information & Current TT	+ Comparative travel times and cost information (transit, rideshare, etc.)	+ Predictive information + Custom traveler based information and guidance

As shown in Figure 1-2, five stages within the trip chain interface with the aforementioned three types of demand. These five stages are —

- **Destination Choice.** This is the decision on whether to make the trip and where to go.
- **Time-of-Day Choice.** This is the decision on when the trip is to be made. It defines travel demand as a function of time. It also helps define transportation demand, as decisions on what mode to use may depend on the availability of particular services at a particular time.
- **Mode Choice.** This is the decision on how the trip is to be made, including the decision to drive alone, carpool, use a form of public transport, or use some other form of ride-share (e.g., slug lines). The transportation demand definition involves the demand for specific transportation modes, so this is a critical decision point.
- **Route Choice.** This is the decision on which road or transit route to take based on the most direct, fastest, or most cost-effective option. Because the mode of travel is already defined, the route decision helps determine facility demand, typically represented by vehicles on the road network and by passengers for transit services.

- **Lane or Facility Choice.** This decision is influenced by current operational conditions on the travel route and may involve options related to higher cost or better level of service (LOS) in comparison with normal costs and normal or substandard LOS, including toll lanes or high-occupancy toll (HOT) lanes. Other options may involve part-time use of shoulder lanes for traffic flow.

Figure 1-2: Trip Chain and Relation to Demand Activities



One key aspect of the ATDM trip chain is that the chain is not unidirectional. Unlike a single corridor, which may entail the use of one major route, ATDM may involve the use of multiple corridors in a region; with multiple routes, lane choice decisions may be supplanted by route choice decisions and even mode choice decisions, if there is a need to use a park-and-ride facility and an alternate mode on the last leg of a trip.

Transportation agencies currently use several strategies to support management and operation of the transportation system. Many of the strategies, however, are currently reactive in nature and are not used to actively manage the system. Various strategies could help achieve the ATDM vision and define ATDM's responsibilities and the features into which ATDM actions can be classified:

- **Active Demand Management (ADM).** Strategies focus on managing the trip demand on the network.
- **Active Traffic Management (ATM).** Strategies focus on managing the flow of vehicle traffic on the network.
- **Active Parking Management (APM).** Strategies focus on managing the parking requirements of vehicles.

When comprehensively applied, active management of transportation and demand include multiple approaches. An agency can deploy a single ATDM approach for a specific benefit, or it can deploy multiple active strategies for desired benefits across the entire transportation system. It is important to note that each ATDM strategy can influence one or more elements of the trip chain and, thus, influence the supply side, the demand side, or both. Table 1-1 provides a list of ATDM strategies that can be used to dynamically manage the transportation system.

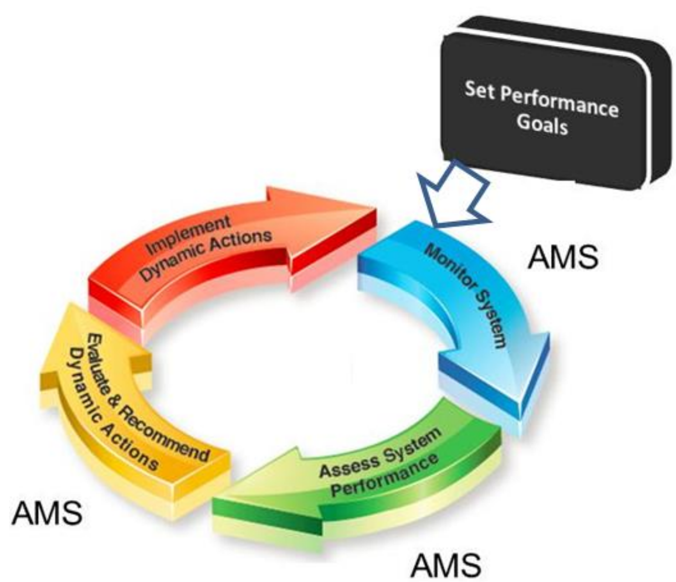
Table 1-1 : ATDM Strategies Classified by Categories

Active Demand Management Strategies	Active Traffic Management Strategies	Active Parking Management Strategies
1. Dynamic Ridesharing	10. Dynamic Shoulder Lanes	19. Dynamically Priced Parking
2. Dynamic Transit Capacity Assignment	11. Dynamic Lane Use Control	20. Dynamic Parking Reservation
3. On-Demand Transit	12. Dynamic Speed Limits	21. Dynamic Wayfinding
4. Predictive Traveler	13. Queue Warning	22. Dynamic Parking Capacity
5. Dynamic Pricing	14. Adaptive Ramp Metering	
6. Dynamic Fare Reduction	15. Dynamic Junction Control	
7. Transfer Connection	16. Adaptive Traffic Signal	
8. Dynamic HOV Conversion	17. Transit Signal Priority	
9. Dynamic Routing	18. Dynamic Lane Reversal or Contraflow Lane Reversal	

1.4 Motivation for AMS

Dynamic management requires a performance—or objectives—driven approach. As described earlier, under an ATDM approach, the transportation system is continuously monitored. Using both archived and real-time data and predictive methods, actions are performed in real time to achieve or maintain system performance. Figure 1-3 shows the ATDM implementation cycle and includes four major components.

Figure 1-3: ATDM Implementation Cycle



The following is a brief description of different elements of the ATDM implementation cycle and the need for AMS to support the implementation:

- **Monitor System.** The system is monitored continuously using real-time and historical data and analysis tools. AMS tools and methods are necessary to process the collected data and analyze the information to monitor the system in real time.
- **Assess System Performance.** Analysis using a continuously moving time window is performed to **predict** future conditions, and predicted conditions and established system-level performance targets

are compared at the current time step. AMS tools and methods are necessary to predict future performance based on existing and anticipated changes to network demand and supply.

- **Evaluate and Recommend Dynamic Actions.** If system performance does not meet the established targets, AMS tools are needed to evaluate and recommend dynamic actions. AMS tools are also needed to identify and recommend ATDM strategies to implement based on predicted improvement in performance.
- **Implement Dynamic Actions.** Dynamic actions are then implemented based on the recommendations that the ATDM decision support tools recommend.

As described earlier, to implement ATDM, AMS tools are needed to support the decisionmakers during three of the four key stages, including monitoring the system, assessing system performance, and evaluating and recommending dynamic actions. In addition, AMS can—

- Test the benefit and value of the ATDM concept, especially the proactive vs. reactive approach
- Support evaluation of different ATDM strategies
- Test tactical and strategic decisionmaking in an integrated way:
    - Tactical decisions consider operational changes.
    - Strategic decisions attempt to look at the entire system and implement demand-management strategies.

The purpose of this report is to document the current and emerging AMS capabilities for evaluating the ATDM concept and to identify AMS gaps for conducting further research. Although this report documents the existing capabilities to support both online (real-time operations) and offline (simulated real-time) analysis, the primary focus of this report is to document the existing capabilities that can support simulated real-time analysis. Although this report refers to existing applications or/and products, the synthesis has been made using publicly available literature and resources. The report neither endorses a particular commercial tool or product nor intends to present a comparative assessment. It should also be noted that this section references several ongoing research activities that are not fully developed or established.

Chapter 2: ATDM Modeling Needs

For ATDM evaluation, the modeling framework should consider both the demand and supply side. On the network supply side, it is important to model changes to network supply or capacity; on the demand side, it is necessary to capture the change in traveler behavior as a response to implemented dynamic actions. In addition, it is essential to capture the dynamic interaction between supply and demand and how the supply changes affect different steps of the trip chain. Reproducing the characteristics of the transportation system is essential for realistic forecasting of future demand and system performance. Models should accurately and reliably reproduce the underlying phenomena or at least their impact. The primary challenge is to model traveler behavior and understand user response to dynamic management strategies. In particular, many ATDM strategies are designed to influence short-term behavior, such as dynamic pricing. It is not only important to understand how ATDM strategies will influence the intended outcome in the short term but also how these short-term dynamic actions can potentially influence long-term, habitual traveler behavior. Prediction is essential for dynamic traffic management, and prediction capability should be embedded in the modeling approach. The following special considerations are needed to evaluate impact of dynamic management using ATDM strategies:

- **Performance Measures.** Performance measures derived from the agencies' goals and objectives determine data needs for the analysis. Such measures might include speeds, volumes, travel times, travel time reliability, crash rates, emissions, delays and mode choice (e.g., percent carpooling or using buses or trains).
- **Supporting Data.** A variety of data inputs need to be accommodated to support ATDM evaluation.
- **Model ATDM Concept and the Strategies.** AMS must be able to directly model specific ATDM concepts with predictive capabilities, ranging from dynamic shoulder usage to variable speed limits to HOV restrictions. To model the ATDM concept and the impact of individual strategies, it is necessary to model how ATDM strategies affect different parts of the trip chain (e.g., destination choice, time-of-day choice, mode choice, route choice, and lane or facility choice).
- **Traveler Behavior.** The tools need to be able to consider traveler behavior, acceptance, and compliance to dynamic actions. For example, the model should be able to address the particular percentage of drivers responding to real-time messaging (e.g., variable speed limits, rerouting, lane closures).
- **Model Execution Speed.** The ability to run faster than real time and model changes in conditions is needed to support dynamic management. Although this is a critical need for real-time operations support, it is not a critical need for simulated real time analysis for planning purposes.

The sections below present the AMS needs to support ATDM evaluation. The needs have been categorized as—

- Monitoring the system in real time
- Continuously assessing or predicting system performance using a moving window
- Evaluating impact of multiple ATDM strategies and recommending best suited strategies.

Note that the needs described in the following sections represent typical AMS needs that are applicable for most situations for evaluating ATDM. Specific needs for ATDM might change depending on the specific evaluation scenario.

2.1 AMS Needs for Monitoring the System

To support dynamic management through ATDM, the fundamental need is to monitor the transportation system continuously and generate performance measures (e.g., speeds, delays, travel time reliability, vehicle and person throughput, emissions, crash rates) that align with the agencies' goals and objectives. To generate these performance measures, the AMS tools need to process data from various real-time and historical sources. Sample data from the real world to monitor the system include—

- Transportation network data (e.g., signal timing plans, turn restrictions, toll rates, transit schedules)
- Data to determine available roadway capacity (e.g.,lane restrictions, parking lanes, shoulder lanes)
- Traffic counts (by single-occupancy vehicle [SOV], HOV with two people or more [HOV-2], HOV with three people [HOV-3])
- Transit data (e.g.,transit ridership, transit schedules)
- Link speeds
- Turn delays
- Emissions.

Table 2-1 describes the AMS needs for monitoring the system.

Table 2-1: AMS Needs for Monitoring the System

ID	AMS Need for Monitoring the System	Description	Criticality to Meet the Need
M.1	Collect and process real-time data from a variety of sources.	*ATDM evaluation will require access to real-time or near-real-time data from multiple data sources, agencies, and transportation modes. Upon completion of analysis, data must be archived to support future analysis.* Transportation and nontransportation-related real-time data can be collected from a variety of sources, including loop detectors, video cameras, weather stations, traffic management centers (TMC), transit operators, private transportation data providers, and fare collection systems. To support simulated real-time analysis, although archived and preprocessed data can be used for analysis, using real-time data mimics the real-world implementation more closely. To support real-time operations, the AMS system needs to process the data collected from these different sources in real time.	High

ID	AMS Need for Monitoring the System	Description	Criticality to Meet the Need
M.2	Collect and process historical data from a variety of sources.	*ATDM evaluation will require access to historical data from multiple data sources, agencies, and transportation modes.* Historical data needs to be analyzed to build baseline models, support analysis, and provide necessary inputs to predictive analysis tools. The AMS system needs to support analysis of data that is archived using different procedures across different agencies in terms of method of storage, structure of database, accessibility, and granularity of the database. Historical data can be preprocessed and be made available for ATDM evaluation in a ready-to-use format.	High
M.3	Access transportation network supply (both highway and transit) data from a variety of sources.	*ATDM evaluation will require data on the supply side of the transportation network from transportation agencies. This data is required as inputs to models in the AMS framework.* Transportation network supply data includes data collected from geographic information system (GIS) resources, data on turn prohibitions, turn lanes, signal timing data, phasing plans, lane restrictions, transit routes, schedules, lane closures, parking, and other types of data. Typically, the regional planning agencies and operators have access to this data. The AMS system needs to be able to assess the transportation network supply from these different sources.	High
M.4	Generate the desired performance metrics to monitor the current traffic conditions of the system	*Postprocessing and analytical procedures are required to translate real-time and historical data into performance measures that can be used to monitor performance of the entire region of interest in real time or simulated real time.* To support ATDM, the AMS system must process data collected continuously from a variety of sources (by modes, agencies, and different systems such as freeways, arterials, and parking) from the real world and process data in real time using analytical tools to generate desired performance measures that align to agencies' objectives, such as travel speeds, delays, queue lengths, crash rates, and emissions for the entire region of interest.	High
M.5	Integrate data collected from different sources.	*Seamless integration and consolidation of data coming from a variety of sources are required to build a structured, accessible data structure that can serve as the single go-to data pool for all AMS tools.* Inconsistencies in format, structure, and temporal and geospatial granularity in data collected from different sources must be addressed. Relational links need to be established between different databases to create a complete database that can support an integrated analysis.	High

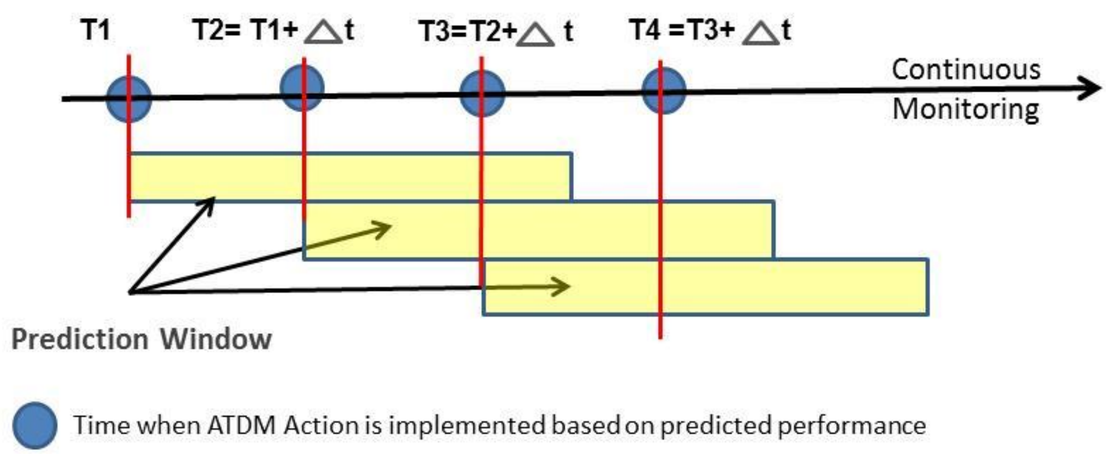
ID	AMS Need for Monitoring the System	Description	Criticality to Meet the Need
M.6	Visualization capabilities are needed to support analysis.	*Visualization tools will be required to depict the insights from analysis and simulation in graphical media. Visualization tools must condense multiple insights in an efficient manner to present a clear representation of system performance (e.g., throughput, speeds).* Tools are required to visualize simulated real-time conditions on the transportation network, such as speeds and delays, for identification of critical locations that require detailed analysis.	Medium
M.7	Understand demand patterns.	*Time-dependent demand patterns need to be generated based on real-time data as well as historical knowledge to support modeling efforts in ATDM to monitor the system in real time.* To monitor the transportation system in real time and to forecast future conditions based on anticipated supply and demand changes, the AMS system must generate time-dependent origin-destination (O-D) trip matrices by mode.	High
M.8	Validate the data prior to analysis.	*Rigorous validation techniques are required within the AMS system to assure the quality of real-time data before analysis. This involves imputation of missing values and correcting erroneous or improbable observations.* Data validation and cleansing methods are needed to clean up and use the data for monitoring the system. Valid data should be used for monitoring the system so that the current monitoring and future performance can be estimated with some level of confidence.	High
M.9	Support the required analysis scale, both temporal and spatial.	*The AMS framework needs to support required temporal and geospatial granularities for ATDM evaluation.* Data from different agencies and systems received in different geographic and time scales needs to be integrated in the AMS system to support the desired analysis scale (e.g., 5-minute or 15-minute time scale for monitoring). To achieve this goal, the AMS system needs to complement contributing data sources.	High
M.10	Auto-correct or self-validate based on the latest data.	*Some level of automation would be required to ensure self-validation and auto-correction of data collected in real time.* The modeling framework in the AMS system needs to reflect the most recent changes in the network by self-adjusting to the network conditions. This need will require that the AMS system include recurring self-validation techniques and procedures.	Medium

ID	AMS Need for Monitoring the System	Description	Criticality to Meet the Need
M.11	Capture uncertainty in data used to monitor the system.	*The AMS system needs to capture uncertainties in data collection, availability, and accuracy (on both the demand and supply sides).* The modeling framework in the AMS system needs to reflect the fact that inherent uncertainties exist with all methods of data collection and processing techniques and that this uncertainty should be explicitly considered during the monitoring stage.	High

2.2 AMS Needs for Assessing System Performance

One of the core elements of ATDM is to monitor the system on a continuous basis and take dynamic actions based on anticipated future conditions before system performance deteriorates. To achieve this goal, AMS tools should assess the current performance conditions and predict system performance in the future (e.g., 20 or 30 minutes in the future) in a moving time window. Figure 2-1 illustrates this concept, where the system is monitored using a moving prediction window. The length of the prediction window can vary depending on the performance goals against which the system is monitored, the type of strategies being considered, or the agency preference. For example, if dynamic congestion pricing is considered an ATDM strategy to implement, it is necessary to capture a longer time window to see the peak spreading effect. In Figure 2-1, *t* represents the time difference between consecutive analysis time steps (e.g., between T1 and T2).

Figure 2-1: Illustrative Example of Future System Performance Using a Moving Window



AMS needs to assess and predict system performance in a moving window using the current, forecasted, and historical information, as described in Table 2-2.

Table 2-2: AMS Needs for Assessing System Performance

ID	AMS Needs to Assess System Performance	Description	Criticality to Meet the Need
A.1	Use both real-time and historical data to support analysis at the desired geographic and temporal scales.	*The AMS system needs to leverage the most recent knowledge from real-time data as well as trends from historical data to support analysis at the desired geographic and temporal scales.* The AMS system must support the ability to use both real-time and archived data in an integrated manner either at the regional or corridor level for the desired analysis scale (peak hour, peak period, daily).	High
A.2	Continuously predict network conditions in a moving window.	*The AMS framework must include a predictive model that updates itself based on recent data and continuously predicts network conditions such as link volumes, speeds, delays, in a moving time horizon window.* The AMS system should include predictive tools and methods that continuously forecast network conditions and predict future network conditions such as link volumes in a moving window (say, forecast for the next 20 minutes in a 5-minute moving window).	High
A.3	Generate performance measures and determine whether they meet agencies' goals and objectives.	*ATDM evaluation will need to predict anticipated conditions in the immediate future and assess those conditions in terms of performance measures that align with the objectives of the operating agency.* The AMS system must be able to use the anticipated network conditions such as flows and speeds to generate a variety of anticipated performance measures, such as speeds, delays, crash rates, emissions, and travel time reliability, in real time at a local, corridor, or regional level, as desired.	High
A.4	Consider possible demand and supply changes in the forecast period and their net impact on system performance.	*To forecast future network performance measures accurately, the AMS system needs to consider the impact of possible changes in both demand and supply on overall system performance in the forecast period.* The AMS system must include forecasting methodologies that can use real-time data in conjunction with historical data to estimate possible changes in demand and supply within the immediate forecast period to forecast conditions accurately.	High

ID	AMS Needs to Assess System Performance	Description	Criticality to Meet the Need
A.5	Explicitly capture human factors and their impact on network demand.	*The AMS system needs to explicitly incorporate human factor elements such as user preference, trust, understanding and compliance in decisionmaking within in the modeling framework.* Use an understanding of human factors such as behavior and decisionmaking to variable message signs, incidents, weather, and work zones to predict near-term performance. Incorporating human factors in modeling the demand-supply interaction will lead to a more accurate reflection of real-world interactions.	High
A.6	Capture uncertainties in demand and supply.	*The AMS system needs to capture uncertainties in data collection, availability, accuracy (on both the demand and supply sides), and lack of knowledge on human factors in the AMS framework.* Inherent uncertainties exist with all methods of data collection and processing techniques. In addition, many unknowns affect modeling human factors accurately. The model and tools need to consider uncertainties in daily decisionmaking (e.g., trip start time flexibility, transit delays) and their impact on the predicted demand and supply changes.	High
A.7	Support interactions between demand and supply for multimodal trip chain analysis.	*ATDM evaluation will need modeling and analysis of multimodal trip chains and activities as well as multimodal ATDM strategies on the demand side.* The AMS system needs to include multimodal integrated analysis capability and consider demand and supply interactions for all modes (SOV, HOV-2, HOV-3+, transit) to accurately capture mode choice impacts and other demand changes across different modes.	High
A.8	Explicitly model transit operations impacts on highway system performance.	*ATDM evaluation will need to consider impacts of transit operations (e.g., bus stopping at a bus stop or increasing the bus frequency) on system performance and overall transportation demand.* The AMS system must incorporate transit operations (e.g., buses, light rail, bus rapid transit [BRT]) in the real-time modeling component of ATDM to model the impact of transit operation strategies on travel demand. The AMS system also needs to capture the impact of bus operations on overall network performance.	Medium

ID	AMS Needs to Assess System Performance	Description	Criticality to Meet the Need
A.9	Include visualization capabilities to display forecasted network conditions.	*Assessing system performance in the forecasted future conditions will require a user-friendly graphical user interface (GUI)/API that can help operators draw insights from the analysis with ease in simulated real time and offer easy-to-use channels to alter or implement their strategies.* The AMS system needs to include visualization tools to display predicted network conditions in a variety of easy-to-understand, insight-rich graphics in conjunction with the network conditions in simulated real time. The tools must facilitate easy visual identification of the performance measure.	Low
A.10	Calibrate/validate the tools to estimate the impact of anticipated demand and supply changes	*Some level of automation would be required to calibrate/validate the tools used for estimating future network conditions based on the anticipated changes in demand and supply.* The modeling framework in the AMS system needs to reflect the behavior changes in response to anticipated changes in the network demand and supply conditions . This need will require that the AMS system include procedures that ensures that the tool used are calibrated and validated to estimate future conditions reasonably well.	High

2.3 AMS Needs to Evaluate and Recommend Dynamic Actions

Upon assessing system performance, AMS tools will be used to evaluate and recommend the implementation of ATDM strategies. Key AMS needs for achieving this objective are presented in Table 2-3.

Table 2-3: AMS Needs for Evaluating and Recommending Dynamic Actions

ID	AMS Needs to Evaluate and Recommend Dynamic Actions	Description	Criticality to Meet the Need
E.1	Identify the ATDM strategy or a group of strategies to implement.	*The AMS system needs to include an automated algorithm or a dynamic set of business rules that can identify the best or optimal strategy to implement, when to implement it, and where to implement it. To select the best strategy, multiple alternatives must be tested simultaneously.* The AMS system must identify best suited ATDM strategies to implement (i.e., replicate a DSS) by using modeling tools that can determine the impact of alternative ATDM strategies. The system needs to compare predicted future performance against the ATDM strategy and the baseline predicted condition to determine the net impact. Tools must be able capture the impact of a variety of demand management, traffic management, and parking management strategies and consider how the dynamic action implemented affects different parts of the trip chain.	High
E.2	Model the impact of the ATDM strategy on different elements of the trip chain.	*ATDM evaluation will require modeling the impact of individual ATDM strategies on the decisionmaking processes involved in different parts of trip chain.* The AMS system must model traveler behavioral changes such as destination choice, mode choice, time-of-day choice, and route choice in response to dynamic ATDM strategies (short term for real-time operations and both short term and long term for planning purposes).	High
E.3	Model microscopic driver behavior changes resulting from dynamic actions, as applicable in the subarea of interest (e.g., for variable speed limit).	*Microscopic components of the ATDM AMS framework will need to model all the components of driving behavior at the individual driver level.* The AMS system must include capabilities to model driver behavior changes (e.g., car following, lane changing, merging) in response to ATDM strategies, as applicable. Depending on the strategies tested, regional level impacts resulting from microscopic driver behavior changes must be estimated.	Medium
E.4	Model the demand-supply interactions resulting from implementation of ATDM strategies.	*ATDM evaluation will need the modeling component to capture impacts of dynamic actions and strategies on the demand and supply sides of the transportation system.* The AMS system must capture demand and supply changes in response to the implementation of dynamic actions and capture the interaction between demand and supply and the net impact of implementing multiple strategies together.	High

ID	AMS Needs to Evaluate and Recommend Dynamic Actions	Description	Criticality to Meet the Need
E.5	Consider anticipated behavior changes to predict future performance.	*The AMS system needs to capture the human factor component to develop a predictive capability that can forecast anticipated changes in behavior under future conditions.* The predictive component used to assess system performance in the moving time window must be supported with human factor modeling that can forecast anticipated changes in traveler behavior in the future. For example, the AMS system must capture user acceptance of traveler information, such as route guidance and multimodal traveler information, when predicting the impact of ATDM strategies.	High
E.6	Support multiple spatial and temporal extents of analysis (e.g., region, corridor, peak period, peak hour).	*ATDM evaluation will need seamless integration of all of the components along the geographic and temporal dimensions. This integration must support consistent and reliable exchange of data, results, and information across different models and levels of analysis.* The AMS system must support different geographic (extent of the region considered) and temporal (time interval considered) extents. Certain strategies, such as congestion pricing, can have regional impacts, whereas strategies such as arterial signal timing is likely to have a localized impact. The system must be sensitive to these differences.	High
E.7	Validate the network performance conditions	*Some level of automation would be required to ensure that the anticipated network conditions are validated using data from past experience or historical observations.* The modeling framework in the AMS system needs to ensure that the impact of the ATDM strategy is captured reasonably well with desired level of confidence. This need will require that the AMS system include recurring real-time calibration and validation techniques and procedures.	High
E.8	Include visualization capabilities to display forecasted network conditions with the ATDM action	*Evaluating impact of dynamic actions in the forecasted future conditions will require a user-friendly graphical user interface (GUI)/API that can help operators draw insights from the analysis with ease in simulated real time and offer easy-to-use channels to finalize the strategies to be implemented.* The AMS system needs to include visualization tools to display predicted network conditions in a variety of easy-to-understand, insight-rich graphics, in conjunction with the network conditions in simulated real time. The tools must facilitate easy visual identification of the performance measure.	Low

Chapter 3: ATDM AMS Capabilities Assessment

Chapter 2: summarized the modeling needs to support evaluation of the ATDM concept for the simulated real-time analysis. This chapter summarizes the current and evolving AMS capabilities for supporting ATDM evaluation under both a simulated real-time (offline) and real-time operations (online) environment. Although the emphasis of the assessment is on capabilities that exist to support simulated real-time analysis for future ATDM test-bed planning efforts, this section also describes the current capabilities to support real-time operations, as many of the capabilities used for real-time operations can also be applied during the simulated real-time analysis for planning purposes. The findings have been identified, categorized, and presented in three sections:

- Monitor the System
- Assess System Performance
- Evaluate and Recommend Dynamic Actions

3.1 Monitor the System

Monitoring traffic conditions in real time has been at the forefront of data-gathering and analysis. Real-time data provides the most relevant source of information to assess traffic conditions and is essential for building rigorous models and reliable predictions of future traffic conditions. Historical data is sufficient and can be used with good results in long-term traffic demand and supply models. Policy and infrastructure planning projects which usually have an impact span of several years or decades, use forecasting models inferred on past trends and logical assumptions. Applying ATDM approaches requires an assessment of the most recent status or condition of the transportation system.

The goal of ATDM is to improve and alter traffic conditions in relatively shorter times. Historical data, although important in planning and deployment aspects of intelligent transportation system (ITS) infrastructure, is not sufficient for exercising dynamic actions to improve performance. In a dynamic management approach, to support a move from conventional, reactive traffic management to more proactive strategies, the needs and extent of real-time monitoring are amplified.

The existing real-time traffic monitoring capabilities range from tracking loop detector counts to leveraging user cell phone traces. Transportation agencies use technologies such as closed-circuit cameras and sensors to monitor traffic conditions in real time. Real-time monitoring of transportation system to meet ATDM goals will require data collection and real-time analysis for both the demand and supply sides across different modes of travel. The geographical extent and frequency of data collection of the existing sources of real-time data vary greatly in range. Table 3-1 provides example data elements to support transportation system monitoring.

Table 3-1: Illustrative Examples of Data Content

Category	Example Data Content
Demand	Vehicle counts
	Speeds
	O-D patterns
	Occupancy
	Vehicle type mix
	Transit ridership
Supply	Transit schedules
	On-demand service
	Lane use and parking restrictions
	Signal timing and phasing plans
	Ramp metering plan
	Variable message signs
	Congestion pricing plan
	Work zone data
	Incident data

Real-time vehicle (traffic count) data and transit ridership data represents the demand side of the transportation system. Vehicle data is mostly collected from sensors embedded in the infrastructure, from surveillance cameras, or by using modern tracking technologies based on cell phones or global positioning system (GPS). The data gathered from these sources ranges from location-based vehicle counts, speeds, flows, vehicle types, and occupancy to destination, activity (trip purpose), and vehicle trajectories. Currently transit ridership data is not frequently collected in real time.

Existing real-time data-collection systems gather data that is useful for both simulated real-time (for planning and design purposes) and real-time (online) operational support. A classification based on the type of data source can be organized as follows:

- **Loop Detectors.** Embedded detectors, such as loop detectors, are the most conventional infrastructure-based data-collection sources. Loop detectors are useful in collecting time-stamped vehicle counts and speed data only for certain data collection points on the road. The use of loop detectors for traffic monitoring is widespread today, and such data is collected by most TMCs.
- **Surveillance Cameras.** Road-side cameras are used to capture images of traffic at certain locations on the road network to collect vehicle counts, vehicle density, and speeds in real time. As the technology has evolved, the supporting algorithms for image scanning can now detect moving objects while eliminating background noise. The vehicles can be categorized and even uniquely identified with number plate recognition systems. According to the U.S. Department of Transportation's (USDOT) 2010 ITS deployment survey, the percentage of freeway miles covered by cameras increased from approximately 15 percent in 2000 to 45 percent in 2010.
- **Mobile Data Sources.** Cell phones and GPS devices provide a more comprehensive data source. In particular, cell phones have recently been envisioned as mobile data sources, which can replace location-constrained data-collection devices. Recently, GPS location data has been used in monitoring traffic conditions. The algorithms and technology are still evolving to improve the accuracy and reliability of collected data. Also, most transit vehicles and taxis carry a GPS that can be used to track schedules.

The recent focus of real-time data collection has been on leveraging the mobility of travelers themselves. GPS-enabled cell phone use has increased significantly, and many vehicles (mostly transit vehicles) carry GPS receivers. The establishment of enhanced 911 (E-911) requirements resulted in making cell phone velocities, directions, and location available to emergency services. The concept has since developed, with several successful experimental setups. For example, the Mobile Millennium system is a joint venture between the University of California (UC), Berkeley, and Nokia that resulted in a proof-of-concept test called *Mobile Century.* In 2008, 100 cars, each equipped with a Nokia smart phone running GPS tracking software, traveled through traffic along a 10-mile stretch of I-880 in the San Francisco Bay area. The cell phone data is useful in establishing O-D patterns and route choices based on the detailed trajectory data of the vehicles. The CarTel project at the Massachusetts Institute of Technology is working toward exploiting penetration of mobile wireless devices in the transportation network.

In addition to the traffic data, weather data and work zone data needs to be collected to monitor the system. The following details current capabilities in weather and work zone data collection:

- **Weather Data.** Clarus is a system designed to display current and forecasted weather-related data for a particular region, using sensors that collect traffic data among different state departments of transportation (DOT). The quality and format of the available data depend on the source DOT. Clarus currently provides users with weather-related data in a standard format for 38 states in the United States and three provinces in Canada. Weather-related data is also available online at the National Climatic Data Center website. Users can access heavy rainfall frequencies provided by the National Oceanic and Atmospheric National Weather Service Hydrometeorological Design Studies Center. Another similar website offering, called *UM Weather,* is provided at the University of Michigan. Users can obtain city-by-city forecasts, conditions, warnings, and weather graphics for the United States. Several websites are maintained by state DOTs and offer traffic- and weather-related data. Users can collect traffic data for the state of Virginia from the Archived Database Management Systems (ADMS). Authorized ADMS users have access to traffic count and speed data in 24-hour periods.

- **Work Zone Data.** Several states also use ITS for work zone traffic management. Some agencies across the nation have deployed portable ITS technologies to monitor traffic and manage mobility and safety during construction. Portable systems provide a solution for deployment, maintenance, operation, and remobilization of monitoring systems, especially because roadway characteristics often change dramatically during construction. Mobile traffic monitoring and management of work zones is implemented through the use of portable sensors that collect traffic data, and integrated portable changeable message signs that display speed or delay information in real time. Agencies often integrate a website into the overall system, providing motorists with pretrip information to enable better trip planning. A few agencies have also used portable ITSs to help manage merging behavior approaching work zone lane closures.

Commercial Real-Time Data Sources

Commercial data vendors along with parallel efforts from government transportation agencies have developed real-time data-collection and analysis services. Over the past 10 years, quality and reliability of real-time analysis from private sources has improved significantly and can currently provide real-time analysis that meets requirements of government agencies. Table 3-2 shows a few of the partnerships between private-sector data providers and government agencies.

Table 3-2: A sample of Private-Sector Traffic Data Vendors—Government Agency Partnerships

Private Data Providers	Consumers of Private Data
Air Sage	Houston—Galveston Area Council
ATRI	Maricopa Association of Governments
INRIX	Michigan Department of Transportation
NAVTEQ	San Francisco Bay Area 511 Program
TomTom	Texas Department of Transportation
TrafficCast.com	Wisconsin Department of Transportation

Source: Synthesis of TxDOT uses of real-time commercial traffic data, Texas Transportation Institute, submitted to TxDOT, January 2012.

Vendors are providing real-time fusion of freeway data in real time. For example, data collected by California DOT (Caltrans) Performance Monitoring System (PeMS) is processed in real time, and system performance is presented through visualizations and analytics. The performance management support extends to transit services and arterial operations.

Cell phone trace data provides real-time information about individual trips undertaken in the recent past. The cell phone trace data can potentially be translated into activity patterns and trip chains.

Current work in relevant fields also focuses on building and testing modeling frameworks to use cell phone data to derive demand patterns in real time.

Data Processing and Analysis

Although several advancements have been made in the area of data collection to monitor the system performance, the data is not sufficient to capture the performance across the entire network, and the data is not easily available on arterial systems and transit. The data analysis includes converting real-time data into performance metrics for monitoring the system and is a critical step to support real-time monitoring of transportation systems. Incoming real-time data first needs to undergo some preliminary processing before it can be used to determine network performance. Data collected from different sources is filtered, cleaned, integrated, and preprocessed to make it usable for dynamic management. This processing generally includes detection of erroneous or missing values, and correcting them with imputation techniques. The processed data is then be used for analysis in real time for monitoring the system while continuously archiving the data in well-organized and easily retrievable formats.

According to the USDOT ITS Deployment Tracking database,[1] several agencies collect and archive traffic volume and speed data. However, in some of these locations, the agencies maintain only recent data, transferring the archived data to some other group for long-term storage and management. The results of a 2005 cross-cutting study of ADMS by the Federal Highway Administration (FHWA) indicate a wide variety in the format, availability, functionality, fidelity, and collection methods of data. Some agencies, such as Washington State Transportation Research Center, do not support automatic interpolation for missing values in the data. The data-collection and archiving system leaves it up to the discretion of the user to choose the best way to interpolate missing values or correct for implausible values in the data. Such suspect data, however, comes with flags to alert users before they use the data. For instance, Caltrans PeMS performs a diagnostics on each loop in the system to detect errors or missing values. Methods of transferring data from the sensors to a common data warehouse vary from flat file formats on CD-ROMs to WANs supported by fiber optics. The interval between successive data transfers among agencies also varies across the agencies.

Currently, most agencies perform some sort of basic error check to identify and eliminate physically impossible or implausible data values. This error check can be performed at the detector controller level or the central database archiving level. The error check can be more sophisticated where implausible combinations of data values are identified.

In summary, although several advances have been made in the area of data collection for monitoring system performance, the data is not sufficient to capture performance across the entire network, and the data is not easily available on arterial systems. Data analysis is the most critical step of real-time monitoring of transportation systems. Processed sensor data in conjunction with historical data is analyzed to infer traffic and performance measures across the region.

Real-Time Monitoring Systems

The following sections describe existing real-time monitoring systems, including—

- Regional Integrated Transportation Information System (RITIS)
- Integrated Corridor Management (ICM) demonstration sites:
    - San Diego

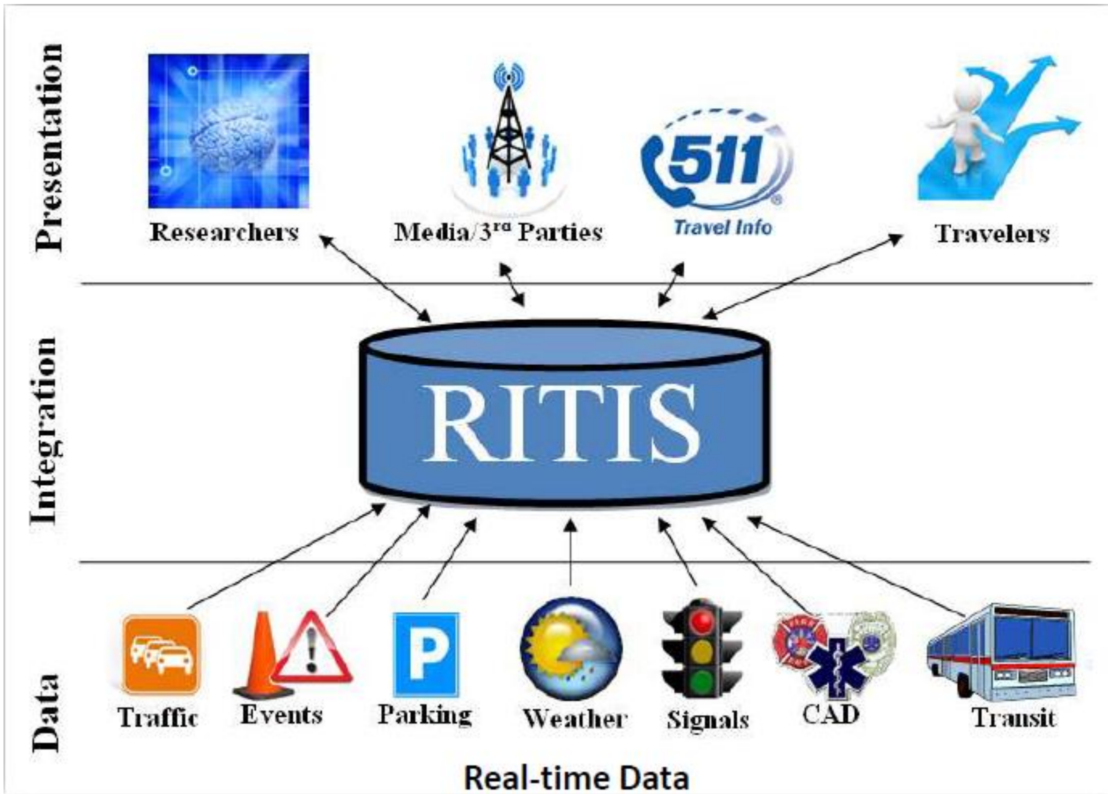
1 http://www.itsdeployment.its.dot.gov.

- Dallas
- IBM Smart Cities–Singapore.

Regional Integrated Transportation Information System (RITIS)

RITIS, developed by Center for Advanced Transportation Technology Laboratory at the University of Maryland, is defined as "an automated data sharing, dissemination, and archiving system that includes tools to compute performance measures, a dashboard, and visual analytics tools that help agencies to gain situational awareness, measure performance, and communicate information between agencies and the public."

Figure 3-1: RITIS Data Exchange Framework



Source: http://www.cattlab.umd.edu/?portfolio=ritis.

RITIS collects data from a variety of sources (Figure 3-1) across six states in the United States and automatically fuses, transforms, and standardizes the data. RITIS maintains this data and provides access to participating agencies as well as other agencies, the media, and traveler information resources through innovative visualizations.

The working framework of RITIS consists of three components:

- Real-time data feeds
- Real-time situational awareness tools
- Archived data analysis tools

These components are detailed below.

- **Real-Time Data Feeds.** The real-time data feeds received by RITIS provide direct access to real-time incident, events, detector, probe, weather, transit, and other data sources, including ITS device status. The data format and data structure design of the feeds facilitate integration of RITIS data back into legacy and other system's database. The data feeds also provide flexible data formats and retrieval methods. The participating agencies are allowed to choose which data elements they would like to provide and which elements to maintain secure and secluded from other agencies or the public.

  RITIS has integrated Clarus data (see *Weather Data* in Section 3.1) in its native format for agency-specific reporting purposes, This Clarus data is also translated and fused into a standard format for enabling regional analysis and visualization. The incorporation of Clarus data into the RITIS platform along with the creation of several visual analytics tools has enabled users to explore the relationships between weather, speed, volume, and incident datasets.
- **Real-Time Situational Awareness Tools.** The RITIS website provides web-based real-time visualization of live events, incidents, weather, sensors, radio scanners, and other data sources. It also provides visualization of ITS devices in maps, lists, and other graphical formats. Users can apply a rich set of filters and request automated alerts for severe weather conditions. Even though this tool is offered at no cost, due to sensitive nature of the data the access is granted only to preapproved public safety and DOT employees who need to register on the RITIS website.

  A few of the key functionalities offered by RITIS are—
  - Weather radar and National Weather Service alerts map
  - Visualization of dynamic message signs (DMS) and ITS devices locations and statuses
  - Visualization of transit operations
  - Access to live closed-circuit television feeds
  - Representation of radio feeds of emergency response agencies such as police, fire, and emergency medical services on maps.

  This graphical representation of transportation data also includes evacuation routes, detector data trends, comparative speeds along links/corridors and queues. After the incorporation of the Clarus data into the RITIS framework, several applications are being created to represent real-time and historical weather related data across the network map.
- **Archived Data Analysis Tools.** The data collected by RITIS is archived indefinitely. The users can query, analyze, and derive performance measures from the entire RITIS archive. The supporting Archived Data Analysis Tools have been developed—primarily—to provide access to users, and hence they afford a high degree of freedom to explore the data. The data within the archive can be downloaded so that users can perform offline analysis. These tools also enable users to identify crash hotspots, analyze queue lengths and traffic congestion/bottlenecks at specific areas, perform after action reviews, and evaluate the effectiveness of transportation operations strategies. The users can also conduct extensive time-series analysis on the road weather data using this archived Clarus data to infer valuable insights. The use of analysis tools with the historical data enables high-fidelity analysis such as performance measures' trends, safety analysis, incident heat maps, detector data analysis, and bottleneck analysis.

  Overall, RITIS provides a user-focused transportation data warehouse to support real-time visualization of the data and extensive offline analysis of the archived data. From the ATDM perspective, RITIS provides operational evidence of several of the modeling needs to monitor the system in real time in an offline setting. The key RITIS functionalities that are relevant to ATDM are—

- Real-time data collection, fusion and integration of multimodal data from multiple participating agencies in a standardized format is essential to create, and maintain a database structure that can support ATDM evaluation. The details of the analytical techniques used for real-time data validation, auto-correction, and imputation are not entirely clear. Further exploration of the RITIS data warehouse structure is, however, warranted.
- Real-time visualization of transportation related data on the network map as performed in RITIS would render real time data as part of the system monitoring component of the ATDM AMS framework. The supporting RITIS IT infrastructure provides excellent flexibility and functionality to the user focused interface and facilitates high fidelity monitoring of the system in real time.
- The query structure established under RITIS offers its users immense flexibility in querying required data from a single database. RITIS offers a user friendly interface that provides access to archived data. An IT framework of this nature would be extremely useful in the ATDM AMS framework to facilitate the analysis of historical data.

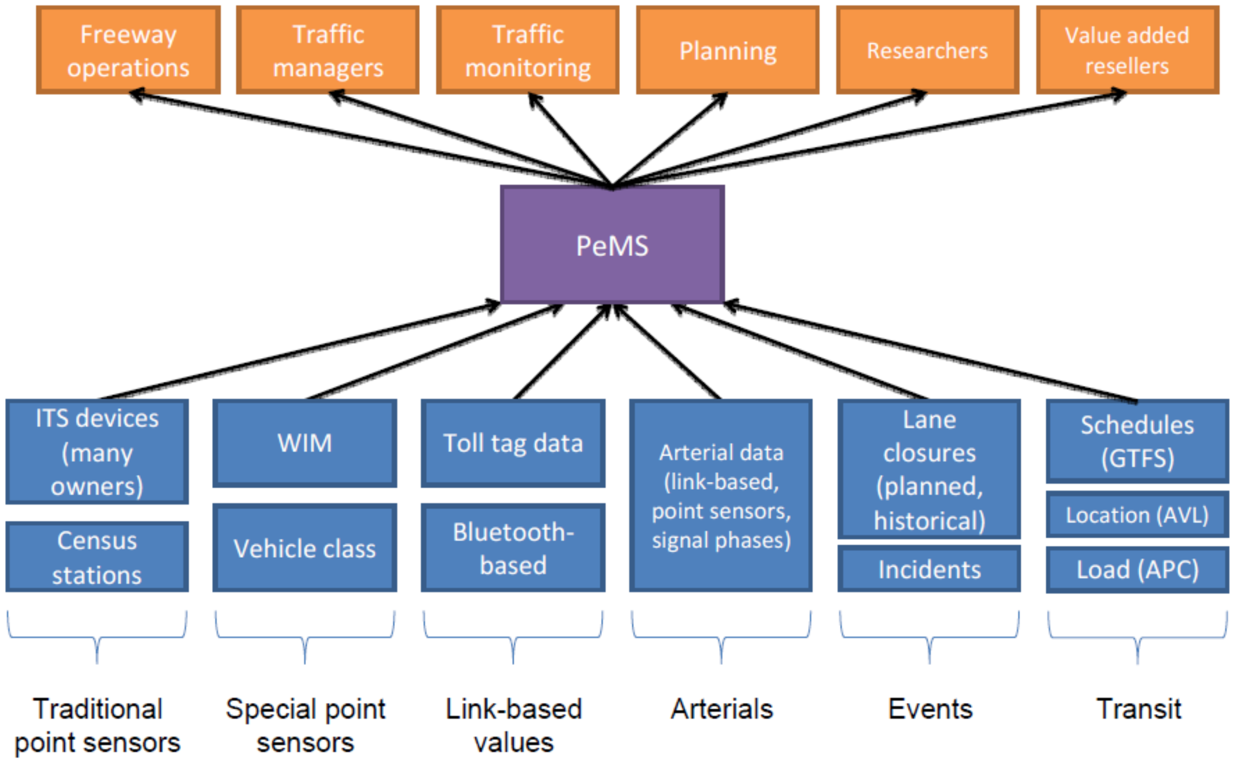
Integrated Corridor Management San Diego—PeMS

San Diego is one of the two sites selected for experimental demonstration of ICM initiatives. The test site demonstration is being carried out on the I-15 North–South corridor to test implementation of strategies such as BRT, managed express lanes, ramp metering, and arterial signal coordination with respect to the ICM vision for the area. The proactive management of the I-15 corridor requires real-time modeling and prediction of traffic flow in the corridor in response to the implementation of one or more of the ICM strategies. The San Diego Association of Governments (SANDAG) aims to leverage the advanced systems already in place on the I-15 to build a predictive simulation capability to estimate anticipated future conditions.

This ICM San Diego demonstration project is using PeMS for real-time monitoring. PeMS has recently been extended to Arterial-PeMS (aPeMS) and Transit-PeMS (tPeMS) to include real-time analysis of data collected from other domains of transportation system. The ICM system for San Diego uses an improvement of PeMS, called *3-PeMS,* which includes aPeMS and tPeMS along with the traditional PeMS. 3-PeMS will support integration of data collected from different modes to support real-time multimodal analysis. Macroscopic and microscopic analysis tools are interfaced within the ICM San Diego AMS framework. These platforms use real-time data to estimate trip tables and travel times across the network.

PeMS collects freeway information from sensors spread across state of California at high levels of detail and can be described as a real-time ADMS. The data that sensors collect is available lane by lane and at 20 to 30 seconds of time granularity. PeMS incorporates many types of transportation data from various types of sensors located in various domains of the transportation system (Figure 3-2).

Figure 3-2: Data Sources for PeMS



Source: Berkeley Transportation Systems, Inc.

PeMS follows an automated process for data fusion and data extraction from the collected data:

- The incoming data from sensors is treated with detector diagnostics to determine the reliability of sensors and hence the collected data. Detector diagnostics is automated and performed every midnight.
- Missing or erroneous values are imputed to complete the data. The 30-second data is aggregated to 5-minute data, which is then aggregated to an hourly data. Imputation of data is conducted based on linear regression from neighboring data points or using temporal or cluster medians.
- Completed data is then used to calculate speed, aggregated metrics, and performance measures as defined by the protocols. Single loop detectors do not provide direct speeds information. PeMS uses a speed algorithm based on statistical methods to estimate speeds. All these processes are collectively completed in real time.

The performance metrics and other processed quantities are presented in a large number of reports and tools that are accessible via a browser. PeMS collects data from more than 28,000 sensors spread over six districts and holds raw data forever, which in 2011 accounted for around 12 TB of data.

The outcome of background real-time analysis and web support is a capability to assess and visualize system performance in real time. For example, the data collected from multiple detectors can be accessed via web tools to generate a plot of total delay (veh-hrs) across the past 6 years to observe trends in delays on the freeway. Automated algorithms for bottleneck identification are based on persistent changes in speed over time and space. Bottlenecks are plotted on maps and color-coded based on the extent and duration of delays. In the PeMS, the percentage of time spent in congestion is used as a performance measure . The sensor locations are color-coded based on average congestion during workday AM shifts over the past month. The web tools can also support queries to track the duration of congestion at an individual location over time. Every night, diagnostics are performed on every detector in the system, and the results are consolidated into a single color-coded report representing the health of the detector along with suspected reasons for failure.

ICM Dallas—SmartNET/SmartFusion

The Dallas Area Rapid Transit (DART) Data Portal and Interagency Information Exchange Network are the supporting systems for real-time monitoring of system of the ICM Dallas demonstration project. The DART Data Portal combines data sources from components of the transportation systems such as transit/paratransit operations, emergency management systems, smart card transactions, and HOV systems into a consolidated central DART network. Along with the regional center-to-center (C2C) systems, it forms the backbone of real-time data collections and analysis for the ICM Dallas test site.

SmartFusion is the real-time monitoring component of the system, supported by a web-based information-sharing tool, SmartNET. The SmartFusion module is responsible for data collection, fusion, archival, storage, and dissemination. SmartFusion along with SmartNET supports—

- A web-based interface to the ICM system
- A data fusion engine
- Entry and management of incidents and planned events
- Receiving and publishing data to regional C2C and other external systems
- Feeding data to the 511 system and the decision support component of the ICM system.

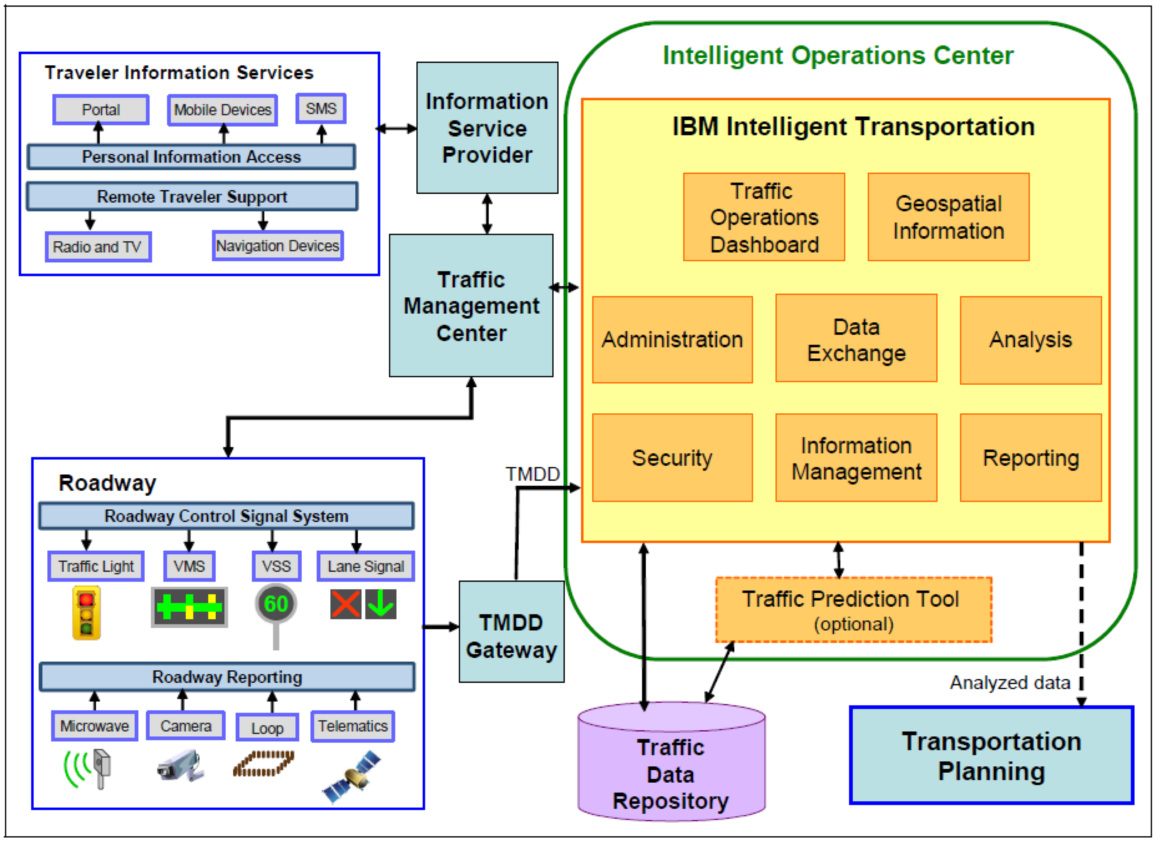
IBM Smart Cities—Singapore

IBM Smarter Traffic is a key component in IBM's Smarter Cities initiative. The goal of IBM Smarter Traffic is to integrate technology and intelligence into the city transportation infrastructure to improve capacity, enhance the traveler experience, and make the most efficient use of the existing transportation system and infrastructure. IBM Smarter Traffic strongly relies on the use of advanced IT systems in gathering and visualizing data, monitoring the system, and optimizing the system operations. IBM Intelligent Transportation version 1.0 is one of the solutions of IBM Smarter Traffic and provides new intelligence and insights, greater transparency, and increased visibility across the network. This solution provides the capability to monitor the transportation network in real time. This solution also—

- Aggregates and normalizes multisource traffic data and transforms multisource data into a standard traffic information model
- Cleans and postprocesses the data to produce a consistent near-real-time information of traffic flow across the network
- Provides near-real-time traffic analysis and reporting capabilities based on historical and near-real-time information about traffic performance, conditions, and incidents
- Monitors the system for detection of incidents and events in near-real time.

Figure 3-3 shows the framework used for real-time traffic management.

Figure 3-3: Traffic Management System with IBM Intelligent Transportation 1.0



Source: Smarter Cities Series: Understanding the IBM Approach to Traffic Management

The roadway reporting component receives real-time traffic data from roadway equipment, including loop detectors, microwave sensors, video cameras, and telematics. Along with the data from the fixed roadside infrastructure, vehicles in the traffic contribute as a data source, especially for traffic queues and congestion data. Traffic data from these multiple sources, which could be gathered from multiple vendors in multiple formats, is cleansed and standardized into a Traffic Management Data Dictionary (TMDD) format by the TMDD gateway. A standards-based information management component collects, manages, and stores traffic data for use in reporting, sharing, and analysis.

TMCs use business intelligence and analytic tools to process multisourced traffic-specific and traffic-related data. This analysis provides the TMC operators and analysts with traffic information. The traffic operators' dashboard provides the key traffic-related data and analysis results. This platform provides TMC operators and analysts with a single view that consolidates multisourced information. The dynamic, near-real-time traffic information can be associated with geospatial reference points and presented in maps. For example, the map can show the level of service, indicating the traffic congestions and general traffic flow.

In one of the real-world deployment case studies, IBM Intelligent Transportation 1.0 was used to study the congestion charging system in Stockholm, Sweden. Eighteen points of entry and exit through a cordon ring around the Central Business District of the city were monitored by free-flow toll gates, where video cameras captured images on front and rear license plates and used local optical character recognition to extract the vehicle license number.

Summary

Real-time monitoring of transportation systems is critical for the dynamic management of a transportation system. A real-time monitoring process gathers, cleans, and integrates data from different sources to convert it into performance measures of interest. The process acts as a continuous pulse check of the transportation system, determining instances where active management from the operators is warranted or needed.

A real-time monitoring process can be divided into two subprocesses: data collection/processing and archiving. The data-collection process for real-time monitoring collects data from a variety of data sources that can be generally categorized into embedded sensors, surveillance cameras, and mobile devices. *Embedded sensors* include fixed-infrastructure units such as loop detectors and acoustic motion sensors that collect data on vehicle flow, average speed, and vehicle type mix. Surveillance cameras are also used to keep track of network conditions.

A 2005 case study across six state agencies clearly indicates a wide variety in data formats, system architecture, data quality, and data-collection methods. The data structure is based on one of many options for relational databases, with some of them being only for proprietary use. Few of the agencies automatically impute the missing values in the data: Most leave it up to the individual user to decide how to deal with bad or missing data. However, some of the agencies that do not impute data have mechanisms to automatically detect and flag errors (physically impossible or implausible values) in the data. Real-time weather-related data is made available on many different websites.

The proliferation of cell phones and GPS devices in the past decade has helped realize the idea of mobile traffic sensors. Today, cell phones carried by car drivers and public transit riders and the GPS devices on public transit vehicles offer a rich pool of trajectory and activity data. AMS capabilities to infer spatial and temporal patterns of travel demand by leveraging cell phone trace data have been tested in pilot programs.

RITIS, an automated data sharing, dissemination, and archiving system develop at the University of Maryland, has established a rigorous IT framework with capabilities to support the real-time system monitoring component of the ATDM AMS framework. The collection and integration of transportation data from a variety of sources, distribution of this data to the participating agencies and users, and the visual analytics capabilities offered by RITIS can be leveraged to meet several of the ATDM AMS needs.

ICM demonstration sites in San Diego and Dallas present the most relevant real-time monitoring system frameworks. Both ICM efforts rely on an integrated framework of data collection, fusion, and archival in real time. An automated module analyzes the processed data to generate traffic parameters and performance measures for the transportation system.

IBM has developed a framework to support real-time monitoring capabilities. The proprietary solutions that IBM provides have been deployed and tested in different cities around the world. Private vendors have shown growth and promise in providing real-time monitoring support to government agencies. Such partnerships are expected to develop further in this domain.

In addition to network demand and the supply data, data elements such as weather data, incident data, and work zone data are currently available through different sources. Traffic-specific and traffic-related data can be collected in real time from a variety of resources from different modes of transportation. This multisourced data is cleaned, processed, and provided to transportation agencies along with analytical insights is by a few commercial vendors. Some variation also exists across different agencies in the way data is collected, stored, organized, and made accessible. ICM demonstration sites and IBM Smarter Traffic solutions demonstrate the capabilities required for an ATDM AMS framework and hence can be used as a good starting point or reference guide for ATDM. Table 3-3 shows the mapping of real-time monitoring capabilities against the needs for ATDM.

Table 3-3: Mapping of AMS Needs vs. Existing Capabilities to Monitor a System

ID	AMS Need for Monitoring the System	Existing Capability Description	Need vs. Capability Assessment
M.1	Collect and process real-time data from a variety of sources.	AMS functionalities required for ATDM would require a vast and rich pool of data. The desired pool of data should be able to meet the AMS demands on three levels: quality, quantity, and frequency. This will imply a shift from using conventional point traffic data to new sources of data, such as from mobile trajectories, and social networking sites, which is a step higher than the conventional data on all three levels. Although advancements have been made, additional capabilities are needed. Currently, agencies collect data in real time from various data sources and follow multiple protocols to integrate, clean, and archive them. However, consistent capabilities are needed to convert real-time data in performance metrics for system monitoring. More real-time data needs to be collected from arterial and transit operations	◑
M.2	Collect and process historical data from a variety of sources.	Currently, agencies provide historical data on their own websites or delegate the responsibility to other agencies. Private vendors also offer historical data for a fee. A wide variety of data structures, protocols, and archival methods exists. Few agencies maintain a good record of transit operations.	◑
M.3	Access transportation network (highway and transit) data from a variety of sources.	Field data from loop detectors and video cameras is well established and accessible. Capabilities exist to offer the most recent transportation network field data. Accessibility to signal data, transit routes, schedules, and lane closures in real time must be established.	◑
M.4	Generate the desired performance metrics to monitor the system.	Metrics reflecting system performance based on mobility, safety, and environmental impacts are used to monitor the system. ICM demonstrations on the I-15 corridor in San Diego is using a set of performance measures based on mobility, reliability of travel time, safety, emissions, and fuel consumption for monitoring the system. Several other agencies use predefined performance measures as a “pulse check” of the system during real-time monitoring. Generating or predicting certain performance metrics (such as crash rates, travel time reliability) in response to dynamic actions is not well established.	◑

ID	AMS Need for Monitoring the System	Existing Capability Description	Need vs. Capability Assessment
M.5	Integrate data collected from different sources.	Currently, data from fixed road-side sensors is collected and integrated into a single database by many local agencies. A few agencies, such as DART, have an integrated data warehouse to store data collected from highways and transit. Recently, efforts have been made to include cell phone data in the data repository.	◑
M.6	Visualization capabilities must support analysis	Extensive visualization capabilities are available to support real-time monitoring . Several agencies use advanced GUI for a better operability.	●
M.7	Understand demand patterns.	Time-dependent O-D matrix generation is well researched, with several applications supporting it. Advanced demand models can be used to forecast demand levels in the anticipated future. However, more testing is needed to support evaluation of dynamic actions.	◑
M.8	Validate the data before analysis.	Existing agencies have some type of automated process to identify and auto-correct anomalies and errors in the data. However, the procedure varies across agencies, and nonuniformity could be an issue.	◑
M.9	Support the required analysis scale, both temporal and spatial.	Nonuniformity across the analysis scales is an area of concern. Certain tools are best suited for macroscopic analysis and others for microscopic analysis, and there is a need to integrate several tools in a seamless way to support different analysis scales.	◔
M.10	Auto-correct or self-validate based on the latest data.	Recent advancements support this need to some extent. For example, self-correction and validation processes are regularly conducted in PeMS. Also, the macroscopic models in the ICM Dallas framework are periodically calibrated to represent the latest trends in the data.	◑
M.11	Capture uncertainty in data used to monitor the system.	Existing agencies have some type of automated process to identify uncertainties and errors in the data. However, the uncertainty is not explicitly considered as a part of the analysis framework during the monitoring stage.	◑

Legend:

● — Capabilities exist to meet most AMS needs.

◑ — Capabilities exist to partially meet AMS needs.

◔ — Not enough capabilities currently exist to m eet AMS needs.

3.2 Assess System Performance

Assessing system performance in anticipated immediate future conditions is the second step in the ATDM AMS cycle. In this step, a continuously moving window (e.g., 20 minutes) is used to predict future conditions. AMS tools and methods are necessary to predict future performance based on the existing and anticipated changes to network demand and supply. Assessing system performance is an extension of the AMS processes from the real-time monitoring step for the future time window. Instead of real time, the system is analyzed for traffic conditions anticipated to occur sometime in the near future. The performance measures that align with agencies' goals (such as travel time reliability, person throughput, delays) are computed to indicate the system performance in the analyzed future time window.

Demand models, analysis methods, and simulation techniques support the predictive capabilities required to assess system performance in future conditions. The trip demand tables are estimated for the immediate future and fed into simulation models, which can vary in the scope of geographical extent and the temporal granularity of the simulation level. The required key features of the predictive part of the simulation are—

- Simulating interactions among agents in the system as well as between agents and the transportation infrastructure. *Agents* in this sense could be individual travelers or vehicles
- Behavior models to capture reactions of the travelers to the traffic conditions and operational strategies in place, including decisionmaking aspects at trip generation, mode selection, and route selection levels.

In the ATDM approach, the system is continuously monitored for the agencies' specific goals and objectives. Although certain performance metrics such as traffic volume, average speed, and travel time delays are easy to monitor and predict, safety-related performance metrics are difficult to assess.

Current Capabilities to Assess System Performance

Predictive traffic simulation modeling is gaining popularity and has been used and tested recently in the transportation industry. The following sections provide examples.

Edmonton Yellowhead Trail Case Study

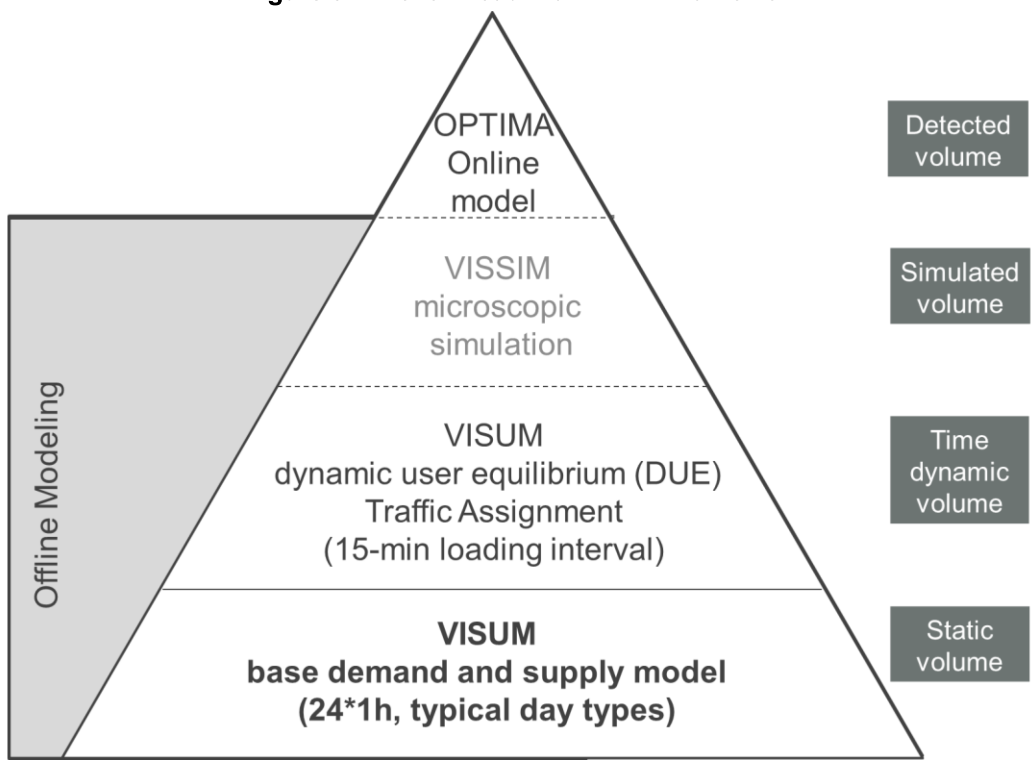
Recent efforts in predictive traffic modeling have focused on using offline (planning-based) analysis in conjunction with online (real-time) analysis. Mygistics tested the methodology in the Edmonton Yellowhead Trail case study. The goal of the case study was to build a pilot test lab to assess the effectiveness of dynamic traffic management. The Edmonton ATDM Lab is essentially a model-based incident response system. A real-time traffic simulation model, OPTIMA, based on an offline dynamic traffic assignment (DTA) model supported by VISUM, was used. Within the experimental framework, volume and speed counts from the sensors, signal controls, and DMS advisories were used to model current traffic conditions and produce a near-term forecast for traffic conditions. The model is implemented in a closed-loop framework with VISSIM. Real-time adaptive traffic signal control is modeled in BALANCE, where traffic signal cycles, splits, and offsets are optimized based on 5-minute traffic forecasts at the network level in addition to continuous local optimization fine-tuning in 1-second increments. This signal control module is again linked up with the VISSIM simulation. Figure 3-4 shows the framework used.

Offline Modeling. The offline module of the framework uses demand and supply models for different day types (weekday, weekend day, and special event/game day) to perform a priori estimations of traffic patterns. For each day type, macroscopic dynamic traffic assignment is performed at equilibrium to infer time-based route choices of the user on congested networks.

Online. Real-time estimation of actual traffic and travel-time evolutions within the immediate short-term future is performed using a sequential macroscopic dynamic network loading model. The model is continuously calibrated in real time based on incoming traffic counts and floating car data trajectories data from the network.

The framework was tested on a network spread over 11 miles and deployed with 127 signals, including 31 adaptively controlled signals. The system implementation was demonstrated for lane closure scenarios caused by an incident. According to the experimental setup, the users were notified about the incident with various degrees of information via texts. The 31 adaptively controlled traffic signals were optimized with respect to the entire system based on 5-minute forecasts of traffic volumes. Benefits of integrating adaptive traffic signals with DMSs were showcased with respect to the Do-Nothing case.

Figure 3-4: Yellowhead Trail ATDM Framework



Source: Edmonton Yellowhead Trail ATDM Test Laboratory, Jingtao Ma, Fort Lauderdale, Florida, June 2012.

Tools for Operational Planning

Tools for Operational Planning (TOPL) program at UC Berkeley, provides tools to analyze and design—

- Major traffic corridor operational improvements, such as ramp metering, incident management, and traveler routing
- Major traffic corridor infrastructure improvements, such as additional lanes and HOT lanes.

TOPL is based on macrosimulation freeway and arterial models that are easily manipulated, self-calibrated, and self-diagnosed from traffic data. Because of the macroscopic level of detail in the analysis, the simulation runs faster than real time. The existing TOPL is being developed for real-time management functionalities to predict short-term future traffic conditions and performance and allow real-time testing and evaluation of strategies. The goal of this management tool will be to provide real-time decision support to TMC operators.

Aurora Road Network Modeler (RNM), the real-time traffic simulation platform that the TOPL developed, uses a relatively simplistic macroscopic model to simulate traffic conditions. Automatic calibration, imputation of ramp flows, and fault detection are performed on a daily basis by querying fresh data from PeMS at midnight.

A 26-mile stretch on I-210W in Pasadena, California, with 32 on-ramps, 26 off-ramps, and one uncontrolled freeway connector has been used as the test site for Aurora models. The models are calibrated and validated using routine procedures. Currently, Aurora RNM supports the testing of various planning applications, such as ramp metering, variable speed limits, incident management, and managed lanes, for their impacts on traffic. At present, it can serve only as a training module for TMC operators. Efforts are still underway to develop this model further as a real-time predictive simulation tool with decision-support functionality.

ICM Demonstration—I-15 San Diego, California

Under the current scope of work in ICM San Diego, Aimsun and Aimsun Online are being used to assess system performance under anticipated future scenarios. This approach is integrated over micro, meso, and macro levels of simulation. The regional model from SANDAG is used to create the macro-level model for the ICM demonstration region of the I-15 corridor, which generates the baseline of traversal O-D matrices and corresponding adjustments to represent future conditions. The meso-level model uses DTA with dynamic user equilibrium to generate the path assignments, which then feed into the micro-level model for detailed simulation. The entire framework is interconnected with data flow across different levels. ICM demonstration in San Diego is now entering a phase where they are predicting conditions in the next hour every 5 minutes. Upon predicting the conditions, five to six response plans are evaluated with respect to the Do-Nothing scenario to determine the best response plan.

The Network Prediction Subsystem (NPS) is one of the components of the ICM San Diego AMS framework (explained in detail in Section 3.3). The goal of the NPS is to generate forecasts within a 2- to 5-minute window for flows, occupancy, and speeds. NPS also uses microscopic simulation to generate 15-minute operational forecasts for full network measures of excellence, LOS, queue, and delay. NPS also supports detection of congestion or incidents across the network. NPS receives data in real time from ATMS, the Regional Arterial Management System, and Sensys. Along with real-time data, NPS uses network capacities and historical detector data as inputs. Offline calibration of NPS is carried out using historical data to reflect the network. Real-time detector data is used in the calibrated NPS to generate detector measure predictions.

Aimsun Online accepts online detector data, detected events, and management strategies in place as inputs to generate forecasts of traffic conditions. If any traffic management strategies are implemented in the system, the Online Event Detection component of the AMS framework picks up the implemented strategies as an “incident,” which in turn alters the traffic forecasts accordingly.

ICM Demonstration—US 75, Dallas, Texas

The ICM demonstration site in Dallas, Texas, is pursuing a collaborative effort with Telvent, Southern Methodist University, and the Texas Transportation Institute to test real-time predictive modeling. The continuous assessment of system performance in a rolling time horizon window is not part of the ICM AMS. However, the predictive capabilities are being developed and tested as part of its framework, which will be described in detail in Section 3.3.

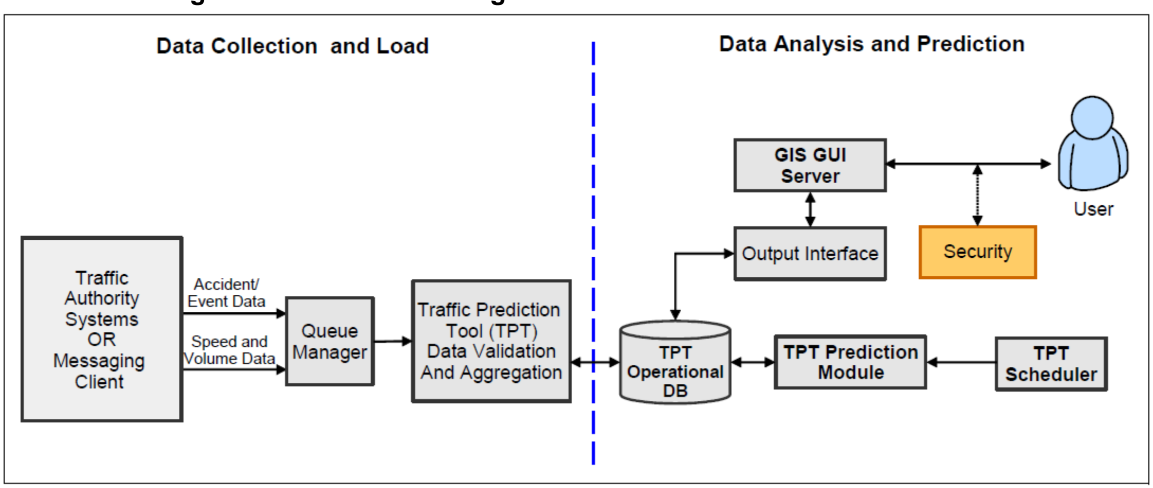
The experimental setup consists of 27 test procedures and includes a decision support system (DSS) and a prediction module. The pilot project is being tested to predict impact on diversion response plans in incident conditions on US 75. Currently, 120 possible diversion response plans have been identified for the ICM playbook. Diversion response plans are characterized in terms of incidents and the affected control devices.

Smarter Traffic Initiative

The IBM Traffic Prediction Tool (TPT) is one of the key IBM solutions for traffic management developed under the IBM Smarter Traffic initiative. TPT was developed for both expressways and urban road networks and uses historical traffic data and real-time traffic input from the system to predict traffic flows and speeds over the next 10- to 60-minute window. TPT is based on a statistical model supported by data collected from a variety sources (from cars to transit networks). The model accounts for the historical trend in traffic flows in a region and time variant deviations from this trend. The model uses serial correlation and spatial correlations in the traffic data to identify neighboring locations that affect local traffic patterns. It is recalibrated every week to adjust for the most recent trends in traffic. Field validation results of TPT's prediction accuracy in Singapore have shown promising results, with more than 85–93 percent accuracy for traffic volume forecasts and 87–95 percent accuracy for vehicle speed forecasts.

Figure 3-5 shows the data processing flow for IBM TPT. TPT can be integrated with existing traffic management solutions or a web portal. A Queue Manager module receives crash and event data and speed-volume data from the source agencies and passes on XML data feeds to the TPT module for data validation and aggregation. The cleansed data is then loaded into the operational database. The TPT Prediction Module, which the TPT Scheduler manages, makes predictions based on the operational database. These predictions are written back to the operational database, which communicates them with the operator or analyst.

Figure 3-5: Data Processing Flow for the IBM Traffic Prediction Tool



Source: Smarter Cities Series: Understanding the IBM Approach to Traffic Management.

Summary

Assessing system performance in the short- or medium-term future requires forecasting the travel demand and network conditions in the anticipated future. This step can be conceptualized as a two-step process: forecasting traffic volume in the future based on the real-time and historical data and assessing system performance for the future time window using forecasted travel demand and network conditions.

Current approaches involve coupling two or more simulation models to assess system performance in anticipated future conditions. In most cases, a baseline demand model is created to represent an overall estimate of the travel demand in the region. This model is periodically recalibrated to adjust its parameters to the most recent trends in the travel demand in the region. A mesoscopic or microscopic simulation model is used to predict anticipated traffic flows and average speeds in a moving time window. Results from the simulation runs for these anticipated future windows are then used to generate simulated performance measures. These simulated performance measures are compared against the goals of the stakeholders to assess the system performance.

ICM demonstration sites in San Diego and Dallas are developing their own supporting models in an AMS framework similar to the one described earlier. For ATDM, assessing system performance in the future is a continuous process that acts as a pulse check for impending mitigating circumstances. However, IBM TPT uses the predictive analysis to forecast link volumes and vehicle speeds in the future to identify impending congestion and take preemptive actions. TPT has also shown good results in the field and has been used in several cities across the world.

Table 3-4 provides a mapping of system performance prediction capabilities against the corresponding AMS needs for ATDM.

Table 3-4: Mapping of AMS Needs vs. Existing Capabilities for Monitoring System Prediction Performance

ID	AMS Needs for Assessing System Performance	Existing Capability Description	Need vs. Capability Assessment
A.1	Use both real-time and historical data to assess and predict future performance.	Current capabilities exist for using both real-time and historical data in assessing and predicting performance of the system in the near-term future.	◑
A.2	Continuously predict system performance in real time in a moving window.	Although some recent efforts have attempted this, there is no example of a system that predicts system performance in real time in a moving window for the entire region, taking into account explicitly the supply and demand interactions.	◑
A.3	Generate performance measures and determine whether they meet agencies' goals and objectives.	Mobility-based performance measure predictions are being used as part of the AMS of the ICM demonstration in San Diego. However, predictive capabilities have not been translated to forecast performance measures capturing environmental and safety goals.	◑
A.4	Consider possible demand and supply changes in the forecast period and their net impact on system performance.	Offline testing of simulation techniques considering anticipated changes in demand and supply in the forecast period has been done. However, not all parts of the trip chain are considered in the analysis.	◔

ID	AMS Needs for Assessing System Performance	Existing Capability Description	Need vs. Capability Assessment
A.5	Explicitly capture human factors and their impact on network demand and supply.	The impact of human factors has been modeled to a certain extent through behavior models. However, more elaborate models are required to capture human factors, such as user acceptance, trust, and adaptability.	◔
A.6	Capture uncertainties in demand and supply.	Uncertainties in sensor operations, message propagation, and fluctuation in demand are not adequately captured.	◔
A.7	Support interactions between demand and supply for multimodal trip chain analysis.	Although multimodal analysis is frequently done for long-range planning, there are no such examples for dynamic actions or management strategies.	◔
A.8	Explicitly model transit operations impacts on highway system performance.	The impact of transit operations on overall system demand and operations is not currently modeled.	◔
A.9	Include visualization capabilities to display forecasted network conditions.	Visualization capabilities to display network performance data is currently available.	●
A.10	Calibrate/validate the tools to estimate the impact of anticipated demand and supply changes.	Automatic procedures to calibrate tools and validate the forecasted conditions have not been fully tested.	◔

Legend:

● — Capabilities exist to meet most AMS needs.

◑ — Capabilities exist to partially meet AMS needs.

◔ — Not enough capabilities currently exist to meet AMS needs.

3.3 Evaluate and Recommend Dynamic Actions

The candidate ATDM strategies intended to mitigate impending stress on the transportation system affect the balance between demand and supply in numerous ways. The strategies focus on exercising control on the supply side of the system via lane use controls, dynamic speed limits, adaptive ramp metering, and others, or they try to directly alter the demand for transportation by promoting dynamic ride-sharing, on-demand transit, predictive traveler information, and so forth. These actionable strategies are at the core of ATDM, where the operator must use the best strategy or an optimum combination of multiple strategies that affect the demand-supply interactions favorably.

The impact of these dynamic actions is realized when users react to the changes in the system. The alterations in supply of the transportation system attempt to direct and reorganize the traffic demand to optimize the performance of the entire system under the given capacity constraints. Actions to alter the demand for transportation attempt to directly manipulate the need for the transportation as perceived by users by penalizing them, providing directive information, or offering desirable temporal or modal alternatives. All these actions in some way bring a change in the behavior of the user, which ultimately might lead to the intended change in demand. Therefore, modeling user behavior and its sensitivity to the ATDM strategies is critical in evaluating impacts of dynamic ATDM strategies.

The dynamic management of a transportation system requires predictive capabilities to assess the system condition before failure occurs. If impending congestion or incident events are detected while assessing system performance in a moving window, the operators need to evaluate ATDM strategies for their impact in mitigating the impending circumstances. For real-time operations, DSS is likely needed for any high-fidelity and partially or completely automated traffic management system. DSSs essentially tie up real-time monitoring with the predictive simulation capabilities to evaluate the impacts and benefits of different strategies that alleviate stress on the transportation system. The solution set of action strategies may include increasingly complex and capable system control strategies with a broader range of potential actions. This makes selection of the optimal control strategy in real time a challenging task, and it often cannot be done manually in the limited amount of time available for decisionmaking. For planning and design purposes, in a simulated real-time analysis setting, a DSS is optional and the modeler can identify the set of strategies to test or evaluate.

A DSS in case of real-time operations, and either a DSS or a manual process in case of simulated real-time analysis helps identify the strategies or the set of strategies to implement. As defined in the "Assessment of Emerging Opportunities for Real-Time, Multimodal Decision Support Systems in Transportation Operations CONOPS" developed by FHWA, transportation-specific DSS technologies and methodologies can be organized as follows:

- **Tables-Based DSS.** Make use of predefined response plans and require minimal processing, modeling, or analysis. They can include basic logic-based analysis of data in the tables or can be as simple as lookup tables. Examples include Toronto COMPASS, Kansas City Scout, and Georgia Department of Transportation NaviGAtor.
- **Knowledge-Driven DSS.** Requires an expert system engine or custom rules to generate recommendations for response plans. Examples include Caltrans ATMS, Oregon DOT (ODOT) Transport, and Pace Transit Operations DSS.
- **Model-Driven DSS.** Incorporate online simulation of toll integration. Examples include Singapore Green Link Determining (GLIDE) System, Madrid, Beijing, and Milan.

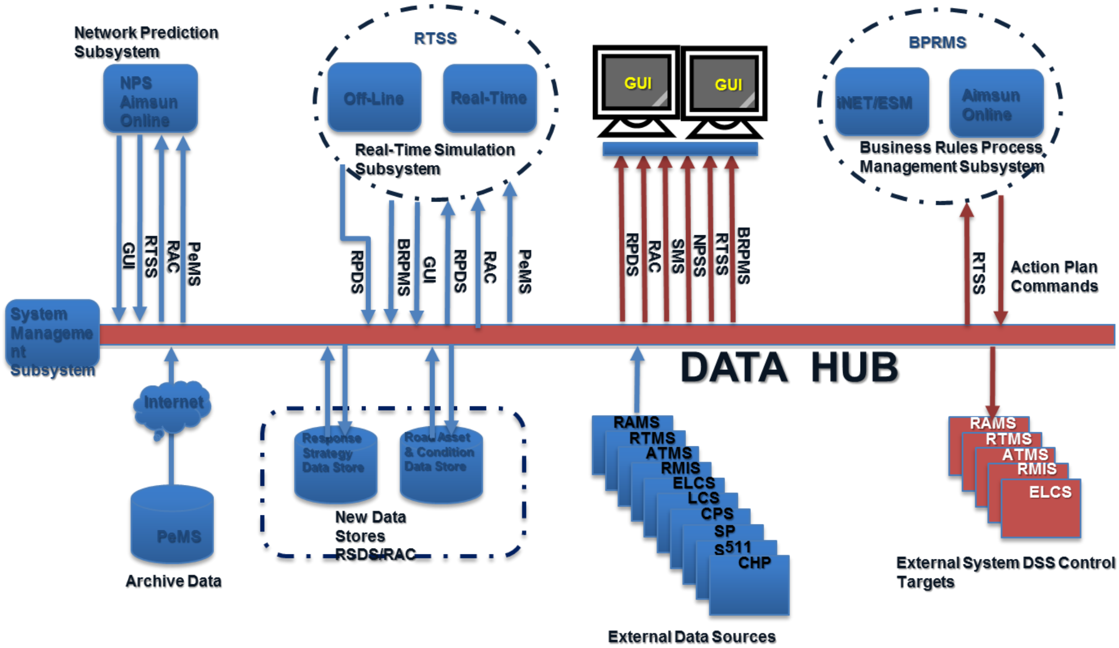
Existing Decision Support Systems

Existing DSSs are limited to offline support with few active real-time DSSs. Most depend on lessons learned from past experiences with few offering truly real-time support.

ICM DSS Implementations

The ICM demonstration in Dallas, Texas, and San Diego, California, are closest to delivering truly real-time DSS. The Business Rules Process Management Subsystem (BRPMS) component of the AMS framework for the ICM San Diego project, shown in Figure 3-6, is the DSS component of the framework. Supported by Aimsun Online, the BRPMS component generates a solution set of ICM strategies to be evaluated at a given time. The underlying algorithms in BRPMS search through a database of action items to suggest a few candidate strategies for evaluation. In the ICM Dallas project, this task is performed by an Expert Rules Manager module that recommends diversion response plans for incident scenarios from a predefined ICM playbook of about 120 diversion response plans.

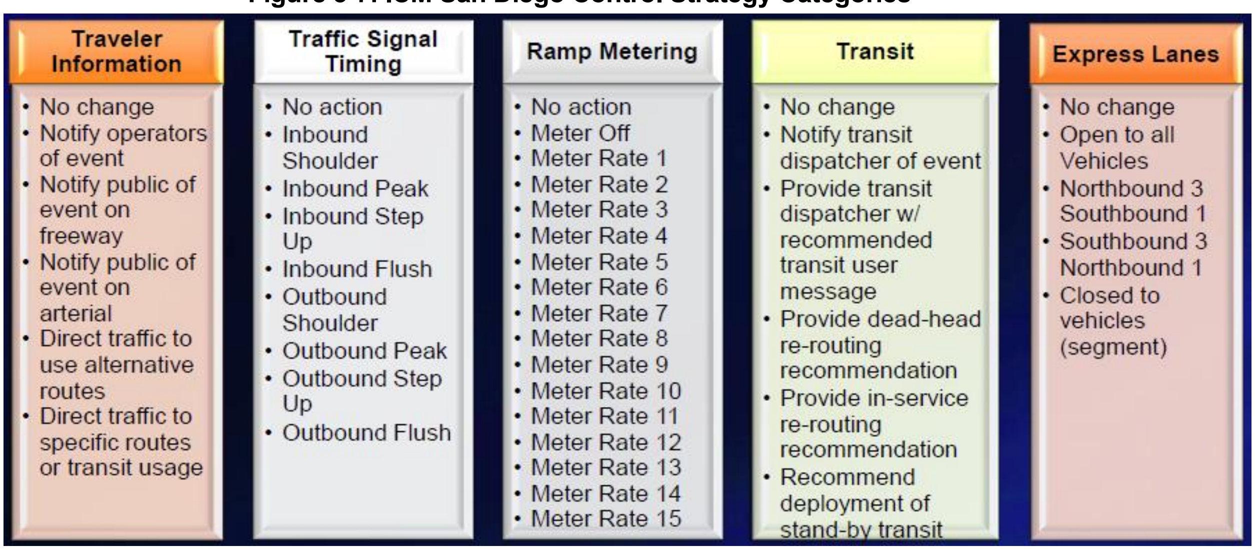
Figure 3-6: ICM San Diego Subsystems



Source: Aimsun, San Diego I-15 ICM Real-Time Traffic Modeling and Network Flow Prediction, June 19, 2012.

The DSS subsystem of the ICM San Diego AMS framework is composed of response actions and management system constraints. A set of candidate action items across different control categories, shown in Figure 3-7, is defined based on internal review.

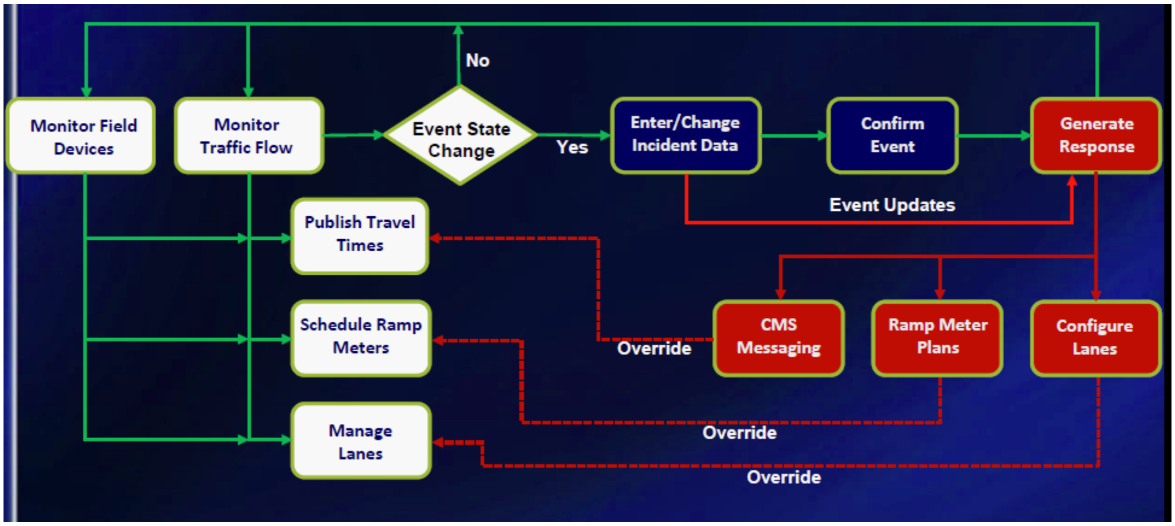
Figure 3-7: ICM San Diego Control Strategy Categories



Source: ITS America 22nd Annual Meeting & Exposition, May 21–23, 2012, National Harbor, Maryland.

For every event, a response matrix is built based on demand characteristics of the network and the corresponding impact of the action item. Different combinations of individual action plans from each of the control categories form unique response plans. These response plans are the candidate strategies that are evaluated for their impact on performance measures. The DSS framework in ICM San Diego follows an algorithm, as depicted in Figure 3-8.

Figure 3-8: ICM San Diego Business Rules and Process Management



Source: ITS America 22nd Annual Meeting & Exposition, May 21–23, 2012, National Harbor, Maryland.

Smarter Cities

The IBM Smarter Cities initiative has developed a DSS Optimizer (DSSO) to help operators use massive amounts of transportation data and make informed decisions. The DSSO includes IBM's traffic prediction tool, which provides traffic condition forecasts under normal or seminormal conditions. An incident detection module, along with an Incident Impact Factor Evaluation component can assess link-by-link list of impacted links and the degree of impact. The business rules for designing intervening strategies are provided by the DSSO optimal control plan generation module. The traffic prediction capability is used to calculate expected benefits under each of the DSSO-generated plans. The DSSO also offers flexibility to accept an operator-customized plan and evaluate its expected benefits. Though the field validation results of this capability are still awaited, a pilot deployment is soon to roll out in Lyon, France.

Current Capabilities to Evaluate Impact of ATDM Strategies

Upon identifying strategies to test, a suite of models or tools is necessary to predict the impact of the selected strategy on system performance. The ability of AMS tools to quantify impact of different operational and management strategies has been improving. The following section describes the current capabilities for evaluating impact. To predict the impact of any management or operational improvement, it is necessary to capture how the action impacts the different elements of the trip chain, such as destination choice, time-of-day choice, mode choice, route choice, and lane choice. Traveler behavior has been well researched, with a range of models that can evaluate impact of dynamic actions to various degrees of detail. The models can be grouped as—

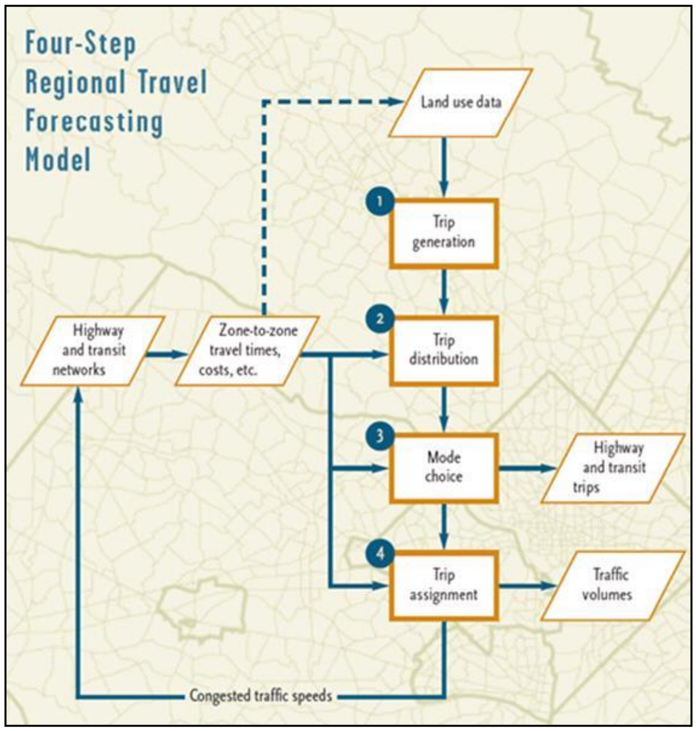
- Traditional four-step travel behavior models
- Tour/activity-based models
- Traffic simulation models.

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. Although the travel behavior 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, and change in trip destination), the supply models (macroscopic, mesoscopic or microscopic simulation models) are used to model the change in network performance as a result of the predicted behavior changes.

Conventional Four-Step Travel Behavior Models

Traditional four-step models have been used in the transportation industry for several decades. 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. **Error! Reference source not found.** depicts the typical (simple) four-step modeling ramework.

Figure 3-9: Simple Four-Step Modeling Framework Adopted by Metropolitan Washington Council of Governments (MWCOG)



Source: MWCOG Four-Step Travel Demand Model.

The four-step model, as the name suggests, models the realization of travel demand in different steps: (1) trip generation, (2) trip distribution, (3) mode choice, and (4) trip assignment. According to this process, the trip generation step uses the land-use data to determine the number of users and employment location segmented by traffic analysis zones (TAZ). The trip attractions and productions determined by the trip generation step are used to develop O-D patterns for the trips within or across the TAZs. Once the trip demands across different O-D pairs are established, various candidate modes of transportation connecting the origin and destination are evaluated based on their costs for every trip in the O-D matrices. The traffic assignment procedures used in traditional travel demand modeling tools (e.g., TP+, TransCAD, EMME2, TRANPLAN) use the volume-to-capacity ratios and the Bureau of Public Roads-based volume delay functions.

Traditional four-step travel demand models are relatively less rigorous and less data-sensitive than advanced activity-based models and traffic simulation models. To validate the model results, daily or period (AM, PM, off-peak)-based counts are used. The counts are typically collected using loop detectors on major facilities in the transportation network.

As noted by the *Special Report 288, Metropolitan Travel Forecasting–Current Practice and Future Direction*, published by the Transportation Research Board in 2007, the traffic assignment procedures in traditional four-step travel demand models and networks that are period-based and not time-sensitive are inadequate to address the impact of management strategies and policy changes. The four-step travel demand models are simplistic and are the conventional tools used by transportation planners. These models are best suited for developing long-term policies and investment plans.

However, the four-step models lack the capabilities needed to support evaluations of dynamic actions as needed by ATDM. The trips are thought to be independent of each other with no trip chaining possible. The model is insensitive to implementation of traffic demand strategies such as congestion pricing, tolls, and HOT lanes. The interactions between members of a household are not considered. The modeling is aggregated over time (peak periods) and space (TAZ), and hence is incapable of modeling changes at a finer level.

Tour-Based and Activity-Based Models

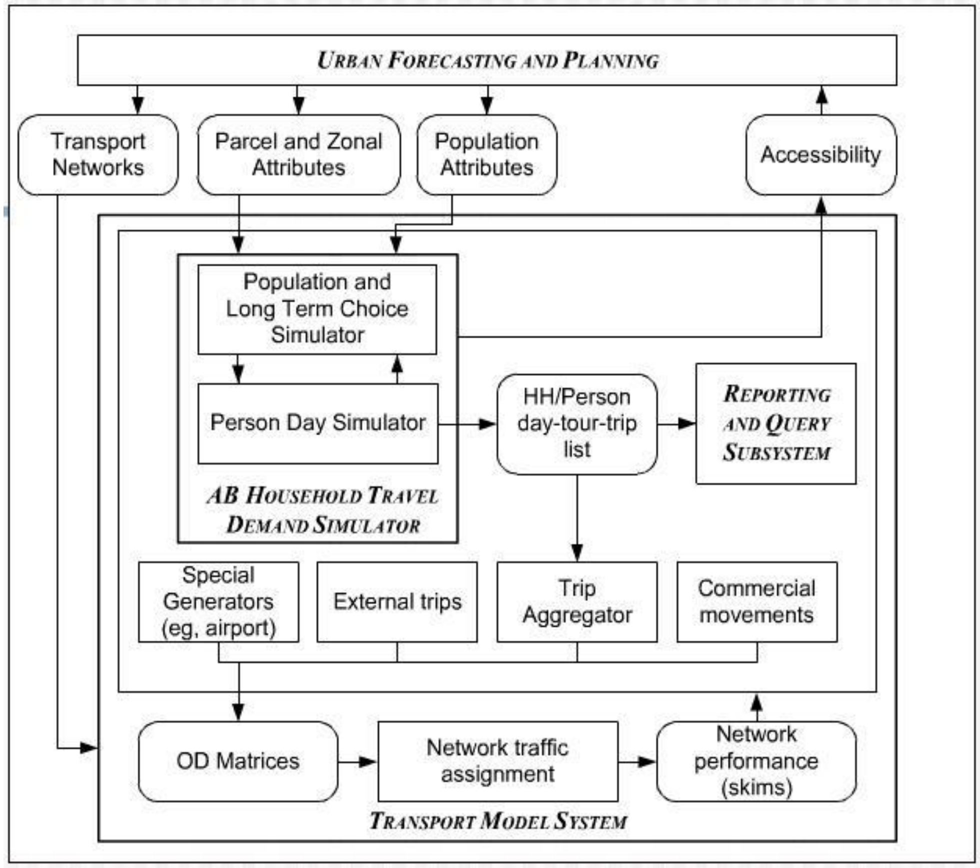
Travelers typically respond to demand management and other ATDM strategies by changing their activity patterns and/or schedules (e.g., change their departure time, sequence of activities, duration of activities, change mode or defer trips altogether) and instead of performing simpler tours, they combine 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. 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 intrahousehold interactions, joint travel, and individual schedule consistency. Activity-based models take the tour-based models one step further and consider interaction between members of a household, vehicle ownership, and joint travel and ensure schedule consistency between individual trips made by every member of the household during the 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 or her time of departure or deviate from his or her shortest travel time path in response to a toll. 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 nonhome-based.

Different partial and fully operational activity-based microscopic simulation systems exist, including the Microanalytic Integrated Demographic Accounting System (MIDAS); Comprehensive Econometric Microsimulator for Daily Activity-Travel Patterns (CEMDAP); Prism Constrained Activity-Travel Simulator; A Learning-Based Transportation-Oriented Simulation System model; Florida's Activity Mobility Simulator; Travel Activity Scheduler for Household Agents; and the Best Practice Models of the New York Metropolitan Transportation Council, Columbus, and San Francisco County.[2] While their overall philosophies are the same, the above activity-based model systems are slightly different in their approaches 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 3-10 presents an overall activity-based modeling framework.

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

Figure 3-10: Activity-Based Model Framework



*Source: John L. Bowman Travel Model Improvement Program (*TMIP*) Webinar, Activity Model Development Experiences, 2009.*

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 nonresidents, and assigned to transit and road networks (as shown in Figure 3-12). 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.

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—

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

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

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

Three active and matured activity-based models are described below.

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 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 reassigns the model results using Synchro or VISUM to produce the fine-grained measures required for their studies.

Columbus Model

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

New York Best Practices Activity-Based Model (NYBPM)

NYMTC reports that the 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
- Bronx Arterial Needs Major Investment Study
- Kosciuszko Bridge Study
- Goethals Bridge Modernization Environmental Impact Study.

The key observations on suitability of activity-based models to support ATDM evaluation are as follows:

- Activity-based models predict traveler behavior at a finer resolution, making it better suited for modeling behavior changes in response to ITS strategies.
- As the activity-based models keep track of socioeconomic characteristics of individuals, they are better suited to analyze travel behavior changes in response to policy changes, such as fuel process, mileage-based gas tax, parking fee, and improved transit.

- Activity-based models are capable of realistically assessing the impact of Transportation Demand Management (TDM) and other ITS strategies on the entire daily travel demand, as they can predict changes in tour patterns in response to changes in network conditions.
- Although theoretically sound and best suited to model travel behavior, activity-based models have not yet been used in the transportation industry to their full potential and have not been rigorously tested to determine 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 time and financial 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 before activity-based models become the most commonly used tool by planning agencies for modeling traveler behavior.

Traffic Simulation Models

In the context of real-time operational control, DTA models on the mesoscopic and microscopic levels are relevant for ATDM evaluation. Real-time DTA models are appropriate to address these types of problems in a systematic manner, because they provide capabilities for estimating future network conditions (flow patterns) that will result from a particular traffic management and/or information provision strategy. They are capable of updating network states and developing new traffic management or information provision strategies based on real-time field data. However, models need to be computationally efficient 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 systemwide or traveler class objectives. These objectives are based on the project characteristics. This characteristic is particularly important for evaluation of the effects of special and short-term events such as ATDM strategies. Hence, advanced DTA models should provide capabilities to handle different classes of travelers, depending on the ATDM strategy under consideration.

The data requirements for microscopic simulation models are much higher than those for the mesoscopic or macroscopic models. The microscopic models require detailed road network geometry, including number of lanes, turn rules, speed limits, signage, and signal controls.

The traffic simulation models also produce detailed outputs compared to macroscopic models, and the outputs need to be postprocessed 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, and deceleration rates) for a fine temporal unit such as sub-seconds.

Large-scale simulation or regional simulation models currently exist for regions such as Baltimore, Chicago, and Knoxville. Work is in progress for the Atlanta, Austin, and San Francisco regions. Agencies across the United States currently use microscopic simulation 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.   summarizes the findings by the American Association of State Highway and Transportation Officials (AASHTO) Standing Committee on Planning in March 2010.

Table 3-5: State-of-the-Practice of Mesoscopic and Microscopic Simulation-Based Models - Examples

Modeling Tool	Example Agency Using the Models	Example Transportation Application	Measures of Effectiveness Generated	Study Objectives
AIMSUN	New York City Department of Transportation	Capacity improvements, operational improvements	*Network-wide:* average speed, vehicle miles traveled (VMT), vehicle hours traveled (VHT), stopped/delay time *Link:* (time-dependent) volumes, travel times	Determine the effects of the 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, traffic optimization studies, or traveler information studies	*Link:* (time-dependent) speeds, volumes, densities, travel times *Path:* vehicle trajectories, travel times	Study the impact on traffic (e.g., route choice, travel time) due to major freeway widening 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, and variable speed limits. Determine the optimum operational strategy for ramp metering, active traffic management, and 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

Modeling Tool	Example Agency Using the Models	Example Transportation Application	Measures of Effectiveness Generated	Study Objectives
				each. Develop visual animations of project alternatives for various audiences. Use simulation work as a corridor operations management tool.
TRANSIMS	Buffalo, New York	Environmental benefits of lowest fuel consumption Route Guidance in the Buffalo-Niagara Metropolitan Region	Network speeds, volumes, and fuel consumption.	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 , California	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?
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 the maximum inputs of TSM/TDM for the corridor.

Source: Best Practices in the Use of Micro Simulation Models, AASHTO, March 2010.

Key observations on traffic simulation models can be summarized as follows:

- Microscopic simulation tools provide capability to track different classes of travelers and vehicles and hence are capable of representing an individual's response to ATDM strategies.
- Microscopic simulation 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, and traffic calming.
- Microscopic simulation tools that come with DTA procedures (TRANSIMS) can be effectively used to change the paths of travelers based on operational improvement changes, real-time traveler information, eco-driving, and so forth.
- Microscopic simulation models are expensive to build and validate. A significant amount of resources are needed in terms of both manpower and computer resources to develop and validate microscopic simulation models.
- Due to very high data needs, most agencies resort to conducting a detailed microscopic simulation for a small subregion or corridor and use macroscopic or mesoscopic models for regional analysis.
- Calibrating all the parameters requires significant effort.

Modeling Traveler Behavior

An analysis report on Network and Non-Network Impacts on Traveler Choice submitted to FHWA by Northwestern University and SAIC, Inc., provides a synthesis of the state of the knowledge in traveler behavior research. The report presents the traveler decisionmaking process as a linked structure of different traveler behavior components segmented by timelines of decisionmaking. Figure 3-11 shows the flow of the traveler decisionmaking process from long term to short term and vice versa.

Long-term decisions include land use, environment, household-work place locations, and employment. These decisions also influence the lifestyles and mobility patterns of individuals. From a traffic management perspective, these decisions are affected at policy levels that drive some of these factors. On the shorter terms of the decisionmaking, day-to-day and within-day behavior changes along with behavior patterns explain the decisionmaking processes. These decisions are sensitive to active traffic management strategies, and hence are very relevant to study the impacts of ATDM strategies. The framework components are presented in Figure 3-11.

Day-to-day and within-day behavior changes are classified as short-term behavior changes. There have been many studies in the literature focusing on route choice, departure time, and trip-chaining decisions. However, only a few studies have addressed destination adjustment in response to real-time information.

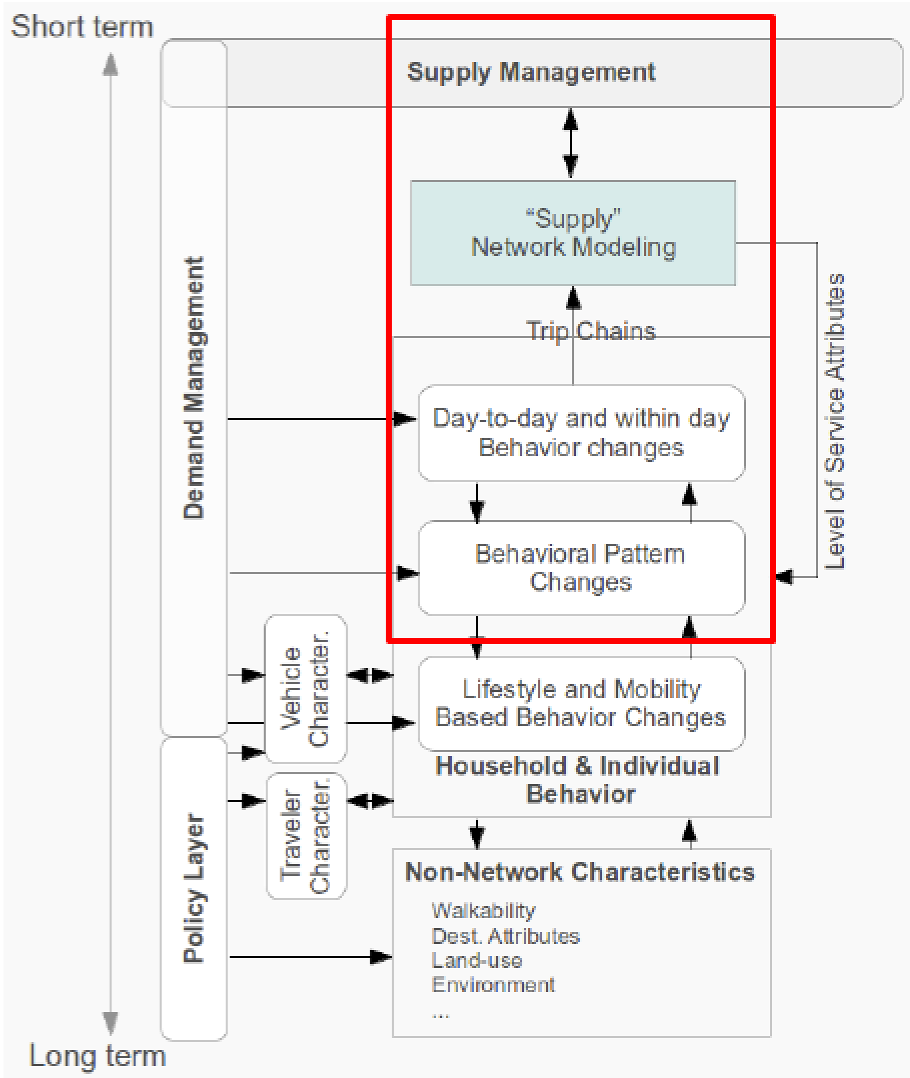
Socioeconomic factors affect the behavioral patterns in traveler decisionmaking. Many studies, mostly focusing on econometric models, have studied the impact of age, gender, vehicle ownership, employment, and health on the daily travel patterns within a region. Studies also show that parking pricing and TDM are effective ways of encouraging people to shift to public transit mode. Some decisions, such as vehicle ownership, can be attributed to inherent attitudes of persons, but this phenomenon has not been well researched.

The longer-term impacts on traveler behavior are manifested via learning and adaptability mechanisms. These impacts alter the trip demand and travel patterns in the future. In the relevant studies, behavior is treated as an outcome of experience or new information about the current conditions. Research studies have approached this problem with both stochastic and laboratory testing procedures. It has been observed that the traveler behavior mechanism of learning from past experiences possesses a certain amount of choice inertia (i.e., a traveler's affinity to modify his or her choice—especially in the short term—is low). Research studies have observed that short-term traveler behavior models that include this inertia factor consistently outperform other models and can explain behavioral changes better.

Household interactions also affect the activity patterns and the daily commute. Social networks affect the trip decisions greatly, and recent research efforts have shown great interest in understanding the phenomenon. However, the impact of information dissemination via social networks on traveler behavior has not been examined beyond a few numerical experiments. The complexity and lack of data have been cited as the key reasons hindering the incorporations of social network concepts into transportation demand models.

Overall, activity-based models are widely accepted as tools to model complexity of travel demand. Many local agencies have put significant resources behind developing and implementing their own activity-based models. However the one-day travel diaries conducted by most national surveys, which are a key data source to build activity-based models, do not account for enough details to understand short-term behavior or capture the extended time periods for long-term effects. Currently capturing the behavior mechanisms in the travel demand models, and integrating them with environmental and traffic safety models are the areas to explore. Information on traveler behavior is available via social networks, and modeling efforts are required to use them in building behavior patterns. The lack of general knowledge, difficulty in capturing and quantifying behaviors, and the inherent behavior modeling complexities are key challenges.

Figure 3-11: Traveler Behavior Modeling Framework



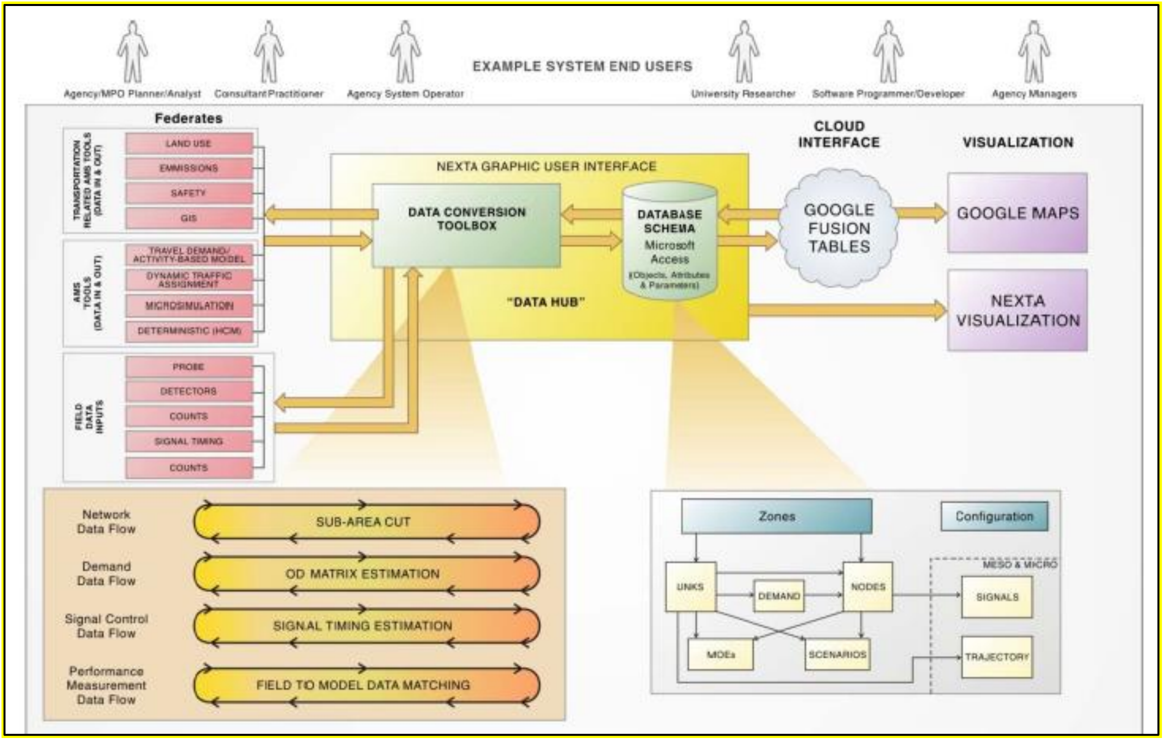
Source: Analysis of Network and Non-Network Impacts upon Traveler Choice: Improve Modeling Accuracy for Better Transportation Decision Making, submitted to FHWA by Northwestern University and SAIC, Inc., February 2012.

Recent Advancements in Integrated Modeling

Integration of AMS Tools

Under the recently completed Effective Integration of Analysis Modeling and Simulation Tools Project, FHWA has developed an open source data hub that enables efficient information exchange and data transfer between models of different domain and scale. A CONOPS report on effective integration of AMS tools was recently developed under this effort. The research and discussion on integration of AMS tools in this report has focused on increasing integration requirements for advanced ITS-related initiatives such as ATDM, ICM, and Connected Vehicles. The overarching idea proposed in this document is the development of an open source data hub with which current modeling practices can be integrated. Figure 3-12 depicts the AMS data hub architecture described in the CONOPS Report.

Figure 3-12: Data Hub Architecture Overview



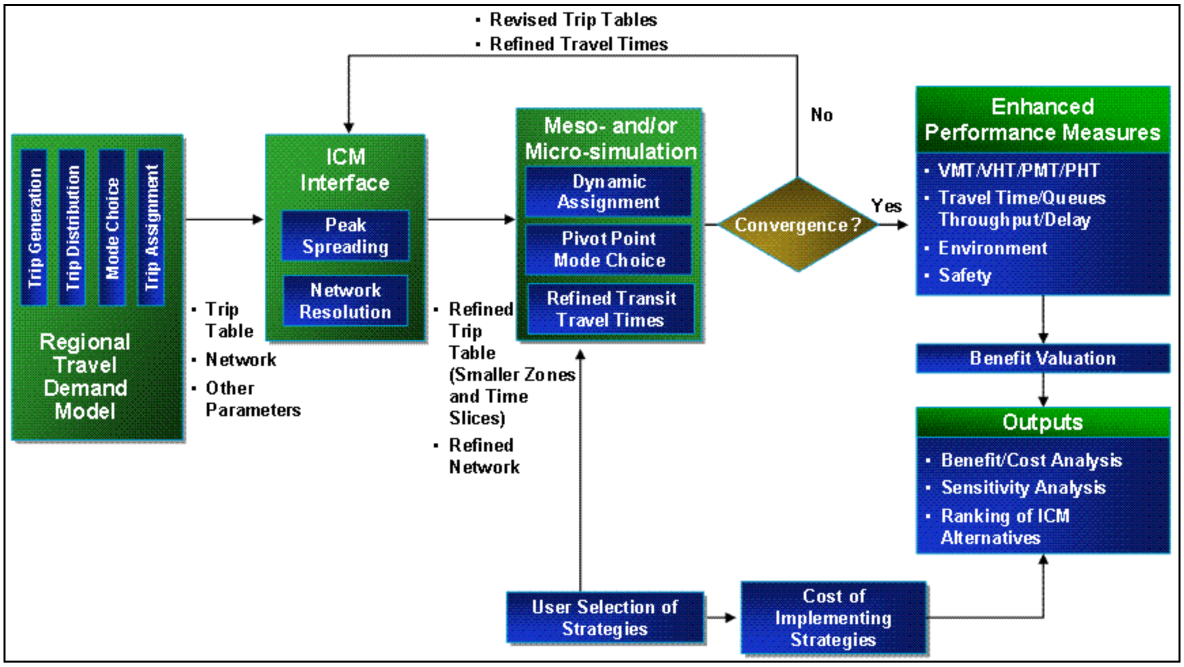
Source: Effective Integration of Analysis Modeling and Simulation Tools Concept of Operations for AMS Data Hub, submitted to FHWA by Kittleson & Associates, February 27, 2012.

The Federates component describes the challenges and possible approaches of integrating macroscopic, mesoscopic, microscopic, and Highway Capacity Manual-based analysis tools across geometrical and temporal dimensions. The issues of handling and exchanging data across different resolution levels of modeling have been addressed in the Data Conversion Toolbox component, whereas the Database Schema component charts out a guideline for a standard data structure that can be used across different model resolutions. The AMS Data Hub would be an open source entity with plenty of contributions expected from researchers and developers.

ICM AMS Approach

Recently 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 the impacts of ICM strategies was modeled. 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. The approach adopted for the test corridor analysis applies the AMS Methodology framework shown in Figure 3-13. 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.

Figure 3-13: Test Corridor AMS Framework



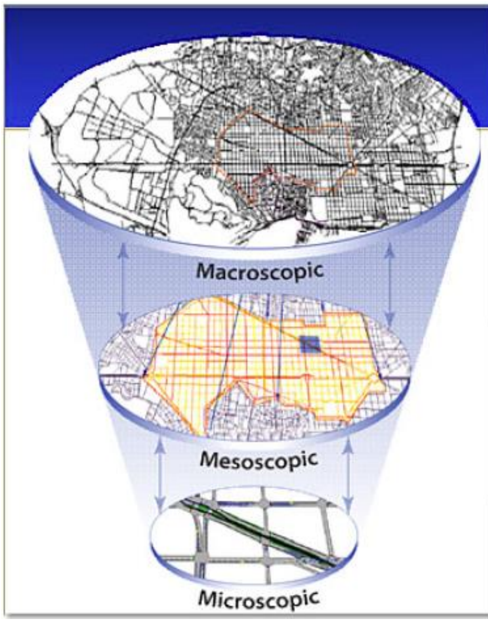
Source: Integrated Corridor Management Analysis, Modeling, and Simulation Experimental Plan for the Test Corridor, 2008, Published by FHWA.

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.[3]

A draft ICM AMS Guide report from May 2012 describes that the ICM AMS methodology includes macroscopic trip table manipulation for the determination of overall trip patterns, mesoscopic analysis of the impact of driver behavior in reaction to ICM strategies, and a detailed microscopic analysis of the impact of traffic control strategies. Figure 3-14 shows the integration of multiple tools selected for the analysis approach at each of the three ICM AMS pioneer sites.

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

Figure 3-14: Integration of AMS Tools at ICM AMS Pioneer Sites



	Minneapolis Minnesota	Dallas Texas	San Diego California
Macroscopic	Metro Model in TP+	North Central Texas Council of Governments Model (TransCAD)	TransCAD
Mesoscopic	Dynus T – supported by University of Arizona	DIRECT – supported by Southern Methodist University (SMU)	
Microscopic			TransModeler Micro

Source: FHWA ICM AMS Guide.

Recent modeling studies conducted to support ICM Pioneer Site evaluations (Source: FHWA ICM AMS Guide) attempt to link macroscopic, mesoscopic, and microscopic simulation models to capture the regional impacts of traffic operational improvements. AMS efforts in ICM site evaluations evaluate strategies such as traveler information, traffic management, HOT/HOV lanes, and transit management on performance measures such as mobility, reliability, emissions and fuel consumption, and cost-benefit ratio. The strategies tested in the preliminary AMS effort on ICM Dallas and ICM San Diego are summarized in Table 3-6 and Table 3-7, respectively.

Table 3-6: ICM Dallas US-75 Corridor—Modeled ICM Strategies and Operational Conditions

Scenario	Daily Operations – No Incident		Minor Incident		Major Incident		
Demand	**Med**	**High**	**Med**	**High**	**Low**	**Med**	**High**
Traveler Information							
Comparative, multimodal travel time information (pre-trip and en-route)	●	●	●	●	●	●	●
Traffic Management							
Incident signal retiming plans for frontage roads			●	●	●	●	●
Incident signal retiming plans for arterials			●	●	●	●	●
Managed Lanes							
HOT lane (congesting pricing)	●	●					
Express toll lane (congestion pricing)	●	●					
Light-Rail Transit Management							
Smart parking system						●	●
Red line capacity increase						●	●

Scenario	Daily Operations – No Incident		Minor Incident		Major Incident		
Demand	**Med**	**High**	**Med**	**High**	**Low**	**Med**	**High**
Station parking expansion (private parking)						●	●
Station parking expansion (valet parking)						●	●

Table 3-7: ICM San Diego I-15—Modeled Operational Conditions

Scenario	Year	Demand Class	Incident	DSS Operational	Probability (Percentage)
Baseline	2003	Typical Day	None	No	–
A	2012	High	None	No	34%
B	2012	Medium	None	No	16%
C	2012	Low	None	No	21%
D	2012	High	None	Yes	34%
E	2012	Medium	None	Yes	16%
F	2012	Low	None	Yes	21%
G	2012	High	Freeway	No	11%
H	2012	Medium	Freeway	No	6%
I	2012	Low	Freeway	No	8%
J	2012	High	Freeway	Yes	11%
K	2012	Medium	Freeway	Yes	6%
L	2012	Low	Freeway	Yes	8%
M	2012	High	Arterial	No	1.9%
N	2012	Medium	Arterial	No	0.9%
O	2012	Low	Arterial	No	1.2%
P	2012	High	Arterial	Yes	1.9%
Q	2012	Medium	Arterial	Yes	0.9%
R	2012	Low	Arterial	Yes	1.2%

Source: ICM: AMS, USDOT—Wunderlich, Noblis; Alexiadis, Cambridge Systematics.[4]

Strategic Highway Research Program 2 C10

The Strategic Highway Research Program 2 (SHRP 2) program is currently supporting two projects[5] (C10 A and C10 B) that attempt to improve modeling and network processes and procedures to address policy and investment questions described such as—

- Variable road pricing
- Ramp metering
- ITS strategies such as customer information on road conditions, travel time, and incidents

4 http://www.apta.com/mc/fctt/previous/2011tt/schedule/Presentations/session%209%20Wunderlich%20Integrated%20Corridor%20Management%20Analysis%20Modeling%20and%20Simulation%20(AMS).pdf.

5 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).

- 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)
- Bottleneck improvements (e.g., reduction in lane width to add a lane, geometric improvements to ramps)
- Shift to nonhighway mode.

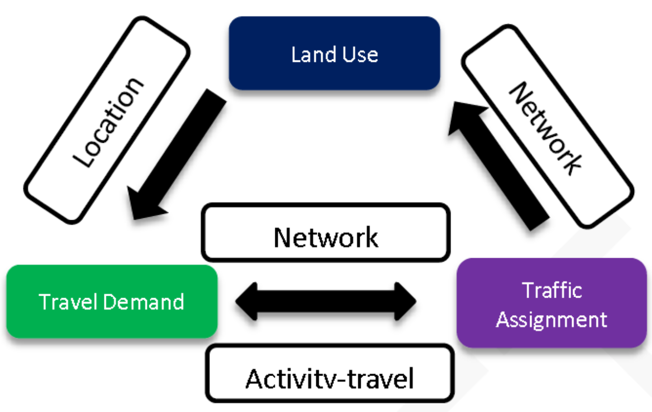
The primary objective of the SHRP 2 C10 project is to operate a dynamic integrated model for two public agencies and demonstrate its capabilities in a real-world environment on selected policies. The SHRP 2 C10 program's objective is to develop an integrated advanced travel demand model and a fine-grained, 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.

Simulator of Transport, Routes, Activities, Vehicles, Emissions, and Land : SIMTRAVEL

SIMTRAVEL (developed by Arizona State University and its university partners) is a universally applicable framework consisting of methods, tools and data structures that is designed to integrate land use modeling, activity-travel behavior modeling, dynamic traffic assignment and simulation. It is an open source framework that tightly ties together demand and DTA models. The interaction between the two models is as frequent as every minute. This type of integration has an advantage over sequential integration of demand and DTA models. SIMTRAVEL is a truly dynamic modeling framework. A good representation of the framework is the flow diagram in Figure 3-15.

Figure 3-15: Weather Responsive Traffic Management (WRTM) Framework



SIMTRAVEL comes with a set of tools that are available with the framework. These tools may be replaced with others available in the market if desired. This type of flexibility allows us to customize the framework with a set of tools that are more suited to our modeling needs.

The tools that are available within the SIMTRAVEL framework are the following:

- PopGen: Synthetic population generation model
- UrbanSim/OPUS: Land use microsimulation model system
- OpenAMOS: Activity-based travel microsimulation model system
- MALTA: Simulation-based dynamic traffic assignment model
- FAST-TrIPs: Flexible Assignment and Simulation Tool System for Transit and Intermodal Passengers

As mentioned earlier, in the SIMTRAVEL modeling framework, the multimodal activity-based travel demand model and the dynamic traffic assignment model (DTA model) are not linked together in a sequential fashion, but rather in a tightly coupled manner with constant communication between the activity-travel model and the DTA model. In this framework, trips are routed on the network as they are generated by the travel model with paths constantly updated based on prevailing conditions on the network. As conditions change, arrival times of travellers at destinations are influenced by path and travel time updates. The activity schedule that emerges is thus impacted by the network conditions along the course of a day. If an individual experiences congestion on the network, then he or she arrives late at a destination and this late arrival will impact subsequent activity-travel engagement. By having a constant communication between the activity-travel demand model and the DTA model, it is possible to reflect the impact of even slight changes in network conditions on activity schedules and patterns. Many dynamic actions/strategies are likely to bring about changes in network operating conditions during specific periods of the day, and the best way to reflect such impacts on activity-travel demand is to have a tightly integrated demand-supply model where the influence of the network conditions on activity scheduling is reflected along the continuous time axis as activity-travel choices emerge.

SIMTRAVEL is being currently applied and tested for the Maricopa County, Greater Phoenix region simulating a total of 14–15 million trips in the base year. The modeled region was a subarea comprising of City of Chandler, Town of Gilbertt and Town of Queen Creek. The area has a population of 505,350 persons residing in 167,738 households. The area was divided into 159 TAZs. The test application included background traffic from O-D trip tables and activity-travel demand for synthesized households/persons of three-city region. It also included nonmandatory activity destinations, work locations and school locations. Recently, SIMTRAVEL was also used to simulate the impact of a temporary network disruption on activity-travel demand, thus demonstrating the efficacy of the modeling framework.

SHRP 2 L02

Reliability of travel time was researched in Project L02, “Establishing Monitoring Programs for Travel Time Reliability,” to create methods to monitor, assess, and communicate travel time reliability to end users of the transportation system. The travel time reliability is defined as the probability of nonfailure of the transportation system over time. A nonfailure is considered an event where actual time of arrival matches desired time of arrival within some buffer window. The length of buffer window depends on the trip constraints and penalty at the destination. A guidebook describing how to develop and use a Travel Time Reliability Monitoring System (TTRMS) was developed as one of the deliverables of the Project L02. L02 focused on how to measure reliability, how to understand what makes a system unreliable, and how to pinpoint mitigating actions. The TTRMS relies on the TMC to gather the sensor data, manage the data processing and storage, and communicate the results of its findings to the outside world. The TTRMS focuses on using the incoming sensor data, along with supplemental information about the influencing factors, and creates a credible picture of travel time reliability. The TTRMS ensures that the TMC knows how reliability will suffer if certain events take place. TMC team can manage the network's reliability in real time based on the up-to-date information about how variability in segment and route travel times varies in response to the actions taken. The TTRMS is intended to provide decision support by executing four key steps:

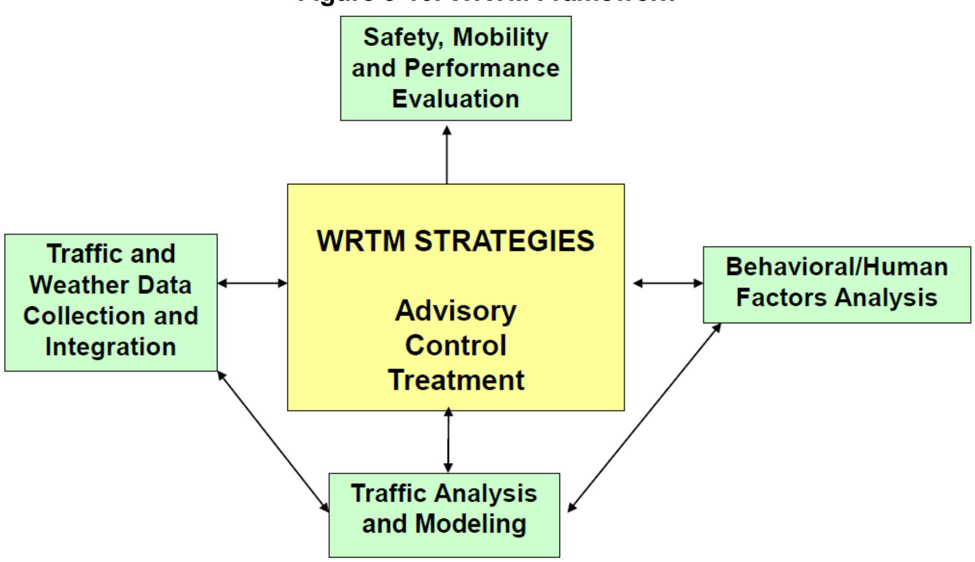
1. Effectively measuring travel times
2. Characterizing the reliability of the system
3. Identifying the sources of unreliability
4. Helping operators understand the impact of sources of unreliability on the system

WRTM

Recent updates in the behavioral models that are very important from an ATDM perspective are the impact of weather on driver behavior and travel demand. FHWA's WRTM aims to develop, promote, and implement strategies and tools to mitigate weather impacts through a better understanding of weather impacts on traffic flow and operations.

Figure 3-16 depicts the underlying framework of WRTM where human factors analysis and traffic modeling in conjunction with traffic and weather data evaluate WRTM strategies based on safety, mobility, and performance of the system. Macroscopic analysis at Minneapolis, Seattle, and Baltimore on traffic flow under inclement weather as part of an FHWA effort measures the sensitivity of traffic parameters such as free-flow speed, speeds at capacity, and capacity of the network based on weather conditions such as rain and snow.

Figure 3-16: WRTM Framework

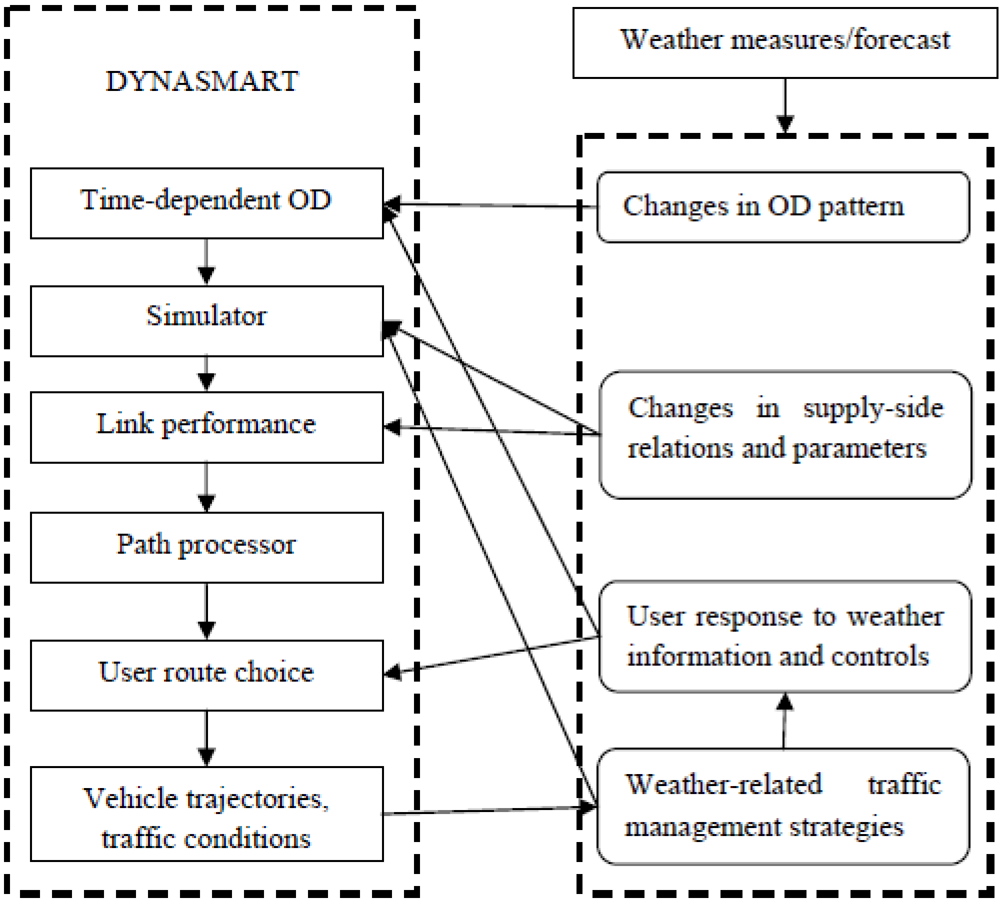


Source: Impact of Weather on Driver Behavior & Travel Demand: FHWA's initiatives, March 15, 2012.

Efforts to modify microscopic models such as car-following, gap acceptance, and lane changing to incorporate environmental impacts have been undertaken. For example, impact of icy roadway surface conditions on car following behavior and variability in driver behavior have been tested in

Japan using controlled field data. Recent work in incorporating weather impacts in traffic estimation and prediction systems (TrEPS) capture the effect of weather on traffic patterns by modifying the demand and supply sides in existing DTA tools. The conceptual framework is shown in Figure 3-17.

Figure 3-17: Demand- and Supply-Side Impacts of Adverse Weather



Source: Incorporating Weather Impacts in Traffic Estimation and Prediction Systems, Final Report, September 2009.

The framework assumes that the following elements on the supply side of the simulation are affected by adverse weather:

- Speed-density model for freeway sections and ramps
- Speed-density model for signalized arterials and unsignalized approaches
- Service rate and section capacities for freeways and ramps
- Saturation flow rates, section capacities, and turning service rates at signalized junctions
- Saturation flow rates and operational parameters at unsignalized junctions
- Operational characteristics associated with incidents and their impact
- Operational characteristics of work zones and other special events.

The demand side of the framework affected by adverse weather is assumed to be categorized into (1) those that affect the dynamic O-D patterns, and (2) those that affect the distribution of flows. The principal decision situations are modeled in DYNASMART by including new message types and their attributes. A new attribute associated with weather-related risk is included in the generalized cost.

Users with varying degrees of risk aversions thus choose their routes accordingly. When the estimation and prediction for a given horizon is completed under inclement weather, the predicted information provided by DYNASMART-X can be used for interventions by TMS operators in the form of traffic control actions or advisories.

The framework was tested on a network consisting of the I-95 corridor between Washington, DC, and Baltimore, Maryland, and bounded by two beltways. Three scenarios reflecting clear weather, moderate rain, and heavy rain were compared to illustrate the network-wide effect on road weather conditions. The proposed model can be used to evaluate weather impacts on transportation networks and the effectiveness of weather-related variable message signs.

Recent developments in Phase 2 of the TrEPS project focus on a decision support tool for identification of appropriate WRTM strategies and integrating the knowledge from simulation outputs from various scenarios into deployment decisionmaking. This framework is along the lines of ATDM needs, and thus the WRTM DSS can be a component of the ATDM DSS.

Ability to Model Individual Strategies

Table 3-8 describes the different ATDM strategies and how they impact different elements of the trip chain.

Table 3-8: Influence of ATDM Strategy on Elements of Trip Chain

		Trip Chain Affected				
No.	**ATDM Strategy**	**Destination Choice**	**Time-of-Day Choice**	**Mode Choice**	**Route Choice**	**Lane/Facility Choice**
Active Demand Management (ADM) Strategies						
1	Dynamic Ridesharing	◔	◔	●	◑	●
2	Dynamic Transit Capacity Assignment		◑	●		
3	On-Demand Transit	◔	◔	●		
4	Predictive Traveler Information	◑	◑	●	●	●
5	Dynamic Pricing	◑	●	●	●	●
6	Dynamic Fare Reduction		◑	●		
7	Transfer Connection Protection		◑	●		
8	Dynamic HOV Conversion		◑	●	◔	●
9	Dynamic Routing			◔	●	

		Trip Chain Affected				
No.	ATDM Strategy	Destination Choice	Time-of-Day Choice	Mode Choice	Route Choice	Lane/Facility Choice
	Active Traffic Management (ATM) Strategies					
10	Dynamic Shoulder Lanes		◑	◔	◑	●
11	Dynamic Lane Use Control	◔	◔		◔	●
12	Dynamic Speed Limits		◔	◔	◑	●
13	Queue Warning		◔	◔	◑	●
14	Adaptive Ramp Metering	◔	◑	◔	◑	◔
15	Dynamic Junction Control		◔		◑	◑
16	Adaptive Traffic Signal Control		◔	◔	●	
17	Transit Signal Priority	◔	◔	◑	◑	
18	Dynamic Lane Reversal or Contraflow Lane Reversal			◑	●	●
	Active Parking Management (APM) Strategies					
19	Dynamically Priced Parking	◑	●	◑	◑	
20	Dynamic Parking Reservation		◑	◔	◑	
21	Dynamic Wayfinding		◑	◔	◑	
22	Dynamic Parking Capacity		◑	◔	◑	

Legend:

● – Strategy has a definite influence on the particular trip chain element.

◑ – Strategy has a probable influence on the particular trip chain element.

◔ – Strategy has only a possible influence on the particular trip chain element.

To evaluate ATDM strategies, it is important to be able to model/predict the impacts of dynamic actions on different elements of the trip chain. Provided below is description of strategies and current capabilities for evaluating the impact of specific strategies.

Dynamic HOV / Managed Lanes

This strategy involves dynamically changing the qualifications for driving in a high-occupancy vehicle (HOV) lane(s). HOV lanes (also known as carpool lanes or diamond lanes) are restricted traffic lanes reserved at peak travel times or longer for exclusive use of vehicles with a driver and one or more passengers, including carpools, vanpools and transit buses. The normal minimum occupancy level is 2 or 3 occupants. Many agencies exempt other vehicles, including motorcycles, charter buses, emergency and law enforcement vehicles, low emission vehicles, and/or single-occupancy vehicles paying a toll. In an ATDM approach, the HOV lane qualifications are dynamically changed based on real-time or anticipated conditions on both the HOV and general purpose lanes. Qualifications that can potentially be dynamically adjusted include the number of occupants (e.g., from 2 to 3 occupants), the hours of operation, and the exemptions (e.g., change from typical HOV operation to buses only). Alternatively, the HOV restrictions could be dynamically removed allowing general use of the previously managed lane.

In the past, HOV lanes have been the focus numerous research efforts and implementations of congestion mitigation strategies. In a continued attempt to increase the efficiency with which people and goods move through the system, more recent efforts have been centered on increasing the efficiency, measured in people throughput, with which HOV facilities are being operated. Toward this end, the transportation community has undertaken two distinct approaches: (1) restriction adjustments and (2) the use of a variable pricing mechanism.

During the early implementations of HOV lanes, a majority of these facilities permitted only vehicles with two or more individuals to use these facilities. However, now there are a larger number of HOV facilities that attempt to increase people throughput by increasing the number of occupants per vehicle and diversifying the types of vehicles that can use the facilities, without meeting the occupancy requirements. These vehicles include motorcycles and low-emission vehicles such hybrid, electric, and those use other alternative low emission fuels. Although requirements generally make HOV facilities rather static, there are facility managers that introduce dynamicity to these facilities by only applying these rules to specific time periods.

As for the variable pricing mechanism that has been used to increase the people throughput of our transportation system, a number of facility mangers have converted HOV facilities to HOT facilities. The central principle behind HOT facilities is to layer a pricing scheme on top the preexisting HOV requirements. This pricing scheme now allows vehicles that do not meet the HOV's preexisting requirements to pay a user fee to use the facility. This user fee, in most instances, is dynamic and increases with the number of vehicles using the facility. This relationship is geared toward enabling the HOV/HOT facility to maintain a high level of service, relative to the general purpose lane.

Both approaches to HOV implementations involve some level dynamicity and have been thoroughly studied and modeled in a number of microscopic traffic simulation packages, such as AIMSUN, Paramics, and VISSIM, and in a number mesoscopic models including DYNASMART. Modeling strategies similar to that of dynamic HOV conversions have been evaluated. However, for an ATDM strategy, it is envisioned that such facilities will be even more dynamic. For instance, instead of merely applying and enforcing HOV/HOT policies and requirements strictly based on a time-of-day plan, these rules are to be enforced based on real-time and predicted performance measures.

Dynamic Pricing

This strategy utilizes tolls that dynamically change in response to changing congestion levels, as opposed to variable pricing that follows a fixed schedule. In an ATDM approach, real-time and anticipated traffic conditions can be used to adjust the toll rates to achieve agency goals and objectives.

Dynamic roadway pricing may be considered as the evolution of toll roads, particularly for regions experiencing high levels of congestion. However, this evolution is not yet complete as many of today's roadway pricing strategies are largely "dynamic" in the sense that the fee to access these facilities changes from one time period to the next but remains static in each time period; this is better termed *static variable pricing*. These changes in fees are also predetermined according to a particular schedule. For most implementation of static variable pricing strategy, the fee schedule varies by time of day and by day of week, limiting the strategy's ability to be truly dynamic. However, there are a few examples that do employ dynamic roadway pricing schemes.

To date there have been a relatively limited number of roadway pricing schemes. These schemes often take one of two forms: (1) charging a fee to access a particular area, typically a central business district, or (2) charging a fee to use a facility. Examples of implementations that charges fees to enter a designated area are typically found overseas. A few of the more notable implementations of this form of pricing strategy are found in London, Milan, Singapore, and Stockholm—all of which employ static variable pricing. As for implementations that charge a fee to use a particular facility, examples include I-25 in Denver; SR-91 in Orange County, California; and I-10 in Houston. These three pricing implementations also use a static variable pricing strategy. Implementation along I-15 in San Diego, I-95 in Miami, I-680 in San Jose, and I-394 and I-35 in Minneapolis charge a fee to use facilities but employ a dynamic pricing that depends on real-time traffic data.

As facility managers continue to improve implementations of dynamic roadway pricing, researchers are also continuously looking to fine-tune their modeling in simulation environments such as VISSIM, Paramics, and TransModeler, which have been able to evaluate pricing algorithms. Researchers have been able to use VISSIM's COM interface and its dynamic toll price model to evaluate the effect of dynamic price strategies on traffic operations. Similarly, Paramics is able to evaluate dynamic roadway strategies using its API to implement dynamic pricing strategies into a traffic simulation model. On the other hand, researchers have used TransModeler's own built-in dynamic pricing strategies to evaluate the effect on traffic performance[6]. This research and other work has highlighted the potential of model dynamic pricing strategies, but for an appropriate level of analysis in an ATDM implementation today's modeling tools require few additional capabilities.

Dynamic Fare Reduction

This strategy involves reducing the fare for use of the transit system in a particular corridor as congestion or delay in that corridor increases. This encourages selection of transit mode and reduces traffic volumes entering the corridor. Fare changes are communicated in real-time to the traveling public, through general dissemination channels such as the transit website, as well as personalized messages to subscribers. In an ATDM approach, real-time and predicted highway congestion levels and/or the utilization levels of the transit system can be used to adjust transit fare in real-time to encourage mode shift necessary to meet agencies goals and objectives.

To date, the ability for a transit agency to implement a dynamic fare reduction strategy is rather difficult as it is very dependent on reliable and detailed information being delivered to the agency in real time. Today's transportation system is unfortunately not fully equipped to either extract or deliver such information to any entity interested in transportation systems information. Although there are

6 . Morgul, E. (2010). *Simulation based evaluation of dynamic congestion pricing algorithms and strategies* (Thesis, Rutgers).

opportunities to extract operation information from the transportation system, greater fidelity of such information will be needed to develop this dynamic transit pricing strategy. The transit agency will also have to have the necessary infrastructure adjust the pricing strategy accordingly in addition to being able to transmit the “new” fare strategy to its various stakeholders, via several media outlets. Elements of the communication infrastructure are already in place for a number of transit agencies, but greater maturity will be needed to implement the ATDM’s dynamic fare reduction strategy.

In terms of modeling the implementation of a dynamic transit fare strategy, today’s modeling technology is currently not able to model such a strategy in its entirety. This is largely due to the various components of the transportation system integrated in such a strategy and the inability for today’s modeling tools to represent the complex relationship among these various components. For instance, there are tools and algorithms available to successfully model transit operation, including fare change and the potential impacts on the transit and the transportation system as a whole. One such algorithm is presented by Zureiqat, H., *Fare Policy Analysis for Public Transport: A Discrete-Continuous Modeling Approach Using Panel Data* (thesis, Massachusetts Institute of Technology), in which the author developed a framework that discretely model fares and continuously model frequency and level use to estimate ridership versus changes in fares. There are also tools capable of very successfully representing transit operations through the transportation network with high fidelity. These tool are usually microscopic traffic simulation tools such VISSIM and Paramics. However, when modeling the interaction of the components of the transit system with that of the traffic network, brought about by the transference of information from one network to the next, a possible change in mode choice results—that complex interaction is currently outside the ability of today model tool set. However, it is important to note that efforts in and outside of the transportation community are continuing to expand the ability of the available tools to incorporate these interactions. TRANSIMS was one of the earlier tools looking to holistically represent the transportation in such manner, but additional developments are required to model a dynamic transit pricing strategy.

Dynamic Ridesharing

This strategy involves travelers using advanced technologies, such as smart phones and social networks, to arrange a short-notice, one-time, shared ride. This facilitates real-time and dynamic carpooling to reduce the number of auto trips/vehicles trying to use congested roadways.

This strategy currently exists in a number of forms but not yet in the form that will lead to immediate incorporation into an ATDM implementation. One of the limiting factors that inhibit this strategy from an ATDM implementation is the inability of today’s technology to model the ride-sharing concept, with high fidelity, and its impact on the transportation system.

An encouraging aspect of the dynamic ride-share strategy is that more than 20 real-world ride-share programs are in operation, according to the Nation Center for Transit Research at the Center for Urban Transportation Research at the University of South Florida. It is further encouraging that a number of these programs are able to align rides within 10 to 15 minutes. Although not as dynamic as the ATMD system would like, it is anticipated that within the near future, given the prolific reach of mobile technologies, the time between requesting a ride will be closer to being more immediate than it is now. With that said, as the transportation community continues to develop tools to model dynamic ride-sharing and its effects on the transportation system, there will already be real-world test beds to further develop these models and increase their fidelity.

The tools available to model dynamic ride-sharing are very limited. To a large extent, today’s tools have only been able to model the operation of “carpool” vehicles in the traffic stream rather than the behavior or the traffic impacts of the entire dynamic ride-sharing concept. One of the closest efforts of simulating dynamic ride-sharing is the work presented by Kirshner, J. 2008, *Electronic “Instant” Ridematch and HOV Lane Time Savings: Simulation Modeling for the San Francisco Bay Bridge Corridor.* However, in this work the ride-sharing concept was modeled in the real world with a number of individuals “simulating” travels to and from various origins and destinations. This further underscores the lack of available modeling tools to fully explore the concept of dynamic ride-sharing.

Dynamic Transit Capacity Assignment

This strategy involves re-organizing schedules and adjusting assignments of assets (e.g., buses) based on real-time demand and patterns, to cover the most overcrowded sections of network. In an ATDM approach, real-time and predicted travel conditions can be used to determine the changes needed to the planned transit operations, thereby potentially reducing traffic demand and subsequent delays on roadway facilities.

Dynamic transit scheduling has been the focus of several research efforts, and a number of algorithms and models have been developed to explore this concept. Some of these efforts are showcased in *Schedule-Based Dynamic Transit Modeling: Theory and Applications* (Wilson, Nigel H. M.; Nuzzolo, Agostino, Eds., 2004) *and Schedule-Based Modeling of Transportation Networks: Theory and Applications* (Wilson, Nigel H. M.; Nuzzolo, Agostino, Eds., 2009). Dynamic routing has also been widely researched and a number of models developed. A few notable works include those presented in Quadrifoglio, L and Li, X. 2009, *A Methodology to Derive the Critical Demand Density for Designing and Operating Feeder Transit Services*; Transportation Research Part B: Methodological Volume 43, Issue 10; Alshalalfah, B., 2009, *Planning, Design and Scheduling of Flex-Route Transit Service*, Dissertation University of Toronto; and Fu, L., 2002, Transportation Research Board, Transportation Research Record 1791.

The concept of dynamic routing has been implemented, in conjunction with dynamic scheduling in the form of Demand Responsive Transport and, more generally, Flexible Transit systems. A rather comprehensive review of these systems is presented in *Operational Experiences with Flexible Transit Services—A Synthesis of Transit Practice,* TCRP Synthesis 53, by David Koffman. An number of the systems reviewed include those implemented by Capital Area Transit in Raleigh, North Carolina; Greater Richmond Transit Company in Richmond, Virginia; and Minnesota Valley Transit Authority in Burnsville, Minnesota. A third component of the dynamic transit service, real-time transit requests, have been somewhat approximated in the real world by instances of applying “dynamic ride-sharing strategies” and have been implemented in some of the aforementioned Flexible Transit Services but currently not as flexible nor as “real time” as the ATDM concept requires.

Despite the aforementioned individualized algorithms and models that have been developed and the various implementations of dynamically inspired transit services, there is not a comprehensive platform to evaluate and develop a transit service that is dynamic enough to be incorporated in an ATDM implementation. Although there are microscopic traffic simulation packages that are able to model the interactions of these transit vehicles with the rest of the traffic stream, there needs to be additional dynamicity and more detailed modeling of the traveler beyond what is available with today’s API.

Transfer Connection Protection

This strategy involves improving the reliability of transfers from a high frequency transit service (e.g., a train) to a low frequency transit service (e.g., a bus). For example, if the train is running late, the bus is held back so train passengers can make their connection with the bus; or providing additional bus services at a later time to match the late arrival time of the train. This ensures that the connections are not missed.

The foundation of an enhanced multimodal traveler information and trip planning system is available today. However, the components of such a system are at various stages of development. Some components are ready to be implemented in an ATDM environment while other are barely in their infantile development phase. One of the more developed components of such a traveler information system is the ability to receive accurate traveler information across the various modes. However, the ability to get multimodal traveler for is a single trip is rather limited. Today's state-of-the-art traveler information system is only capable of providing travel information of multimodal trip trips that involve walk and transit modes. Incorporating the other modes is yet to be realized primarily because traveler information of those modes, such as ride-share, are as yet to be developed to the point that they may be integrated with other modes of transportation and subsequently be part of a multimodal travel information system. One more developed and comprehensive application of a multimodal traveler information system is California PATH's Path2Go System (http://www.networkedtraveler.org).

In terms of modeling the operation and the impacts of a travel information system, today's modeling capabilities is still relatively limited. However, the work presented by Zhang et al. in *A Multimodal Transport Network Model for Advanced Traveler Information Systems* (2011) developed generic multimodal transportation network that makes use of transfer links to a form a "supernetwork." The Advance Traveler Information System (ATIS) algorithm that was developed incorporates a shortest-path search technique, the Dijkstra algorithm, and was evaluated using a multimodal transportation network based and the Eindhoven region in the Netherlands. The results from this evaluation indicated that the developed was a suitable basis for ATIS applications. This work indicates the ever-increasing potential to model such complex system.

Predictive Traveler Information

This strategy involves using a combination of real-time and historical transportation data to predict upcoming travel conditions and convey that information to travelers pre-trip and en-route (such as in advance of strategic route choice locations) in an effort to influence travel behavior. In an ATDM approach, predictive traveler information is incorporated into a variety of traveler information mechanisms (e.g., multi-modal trip planning systems, 511 systems, dynamic message signs) to allow travelers to make better informed choices.

The concept of predictive traveler information is heavily researched as it pertains to providing information to the traveling public. The goal of such a concept is not only to provide accurate information but also to provide sufficient and reliable data to travelers to influence their behavior.

Research efforts in this area have led to a number of models that are capable accurately of predicting relevant traveler information. A few of these notable efforts are Dong, J., H. Mahmassani, and C. Lu, *How Reliable Is This Route? Predictive Travel Time and Reliability for Anticipatory Traveler Information Systems* (2006) and Khan, A., *Bayesian Predictive Travel Time Methodology for Advanced Traveler Information System* (2010). In terms of simulating predictive traveler information, efforts have been concentrated on the use of microscopic traffic simulation, such as AIMSUN with its AIMSUN Online capability, Paramics, and VISSIM. However, when it comes to implementing these models one of the limiting factors is the large amount of high-fidelity data required to accurately predict traveler information.

An additional limiting factor to being able to analyze predictive traveler information for the purposes ATDM is the inability for today's modeling tools to represent traveler reaction to information regarding future traffic performance. However, a number of research efforts have explored this concept. *Understanding and Predicting Traveler Response to Information: Literature Review* (Lappin, J., and J. Bottom, 2001) provides a comprehensive synopsis of the work that has been done in this field. Efforts like this and others are all geared toward improving the transportation system and, in the nearer term, today's modeling.

On-Demand Transit

This strategy involves travelers making real-time trip requests for services with flexible routes and schedules. This allows users to request a specific transit trip based on their individual trip origin/destination and desired departure or arrival time.The ability to demand transit in real time is similar to the dynamic ride-sharing strategy outlined above. Therefore, based on the advancements made with dynamic ride-sharing (and dynamic transit service) the modeling challenges and potential are very similar to those previously mentioned.

However, a series of targeted research efforts have focused on on-demand transit. In this arena, this strategy is often referred to as *demand-responsive transit,* and substantial modeling and simulation work has been done related to this concept. One such work is presented in Lamonia, J. and Bhat, C., *Development of a Paratransit Microsimulation Patron Accessibility Analysis Tool for Small and Medium Sized Communities* (2009). The authors developed a GIS-based tool to analyze paratransit operation on a microscopic scale. Along these same lines, Josselin, D., N. Marilleau, and C. Lang presented "Modeling Dynamic Demand-Responsive Transport Using an Agent-Based Spatial Representation," which expanded modeling possibilities of on-demand transit. D. Yankov's *Discrete Event System Modeling of Demand-Responsive Transportation Systems Operating in Real Time* (2008) demonstrates a strategy that is rather similar to what is require for on-demand transit strategy for the ATDM concept.

Adaptive Ramp Metering

This strategy consists of deploying traffic signal(s) on ramps to dynamically control the rate at which vehicles enter a freeway facility. This encourages a smooth flow of traffic onto the mainline, allowing efficient use of existing freeway capacity. Adaptive ramp metering utilizes traffic responsive or adaptive algorithms (as opposed to pre-timed or fixed time rates) that can optimize either local or system-wide conditions. Adaptive ramp metering can also utilize advanced metering technologies such as dynamic bottleneck identification, automated incident detection, and integration with adjacent arterial traffic signal operations. In an ATDM approach, real-time and anticipated traffic volumes on the freeway facility will be used to control the rate of vehicles entering the freeway facility. Based on the conditions, the ramp meter rates will be adjusted dynamically.

The study of adaptive ramp metering has been one of the more recent traffic congestion mitigation strategies that has both been the focus of many research efforts and the strategy that have been implemented along the nation's highways to help combat the growing congestion problem. Adaptive ramp metering strategies have been implemented in Georgia, Oregon, California, and Minnesota, and these states have cited the benefits of such a system. However, the transportation community continues to research this strategy as greater efficiencies can be eked out of highway facilities. One of the primary means to increase the efficiency of highway operation via a ramp meter strategy is improving the fidelity of incoming traffic data that is being used to dictate how the strategy will adapt to changing traffic conditions. As technological advancements continue to make extracting more accurate traffic information possible, researchers are simultaneously fine-tuning their algorithms in simulated environments.

A number of simulated environments are capable of evaluating the effects of ramp metering algorithms on highway traffic operations. Two of the more prominent ones are Paramics and VISSIM. These two packages are used most often as they are not only able to accurately model traffic behavior but also to incorporate external algorithms, via their API, to affect simulated traffic behavior. *Design, Field Implementation and Evaluation of Adaptive Ramp Metering Algorithms UCB-ITS-PRR-2005-2 California PATH Research Report* presents one of the more comprehensive efforts in both modeling and analyzing the impacts of adaptive ramp metering strategies. Although the adaptive ramp metering strategy is one of the more developed tools for the ATDM concept, continued development is needed both in terms of the available algorithms and the modeling capabilities.

Adaptive Traffic Signal Control

This strategy continuously monitors arterial traffic conditions and the queuing at intersections and adjusts the signal timing dynamically to optimize one or more operational objectives (such as minimize overall delays). Adaptive Traffic Signal Control approaches typically monitor traffic flows upstream of signalized locations or segments with traffic signals, anticipating volumes and flow rates in advance of reaching the first signal, then continuously adjusting timing parameters (e.g. phase length, offset, cycle length) during each cycle to achieve operational objectives.

Adaptive signal control systems have been popular in the United States for a while even though they control less than 1 percent of all traffic signals in the country. These adaptive control systems include SCOOT, SCATS, RHODES, OPAC, ACS-lite, and TRANSYT. Each of these systems has its algorithms to determine signal timings, and each has its own merits. Adaptive traffic signal control systems are usually evaluated for their benefits in a microscopic simulation tool. The signal control algorithm can be coded into the control systems component of the simulator, and different adaptive control scenarios can be evaluated for their potential impacts. Simulation studies are carried out prior to the field deployment and test results.

Overall, adaptive traffic signal control has been well researched in terms of its impact on traffic conditions. However the strategy is heavily dependent on good reliable detection of traffic flow and speed. From the point of view of ATDM AMS, current simulation frameworks should be extended to simulate proactive use of adaptive controls to mitigate impending congestion. In extending today’s model capabilities, the research community will build on previous efforts that have successfully incorporated SCOOT and SCATS in microscopic simulation packages such as Paramics and VISSIM.

Dynamic Junction Control

This strategy consists of dynamically allocating lane access on mainline and ramp lanes in interchange areas where high traffic volumes are present and the relative demand on the mainline and ramps change throughout the day. For off-ramp locations, this may consist of assigning lanes dynamically for through movements, shared through-exit movements, or exit-only movements. For on-ramp locations, this may involve a dynamic lane reduction on the mainline upstream of a high volume entrance ramp, or might involve extended use of a shoulder lane as an acceleration lane for a two-lane entrance ramp that culminates in a lane drop. In an ATDM approach, the volumes on the mainline lanes and ramps are continuously monitored and lane access will be changed dynamically based on the real-time and anticipated conditions.

Dynamic junction control is implemented in Germany where lane control signs are installed over both upstream approaches before the merge, and priority is given to the facility with higher volume. The result is a more uniform traffic flow with less conflicting and safer maneuvers.

A pilot field test at Dieman interchange in the Netherlands showed promising results for the effectiveness of dynamic junction control in reducing trip delays and increasing average speed. Washington State DOT (WSDOT) conducted a study in 2007 to learn from the European experience and assess the potential benefits of ATM strategies including junction control. A microscopic simulation model was built in VISSIM for the I-405 and I-5 interchange to simulate the dynamic junction control strategy. The strategy algorithm was coded into the simulator, and test simulations were run at two intersections for peak traffic hours. A static compliance rate of 95 percent was assumed for the study.

There are no published studies researching the impact of dynamic junction control on improving traffic flow and increasing traffic safety. The strategy has been evaluated from field results or on simulation platforms. Research efforts are required to identify optimization algorithms that can be used to use dynamic junction control as an active management strategy.

Today's modeling tools are capable of accurately reflecting traffic operations after implementing a dynamic control strategy but with limited possibilities. Today's modeling capabilities lack algorithms to optimize traffic operations and the ability to appropriately model the associated impacts that will be necessary for the ATDM concept.

Dynamic Lane Use Control

This strategy involves dynamically closing or opening of individual traffic lanes as warranted and providing advance warning of the closure(s) typically through dynamic lane control signs, to merge safely traffic into adjoining lanes. In an ATDM approach, as the network is continuously monitored, real-time incident and congestion data is used to control the lane use ahead of the lane closure(s) and dynamically manage the location to reduce rear-end and other secondary crashes.

The HSR models can be extended to include dynamic closure and opening of other lanes of the network to simulate dynamic lane use strategy. Therefore, the challenges and opportunities for modeling the dynamic lane use control strategy, for the ATDM environment, are very similar to those presented in the priced dynamic shoulder lanes strategy (see strategy number 14).

Dynamic Routing

This strategy uses variable messaging to disseminate information to make better use of roadway capacity by directing motorists to less congested facilities. These messages could be posted on dynamic message signs in advance of major routing decisions. In an ATDM approach, real-time and anticipated conditions can be used to provide route guidance and distribute the traffic spatially to improve overall system performance.

Dynamic routing of vehicles using variable message signs to relieve congestion stress on the road network has been widely used as a traffic management strategy. Efforts to evaluate the impact of dynamic routing in alleviating congestion and finding the optimal ways of rerouting have been extensively undertaken in academia. The methodology in these efforts has invariably focused on use of microscopic simulation tools to model impact of dynamic routing advisories on the route choice of the driver. Past efforts have demonstrated the effectiveness of capturing the route choice process under dynamic routing conditions. However, human factors such as user acceptance and user trust are still external factors that are incorporated into these models via a few assumptions. An explicit detailed modeling component for human factors is required to complement the simulation modeling framework. Such an integrated AMS framework would be useful in meeting ATDM AMS objectives.

Dynamic Shoulder Lanes

This strategy enables use of the shoulder as a travel lane(s), known as Hard Shoulder Running (HSR) or temporary shoulder use, based on congestion levels during peak periods and in response to incidents or other conditions as warranted during non-peak periods. In contrast to a static time-of-day schedule for using a shoulder lane, an ATDM approach continuously monitors conditions and uses real-time and anticipated congestion levels to determine the need for using a shoulder lane as a regular or special purpose travel lane (e.g., transit only).

HSR may be activated for peak travel periods but may also be activated as a result of sustained congestion during off-peak periods. HSR may be accompanied by reduction in travel speeds (using variable speed limit operations) in the general purpose lanes. Signs provide dynamic indications that show the shoulder either being open or closed. HSR may also involve restrictions, for example, access only to HOVs, as well as limits on truck use. In some cases, HSR may be accompanied by dynamic pricing for single-occupancy vehicles as well as free access to HOVs (this concept is called *priced dynamic shoulder lanes* [PDSL]). An active traffic management strategy called *HSR* along with a pricing mechanism is called PDSL. HSR is an operational strategy which opens up access to the shoulder lane to temporarily increase freeway capacity under congestion conditions. HSR has been widely implemented in European countries and the empirical benefits of the implementation have been documented as a before and after scenario evaluation. In the United Kingdom, even potential economic impacts of HSR have been researched.

The simulation approach has also been widely used in assessing the HSR. HSR strategy was incorporated in the UK’s National Transport Model to conduct a comparative evaluation of expansion of HSR to other networks in the United Kingdom. The macroscopic was model was updated to include an HSR speed curve for modeling. In another study in the United Kingdom, HSR has been evaluated for its benefits on microscopic simulation platforms such as VISSIM and MIDAS. In January 2012, a deployment guideline for HSR was released as part of a trans-Europe project.

In the United States, a PDSL strategy has been implemented on a section of I-35 in Minnesota. The results for its operational benefits are not yet available. However, results from simulation case studies to test impact of peak-period shoulder lane use(a test corridor in Austin, Texas), are available a traffic safety study for FHWA has indicated some safety concerns regarding the speed differential between regular lanes and operational shoulder lanes. The speed differentials have been hypothesized to cause riskier lane changing maneuvers.

Overall, dynamic use of shoulder to temporarily increase freeway capacity has been widely used and empirical and simulation studies and results are available. The pricing algorithm in PDSL shall be analyzed in greater details to find the optimal pricing strategy for achieving ATDM goals. In doing, pricing algorithms, such as those used for HOV/HOT lanes (and any other manages lane strategy) will also be explored to continue the development of the PDSL strategy. In terms of simulating the PDSL strategy, many of today’s state-of-the-art traffic simulation packages are able to model PDSL on a somewhat ad hoc basic.

Dynamic Speed Limits

This strategy adjusts speed limits based on real-time traffic, roadway, and/or weather conditions. Dynamic speed limits can either be enforceable (regulatory) speed limits or recommended speed advisories, and they can be applied to an entire roadway segment or individual lanes. In an ATDM approach, real-time and anticipated traffic conditions are used to adjust the speed limits dynamically to meet an agency’s safety, mobility, and environmental goals and objectives.

The speed limit signs are placed in clear sight along the freeways and are operated from the Traffic Management Center based on certain operational rules. The roadside sensors keep track of average speed over the freeway. When these performance measures cross a certain threshold, speed limits are dropped as a measure to ease the traffic flow before onset of congestion. Similar dynamic speed limits are applied to delay onset of congestion under unfavorable weather forecasts. The operational rules for dynamic speed limits vary across cities. Some of these implementations are based on empirical field studies. One such program of field trials with Dynamic Speed Limits was conducted in the Netherlands from 2009 to 2010. Five field trials were conducted at four locations, and before and after scenarios were compared to observe the impact of dynamic speed limits. Changes in driving behavior, traffic flow characteristics, traffic safety, air quality, and noise levels were analyzed based on the data from loop detectors and video cameras. A user compliance study was also conducted.

Other approaches include simulation test runs in the laboratory to test the impact of the strategy in alleviating congestion or delaying its onset. Integration of a traffic simulation platform with an emissions simulation platform has also been used to study the impact of dynamic speed limits in reducing emissions. However, accurately modeling human factors in these simulation studies has been an area of concern. Empirical studies have been the most consistent way of assessing human factors, such as user acceptance and user trust in dynamic speed limits. Studies already show that travelers in European countries show more compliance toward speed limits than their counterparts in the United States. Human factors study would be a major area of development for this strategy in the ATDM AMS framework.

In general, today's modeling tools have been able to successfully implement the dynamic speed limit strategy in a simulated environment. Paramics and VISSIM are two of the more frequently used tools to successfully accomplish this. However, as previously mentioned, there is still a considerable amount to do, particularly with respect to modeling traveler behavior, before this strategy is mature enough to be evaluated in an ATDM environment.

Queue Warning

This strategy involves real-time display of warning messages (typically on dynamic message signs and possibly coupled with flashing lights) along a roadway to alert motorists to queues or significant slowdowns ahead, thus reducing rear-end crashes and improving safety. In an ATDM approach, as the traffic conditions are monitored continuously, the warning messages are dynamic based on the location and severity of the queues and slowdowns.

The benefits of queue warning include reduced trip delays and increased safety. Queue warning has not been assessed as an active management strategy with respect to its safety benefits because the safety benefits have not been quantified. However its implementation has been tested in the virtual world on simulation platforms such as VISSIM. A VISSIM model was created as part of WSDOT's I-405 Corridor Program to test impacts of several ATDM strategies. A queue warning algorithm was coded in the VISSIM model, via its COM interface. Simulation runs were able to demonstrate benefits of queue warning. Such microscopic simulation models could be adapted within ATDM AMS framework.

Transit Signal Priority

This strategy manages traffic signals by using sensors or probe vehicle technology to detect when a bus nears a signal controlled intersection, turning the traffic signals to green sooner or extending the green phase, thereby allowing the bus to pass through more quickly. In an ATDM approach, current and predicted traffic congestion, multi-agency bus schedule adherence information, and number of passengers affected, may all be considered to determine conditionally if, where, and when transit signal priority may be applied.

TSP has been thoroughly researched and extensively implemented across several transit agencies. A Planning and Implementation Handbook published by FTA in May 2005 provides in-depth information on planning, designing. and implementing TSP. Fine-tuning or using TSP as an ATDM strategy can be achieved by simulation techniques. There are several examples in academia where TSP has been assessed on a simulation platform to gauge its impact on traffic conditions. The selection of simulation platform depends on the capabilities and flexibility offered by the simulator. TSP strategy is incorporated into the simulation runs by coding in the signal priority logic in the signal control module of the simulator. Overall, this strategy has been very well researched, and capabilities exist to meet the ATDM AMS requirements. A few of the more notable simulation tools that have been used to effectively model TSP are AIMSUN Paramics and VISSIM.

Dynamic Lane Reversal or Contraflow Lane Reversal

This strategy consists of the reversal of travel directionality of lanes in order to dynamically allocate the capacity of congested roads, thereby allowing capacity to better match traffic demand throughout the day. In an ATDM approach, based on the real-time traffic conditions (e.g. incidents), the lane directionality is updated quickly and automatically in response to or in advance based on anticipated traffic conditions.

Dynamic Parking Capacity

This strategy involves the practice of dynamically increasing the capacity of parking facilities through technology based on demand. In an ATDM approach, the parking availability is continuously monitored additional parking capacity is needed.This strategy is typically implemented for some special events when an artificial temporary surge in parking capacity is warranted. Few direct studies demonstrate the effectiveness of adding parking capacity on traffic flows in the network. However, better modeling techniques that capture demand-supply interactions more effectively can be used to model the impact of this strategy.

Dynamic Parking Reservation

This strategy provides travelers the ability to utilize technology to reserve a parking space at a destination facility on demand to ensure availability. In an ATDM approach, the parking availability is continuously monitored and system users can reserve the parking space ahead of arriving at the parking location.

Few past studies have focused on capturing the impacts of dynamic parking reservation on network conditions, especially its effectiveness in reducing congestion. However, a few simulation-based academic studies have been conducted to evaluate the effectiveness of parking reservation systems in dispersing the travel demand temporally and spatially. These studies include the work presented in *Simulation Analysis on the Evaluation of Parking Reservation System* (Japan Working Paper Series No.08-2, 2008) in which the author, F. Kurachi modeled a parking reservation system based on users' responses to a questionnaire regarding a parking reservation system. These responses were then incorporated in a traffic simulation model.

Dynamic Wayfinding

This is the practice of providing real-time parking-related information to travelers associated with space availability and location so as to optimize the use of parking facilities and minimize the time spent searching for available parking. In an ATDM approach, the parking availability is continuously monitored and the user is routed to the parking.

The work presented in Beverly Kuhn and Debbie Jasek's *Enhancement and Outreach for the Active Management Screening Tool* (2002) delivers an insightful overview of a number of active manage strategies including dynamic wayfinding. Throughout the overview of dynamic wayfinding, not much implementation of this strategy was found in the simulation environment.

Dynamically Priced Parking

This strategy involves parking fees that are varied dynamically based on demand and availability to influence trip timing choice and parking facility or location choice in an effort to more efficiently balance parking supply and demand, reduce the negative impacts of travelers searching for parking, or to reduce traffic impacts associated with peak period trip making. In an ATDM approach, the parking availability is continuously monitored and parking pricing is used as a means to influence travel and parking choices and manage the traffic demand dynamically.

Dynamic priced parking has garnered attention of city planners in recent years. It has come forth as an effective way to affect the demand for parking spots and choice of parking location, which effectively affect the trip demand and route patterns. ExpressPark in Los Angeles is an example of a currently operating dynamic parking pricing program. ExpressPark uses a demand-based pricing strategy in which meter rates increase when and where demand is highest while maintaining lower hourly rates in areas with less demand. Data from in-ground vehicle detection sensors, along with rate, time limit, and operating hour information from smart parking meters, is used to analyze demand and determine pricing. Xerox offers a more sophisticated solution for dynamically priced parking that aims at consistently meeting parking occupancy targets. Xerox uses call center operations analogy to model telecommunications traffic to predict demand even when streets are fully occupied. Xerox models also exploit state-of-the-art choice models in marketing to capture the heterogeneity in people's preferences. Xerox uses these discrete choice models to predict value of a parking pricing structure to local drivers and businesses. Overall, the operating agencies leverage dynamic pricing for parking spaces as a tool to alter the trip demand as well as local route patterns.

Today's microscopic (VISSIM and Paramics) tools have the elements to model dynamically priced parking, though this often done through their APIs. Even with the flexibility offered via these APIs, today's model tools still lack the ability to fully model this strategy.

Summary

Evaluating traffic management strategies for their impact on traffic conditions is a critical step in the ATDM evaluation. It is necessary to help select the best strategy that can be proactively implemented to mitigate impending congestion or other undesirable network conditions. Defining the *best strategy* varies according to the objectives of the operating agency. While to support real-time operations, a DSS is needed to support selection of strategies in real time, a manual process for selecting the strategies will likely be sufficient for conducting a simulated real-time analysis for planning and design purposes.

Predicting traveler behavior and response of travelers to dynamic actions is crucial in evaluating the impact of various ATDM strategies. Activity-based models are theoretically best suited to predict travelers' 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, and eco-driving. The predicted traveler behavior changes must be interfaced with DTA and microscopic simulation 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.

Although the model structure of the activity-based model is technically sound, development of activity-based models is very expensive in terms of both time and resources. 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. Although most of the ATDM strategies have been modeled to some extent, the dynamic aspects of these strategies have not been modeled adequately.

Impact of environmental factors such as weather on driving behavior is one of the factors to be modeled in ATDM. The recent work in TrEPS in modeling weather impacts proved effectiveness of a modeling framework using DYNASMART and can be explored further.

In an operational context, DSS have been and are being developed and tested in transportation domain. The DSS examples most relevant to ATDM come from the ICM demonstration sites in San Diego and Dallas. Both these examples have built their own DSS framework supported by a network of real-time data communications and AMS tools. Under its Smarter Traffic effort, IBM also has developed a DSS framework to support active traffic management efforts. The IBM DSSO framework is very much relevant to the ATDM framework, as it incorporates response plans to mitigate undesirable traffic conditions as predicted in the traffic forecasts. Thus, the IBM DSSO aims to support proactive decisionmaking, which is at the core of the ATDM concept.

Existing modeling methods and tools can support the evaluating impact of strategies task of the ATDM framework. Relevant DSS frameworks are being developed under ICM and IBM. The operational results from their implementation and the lessons learned would be of high importance while charting out the DSS design for the ATDM framework. Table 3-9 summarizes the capabilities to assess the impact of ATDM strategies.

Table 3-9: Mapping of AMS Needs vs. Existing Capabilities to Asses Impact of Strategies

ID	AMS Needs to Assess Impact of Various ATDM Strategies	Existing Capability Description	Need vs. Capability Assessment
E.1	Identify of the ATDM strategy or a group of strategies to implement.	DSS capabilities being developed at ICM demonstration sites to support identification of best strategies to implement. Similar capability also offered by IBM DSSO.	●
E.2	Model impact of the ATDM strategy(s) on various elements of the trip chain	Activity-based models are capable of incorporating impacts of ATDM strategy. The capability depends on the type of ATDM strategy. Behavior models are currently not used widely to assess impacts of dynamic actions.	◔
E.3	Model microscopic driver behavior changes	This is a relatively well-established area with certain limitations, such as lack of rigorous modeling framework for driving behavior at microscopic level. However, developing microscopic simulation models for large regions continue to be a challenge.	◑

ID	AMS Needs to Assess Impact of Various ATDM Strategies	Existing Capability Description	Need vs. Capability Assessment
E.4	Model the demand-supply interactions resulting from implementation of ATDM strategies	Not fully tested for dynamic actions/management.	◔
E.5	Consider anticipated behavior changes to predict future performance	Behavior and human factors modeling to capture anticipated changes in traveler behavior is weak and not satisfactorily tested.	◔
E.6	Support multiple spatial and temporal extents of analysis (region, corridor, peak period, peak hour)	There are a few example of models spread across different geographic and time spans. However, none of these models have been rigorously tested for multimodal regional analysis.	◑
E.7	Validate the network performance conditions	Capturing behavior changes and the network-supply interactions resulting from dynamic actions is not fully understood	◔
E.8	Include visualization capabilities to display forecasted network conditions	Visualization capabilities to display network performance data is currently available.	◔

Legend:

● —Capabilities exist to mostly meet AMS needs.

◑ —Capabilities exist to partially meet AMS needs.

◔ —Not enough capabilities currently exist to meet AMS needs.

Chapter 4: ATDM AMS Needs-Capabilities Gap Assessment

Chapter 3: describes the existing AMS capabilities to support the needs of the ATDM AMS framework. As described, AMS capabilities can support several aspects of ATDM evaluation. However, some gaps exist. Key findings are summarized below.

4.1 Monitoring the System in Real Time

Capabilities for monitoring the system in real time have been explored in the past and have undergone significant improvement recently. Gathering data from sensors and using it in real time to compute preliminary performance measures such as traffic flow and average speeds has been done widely. However, to support advanced active traffic management initiatives such as ATDM, it has become imperative to integrate data collected from various resources in real time. The key challenges in this process include differences in data format, nonuniformity in geographical and temporal granularity of data, different data schema used by participating agencies, and addressing multimodality of trips. Also, the real-time data should be linked directly to the models/tools used for monitoring the system in real time.

Recent examples, such as ICM San Diego, ICM Dallas and IBM Smarter Traffic in Singapore, have worked towards leveraging data from various sources in real time to monitor the system. ICM Dallas even uses data with real-time access to transit operations for its AMS framework. These examples have demonstrated the application of their framework in monitoring the system in real time and could be used as a good starting point to expand real-time monitoring capability for ATDM. However, conscious efforts would be required to understand how the underlying uncertainties in field measurements and data analysis processes accounted for in this step. Also, more work is needed in capturing the weather, work zone, and incident data while monitoring the system. There has been some recent work in determining travel time reliability, but monitoring the traffic safety and vehicular emissions are still areas which require further research.

4.2 Assessing System Performance

In the recent past, assessing system performance in a moving future time window has been attempted. There have been a few applications in the industry to demonstrate the predictive components of modeling and simulation. Forecasting traffic conditions in the future time window has been done using mesoscopic simulation models where existing conditions are extrapolated to the forecast time window. This capability was demonstrated from the ATDM perspective on a macroscopic dynamic network loading model in the Edmonton Yellowhead Trail case study. ICM San Diego and ICM Dallas are also developing this capability as part of their respective AMS frameworks.

Assessing system performance in the anticipated future can be a computation-intensive task, and hence has been limited to macroscopic level analysis in the real-world demonstrations. However, computational constraints are not a binding factor for offline evaluation of ATDM. ICM demonstration sites are doing the work that is most relevant to ATDM, but the predictive components are incorporated only for evaluating impacts of ICM strategies. To enable the active management functionality of ATDM, it is essential to use these predictive capabilities in conjunction with standardized performance measures baselines to assess system performance in the anticipated future. IBM Smarter Traffic demonstration in Singapore includes a Traffic Prediction Tool that predicts some preliminary performance measures such as traffic volume and travel times within 10 to 60 minutes of moving time windows. Similar capabilities need to be developed for ATDM covering a broader spectrum of performance measures (e.g., safety) relevant to ATDM. Also, predicting the impact of ATDM strategies on the transportation system will require better understanding and modeling of human factors such as behavior and decisionmaking. Current behavior modeling would be required to improve on reliability and sensitivity of models. Since user behavior is a moving target that changes dynamically over time, behavior modeling shall be adaptive and able to learn from rapidly changing circumstances. Also, the heterogeneity of the user population needs to be better represented for high fidelity prediction of user behavior.

4.3 Evaluating Impact of ATDM Strategies

Evaluating impact of dynamic traffic management strategies will likely require modeling impact on every part of the trip chain that can be affected by the strategy. Activity-based models are theoretically best suited to analyze changes in activity patterns of travelers in response to traffic management strategies, but they are very expensive to build both in term of time and resources. Some of the ATDM strategies have been well researched and modeled; however, the dynamic aspect of implementation of these strategies still require further work. In the ATDM context, to support real-time operations, evaluation of ATDM strategies is likely to be done in conjunction with a DSS. A DSS in this instance is expected to generate a set of possible strategies or combinations of strategies (action plans) that could be implemented to tackle a particular scenario. This DSS capability is being developed under the ICM demonstration efforts in San Diego and Dallas. In these examples, a playbook of predefines response plans is created and the business/expert rules algorithms in the DSS generate a set of action plans relevant to the current situation. This process of creation of a playbook of response plans and a supporting DSS algorithm can be replicated for the ATDM AMS framework as well. To date, the dynamic supply/demand relationships have not been captured effectively. In particular, the likely response of individual travelers in response to dynamic actions is not well understood.

Evaluating impact of management strategies is being done for specific traffic management in the ICM frameworks. These examples use predictive simulation tools to model the impacts on trip chain. The predictive modeling component is strategy specific and needs to be researched and developed independently for the ATDM strategies.

Based on the capability assessment findings, the AMS needs versus capabilities gap assessment is described below.

Traveler Behavior

Traveler behavior is a reasonably well researched area with various approaches, such as the four-step demand model and activity-based models. However, more effort is needed in the following areas:

Sensitivity to Individual Dynamic Actions (ATDM Strategies)

Behavior models usually target long-term behavior in response to certain predefined or expected scenarios. The set of potential ATDM strategies and their deployment plans can vary over time. Hence, the behavior models in the AMS suite need to be sensitive to every ATDM strategy and capture the “dynamic” element of ATDM strategies. Although activity-based models are best suited to model traveler behavior at a fine level of detail, uncertainty exists regarding the modeled trip chains, as any unexpected changes can throw off entire activity schedules. Hence the activity models for ATDM must dynamically adapt to real-time changes in conditions, and a continuous and tighter integration between the demand/activity pattern estimation and traffic assignment is needed. The performance measures need to be sensitive to reflect dynamic changes in the stress levels across the system. Current active management systems such as the one used in ICM Dallas use static O-D patterns for evaluation purposes. The ATDM framework will consider how people adapt to the different strategies and the resultant effects (both short term and long term) on the O-D patterns. While identifying the impact of strategies, replication of sensors, their locations, data collection types, frequency of data collections, reliability and uncertainty of the collected data, break down periods, and so forth, should be explicitly modeled.

AMS functionalities required for ATDM would require a vast and rich pool of data. The desired pool of data should be able to meet the AMS demands on three levels: quality, quantity, and frequency. This will imply a shift from conventional point traffic data to new sources of data, such as from mobile trajectories and social networking sites, which is a step higher than the conventional data on all three levels. In addition, modeling efforts for ATDM are likely to make use of activity-based models that tie all transportation trips to a trip purpose or activity. These models will need data on different decision points during the trip.

Human Factors

To evaluate ATDM strategies accurately, user acceptance to particular strategies should be modeled adequately. User acceptance of strategy and behavior changes will vary greatly across the population and will be correlated with socioeconomic characteristics. The heterogeneity of the real-world population of travelers needs to be replicated in the AMS tools to achieve realistic predictions.

Predicting the impact of ATDM strategies on the transportation system will require better understanding and modeling of human factors such as behavior and decisionmaking. Current behavior modeling is required to improve on reliability and sensitivity of models. Since user behavior is a moving target which changes dynamically over time, behavior modeling shall be adaptive and able to learn from rapidly changing circumstances. For example—

- The activity-based models should be sensitive to ATDM strategies that might change the activity schedules altogether
- Behavior models should be responsive to dynamic changes in supply or network characteristics.

The heterogeneity of the user population needs to be better represented for high-fidelity prediction of user behavior. In addition, there are several inherent uncertainties in the daily decisionmaking, such as transit delays or change in the trip start time. Reliable predictions of ATDM impacts should account for these uncertainties in the underlying models. Current capabilities do not address this adequately.

Proliferation of personal mobile phone devices and GPS receivers on the vehicles over the past decade has opened another source of traffic data. This data is rich on individual trajectories and travel patterns. This information can be useful in identifying activity patterns for building activity-based models. Behavior models in the ATDM AMS framework need to utilize this data.

Real-Time Analysis/Simulation

Monitoring the system in real time will be a very computation-intensive task. In current practices of predictive real-time simulation, such as the framework used in the Yellowhead Trail case study, predictions are generated in real time based on macroscopic or mesoscopic simulation tools. The computational burden of microscopic simulation is too much to handle reliably. Although not a major constraint for simulated real-time analysis, as we move toward real-time transportation management, we need to overcome computational issues, and analyses needs to be completed several times faster than real time.

The real-time component of ATDM needs to accommodate simulation modeling for a variety of ATDM strategies in parallel. The capacity of performing simulation in parallel refers back to restructuring underlying models to achieve best results with existing computational capabilities.

Real-time analysis depends greatly on data collected from different resources and on the methodology of inferring performance metrics. A reliable data flow structure to continuously update performance metrics for the ATDM approach needs to be established.

The performance of real-time functionality depends on the geographic extension of the network and the resolution of simulation. ATDM strategies will also leverage higher amounts of incoming data as input to integrated traveler behavior models to support sophisticated decision support systems with minimum human interference. Current real-time analysis/simulation capabilities need to grow along with behavior models to address ATDM AMS needs.

Integration of Models

In the ATDM AMS framework, real-time monitoring of the system would rely on data collected from multiple sources, differing greatly in structure and geographical or temporal scale of availability. This leads to serious compatibility issues for integrating, cleaning, processing, analyzing, and archiving the data. Hence, a standardized framework for data collection, processing, and archiving needs to be established to facilitate the analysis.

Also the models are integrated sequentially in the current state of the practice if feedback loops between the demand and the traffic assignment tools. To capture the dynamic impacts of ATDM actions, in addition to feedback loops, constant communication from demand estimation and traffic assignment is needed to enable adjustment of activity patterns in response to current network conditions.

Performance Measures for Mobility, Safety, and Environmental Efficiency

In the ATDM concept, a variety of strategies are selected to meet mobility, safety, and environmental performance goals. Mobility and environmental efficiency can be indirectly measured in terms of average speeds/travel times or greenhouse gas emissions/fuel consumption per VMT, respectively. However, the question of how to measure safety has not yet been answered satisfactorily. The ICM demonstration in San Diego uses certain performance measures for mobility, safety, and environmental efficiency, which could be a good start for ATDM. However, a significant opportunity exists to define tractable and tangible performance measures that can be computed in real time.

Support for Integrated Multimodal Modeling

Highway and transit models should be better integrated to evaluate the impact that ATDM strategies have on mode choice. ICM Dallas AMS framework has a wide data collection network that integrates data from public transit and highway operations. It is not clear what extent of multimodal integration exists in the supporting models, but ICM Dallas might be a good starting point for integrated multimodal models for ATDM.

Capturing Supply/Demand Interactions

Capturing the impact of ATDM operations on network conditions will require high-fidelity modeling and understanding of supply and demand interactions. Currently ICM San Diego, ICM Dallas, and IBM have developed DSS frameworks that are highly relevant to ATDM needs. However, further enhancement is needed to support dynamic action of transportation systems using a variety of ATDM actions. As uncertainty in the real-time data propagates the framework to impact other components, reliable imputation methods will be key for removing uncertainties at the data level as much as possible. To replicate the uncertainty in the collected data even after the preliminary imputation and processing, a certain level of randomness appropriate of the data source will be added to the data before it is passed to other components of the ATDM framework.

The criticality of addressing the gaps referenced above with respect to ATDM AMS needs is summarized in Table 4-1.

Table 4-1: ATDM AMS Gaps Assessment Summary

AMS Capabilities-Needs Gap	Criticality to Address the Gaps	Actions Required
Sensitivity of behavioral models to ATDM strategies	High	Expand current behavior models to capture short-term impact due to dynamic actions. Also, provide mechanisms to model all parts of the trip chain, including destination choice, time-of-day choice, and mode choice.
Modeling user acceptance and user response to ATDM actions	High	Establish user acceptance of dynamic actions and their impacts in models. Also, expand existing models and tools to capture anticipated user response to ATDM strategies.
Integration of data from various sources	Medium	Develop accessibility to real-time data from supply side and include cell phone and other new data collection mechanisms.
Real-time simulation runs for multiple strategies in parallel	Medium	Optimize computational power to improve reliability of conducting multiple simultaneous simulations.
Integration of simulation models from different levels of temporal and geographical scale	Medium	Continue to test integrated modeling frameworks such as the SHRP2 C10 and SIMTRAVEL
Modeling uncertainty	Medium	Expand existing ways to model uncertainty in demand models, to incorporate uncertainties in data collection, response to ATDM actions and modeling error.
Multimodal analysis capability	High	Improve integration of highway and transit models to model ATDM strategies.
Commercial traffic simulator models are hard-wired and cannot be customized for specific scenarios or strategies	High	Enough guidance should be made available to allow user to develop APIs to override the default settings in the commercial tools (e.g., change the driving behavior and signal system operations specific to the strategy).

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Appendix A: List of Acronyms

Acronym	Definition
AAHSTO	American Association of State Highway and Transportation Officials
ADM	Active Demand Management
ADMS	Archived Database Management System
AMS	Analysis, Modeling, and Simulation
APM	Active Parking Management
aPeMS	Arterial-PeMS
ATDM	Active Transportation and Demand Management
ATIS	Advance Traveler Information System
ATM	Active Traffic Management
ATSC	Adaptive Traffic Signal Control
BRPMS	Business Rules Process Management Subsystem
BRT	Bus Rapid Transit
C2C	Center-to-Center
DSS	Decision Support System
DTA	Dynamic Traffic Assignment
GIS	Geographic Information System
GUI	Graphical User Interface
HOV	High-Occupancy Vehicle
HOV-2	High-Occupancy Vehicle with Two or More People
HOV-3	High-Occupancy Vehicle with Three or More People
Caltrans	California Department of Transportation
CEMDAP	Comprehensive Econometric Microsimulator for Daily Activity-Travel Patterns
CONOPS	Concept of Operations
DART	Dallas Area Rapid Transit
DMS	Dynamic Message Sign
DOT	Department of Transportation
DSSO	Decision Support System Optimizer
DTA	Dynamic Traffic Assignment
FHWA	Federal Highway Administration
GPS	Global Positioning System
HOT	High-Occupancy Toll
HSR	Hard Shoulder Running
LOS	Level of Service
ICM	Integrated Corridor Management
ITS	Intelligent Transportation System
MAG	Maricopa Association of Governments

Acronym	Definition
MIDAS	Micro-Analytic Integrated Demographic Accounting System
MORPC	Mid-Ohio Regional Planning Commission
MWCOG	Metropolitan Washington Council of Governments
NCTCOG	North-Central Texas Council of Governments
NYBPM	New York Best Practices Activity-Based Model
NYMTC	New York Metropolitan Transportation Council
NPS	Network Prediction Subsystem
O-D	Origin-Destination
PeMS	Caltrans Performance Measurement System
PDSL	Priced Dynamic Shoulder Lane
RAMS	Regional Arterial Management System
RITIS	Regional Integrated Transportation Information System
RNM	Road Network Modeler
SANDAG	San Diego Association of Governments
SFCTA	San Francisco County Transportation Authority
SHRP 2	Strategic Highway Research Program 2
SOV	Single-Occupancy Vehicle
TAZ	Traffic Analysis Zone
TDM	Transportation and Demand Management
TMC	Traffic Management Center
TMDD	Traffic Management Data Dictionary
TOPL	Tools for Operational Planning
tPeMS	Transit-Performance Measurement System
TPT	IBM Traffic Prediction Tool
TrEPS	Traffic Estimation and Prediction System
TSP	Transit Signal Priority
TTRMS	Travel Time Reliability Monitoring System
TxDOT	Texas Department of Transportation
UC	University of California
USDOT	U.S. Department of Transportation
VHT	Vehicle Hours Traveled
VMT	Vehicle Miles Traveled
WRTM	Weather-Responsive Traffic Management
WSDOT	Washington State Department of Transportation

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