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Integrated Corridor Management Analysis, Modeling and Simulation (AMS) Methodology

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16. Abstract

This AMS Methodologies Document provides a discussion of potential ICM analytical approaches for the assessment of generic corridor operations. The AMS framework described in this report identifies strategies and procedures for tailoring AMS general approaches toward individual corridors with different application requirements and modeling characteristics.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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1.0 Introduction

The objective of the Integrated Corridor Management (ICM) initiative is to demonstrate how Intelligent Transportation Systems (ITS) technologies can efficiently and proactively manage the movement of people and goods in major transportation corridors. The objectives of the "ICM – Tools, Strategies and Deployment Support" project are to refine Analysis Modeling and Simulation (AMS) tools and strategies, assess Pioneer Site data capabilities, conduct AMS for up to four Stage 2 ICM Pioneer Sites, and conduct AMS tools post-demonstration evaluations.

Efforts under this project focus on analyzing the ICM systems proposed by the Stage 2 Pioneer AMS Sites and evaluating the expected benefits to be derived from implementing those ICM systems. The overall benefits of this effort include:

- Helping decision-makers identify gaps, evaluate ICM strategies and invest in the best combination of strategies that would minimize congestion and improve safety;
- Helping estimate the benefit resulting from ICM across different transportation modes and traffic control systems; and
- Transferring knowledge about analysis methodologies, tools, and possible benefits of ICM strategies to the Pioneer Sites and to the entire transportation community.

The overall AMS effort includes the following tasks:

1. Identify AMS data needs and assess Pioneer Site capabilities.
2. Develop methodologies to model ICM strategies – the results of this task are summarized in this document.
3. Test and validate these methodologies in a test corridor. This will result in flexible, relevant methods for tractable, valid modeling of ICM concepts.
4. Use AMS methodologies and existing tools to model up to four Pioneer Site corridors. This will help identify cost-effective ICM strategies, and help prioritize ICM investments based on expected performance.
5. Validate methodologies and tools based on Pioneer Site demonstrations. The overall effort will result in validated and tested methodologies to support ICM analysis.

This ***AMS Methodologies Document*** provides a discussion of potential ICM analytical approaches for the assessment of generic corridor operations. The AMS framework described in this report identifies strategies and procedures for tailoring AMS general approaches toward individual corridors with different application requirements and modeling characteristics. This framework is based on the analysis of advantages and deficiencies of existing tools, and the identification of cost-effective and low-risk strategies to integrate existing tools into an internally-consistent and flexible system approach that is able to support various ICM functional requirements.

This document outlines a range of potential analytical approaches for the assessment of corridor operations, and includes a description of the proposed methodological approaches based on an assessment of existing types of tools and their potential enhancement. This document describes the specific recommended tools, deficiencies to be overcome, and how these tools can be improved to support the AMS methodology.

This document is not a guide on how to conduct AMS for Pioneer Sites. In Task 2.7, we will document the previously developed tools and strategies in a final report. The final report will document lessons-learned from the application of the AMS methodology on the test corridor, and will present the modified AMS methodologies. In addition to documenting the AMS methodologies, the documentation will include a categorization of AMS tools and interfaces to be used in different corridor settings; for different ICM strategies to be modeled; for different types of analysis scenarios; desired performance measures allowing for consistent comparison of ICM strategies; recommended validation/calibration steps and targets; the relative capability of the AMS activity to support benefit-cost assessment for the successful implementation of ICM; potential risks and applicability; and schedule/budget guidelines for ICM AMS activities.

This report is organized as follows:

- The remainder of **Chapter 1.0** outlines the principles guiding the development of the ICM AMS methodologies;
- **Chapter 2.0** provides definitions for existing AMS tools and assessments of these tools' abilities to model ICM strategies.
- **Chapter 3.0** presents a proposed structure for the corridor analysis approach, desired performance measures, how to take into account non-recurrent congestion, guidelines for the analysis of existing and future conditions, and expected output from the ICM AMS analysis efforts.
- **Chapter 4.0** presents the proposed AMS methodologies including model components (macroscopic travel demand models, and mesoscopic and microscopic simulation models), the representation of mode shift and transit, the representation of traveler information, the representation of congestion pricing strategies, and interface requirements;
- **Chapter 5.0** presents conclusions and next steps; and
- **Appendix A** presents additional options for the analysis of traveler information in ICM AMS.

1.1 Principles in Developing AMS Methodologies

A number of principles apply in developing and applying AMS methodologies. These are summarized as follows:

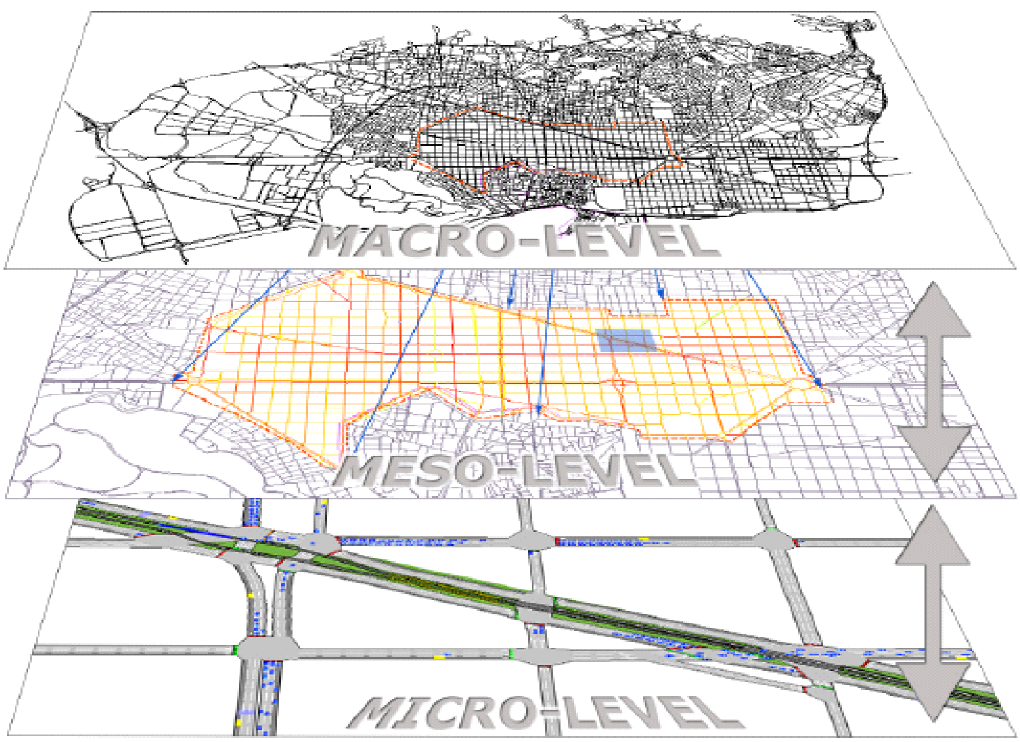
- **Resource and schedule constraint –** The overall ICM AMS effort must take place within the budget and schedule specified in the Scope of Work and Workplan. Data, models, and tools available at the Pioneer Sites will be leveraged in the AMS effort.
- **Focus on integration of existing tools –** The ICM AMS effort does not focus on developing new analytical tools; instead, it focuses on a relevant, meaningful application of **existing** modeling and simulation tools.
- **Recognize current limitations in available tools and data –** There are known gaps in existing analysis tools that the AMS methodology must bridge. Examples of these gaps include the dynamic analysis of transit and mode shift, and the dynamic analysis of ICM strategies such as traveler information or congestion pricing. Bridging these gaps requires the interface of existing analysis tools with different capabilities.
- **Be vendor-neutral –** Developed AMS methodologies and interfaces must be vendor-neutral and not favor one specific tool over other available tools. Interfaces developed under this effort must be universal enough to be able to function with the structure of major available tools used by transportation analysts.
- **Consistency of analytical approaches and performance measures –** ICM Pioneer Sites have different analysis tools at their disposal. The application of the AMS methodology to the various Pioneer Sites must be consistent in terms of analysis approach and performance measures. Consistency is necessary for a meaningful comparison of expected benefits resulting from the implementation of ICM strategies at the different Pioneer Sites.
- **Benefit-cost analysis –** Expected benefits resulting from the implementation of ICM strategies will be compared to expected costs to produce estimates of benefit-cost ratios and net benefits associated with the deployment of ICM strategies. This will help identify cost-effective ICM strategies, help differentiate between low-payoff and high-payoff ICM strategies, and help prioritize ICM investments based on expected performance.

2.0 Existing AMS Tools

At the outset of this effort, existing candidate ICM AMS tools were evaluated and compared for their ability to model ICM strategies; and for their input/output interface, usability, modeling features, and calibration requirements. Findings from this evaluation reveal that existing models share certain common features, but vary widely in their implementations and data requirements. Most existing tools do not fully integrate the *representation of transit services* with other auto-based traffic flow and facilities. Also, most of these tools are designed to model *recurrent* congestion conditions. Modeling *non-recurrent* congestion conditions requires integration with macroscopic travel demand models and possibly other special modeling techniques. Further, model computational *scope, efficiency, and complexity* are often closely related to the model resolution.

For the purposes of this evaluation, existing analysis tools were split in three general categories, including travel demand models, mesoscopic simulation models, and microscopic simulation models. Figure 2.1 presents a graphical depiction of the geographic scope and interrelationships between these tools.

Figure 2.1 Geographic Scope in Existing Traffic Analysis Tools



Definitions and assessments of these tool categories are provided here:

- **Travel Demand Models –** Predicting travel demand requires specific analytical capabilities, such as the consideration of destination choice, mode choice, time-of-day travel choice, and route choice, as well as the representation of traffic flow in the highway network. These attributes are found in the structure and orientation of travel demand models; these are mathematical models that forecast future travel demand from current conditions, and future projections of household and employment characteristics. Travel demand models were originally developed to determine the benefits and impacts of major highway improvements in metropolitan areas. Today, travel demand models are used in more wide-ranging tasks, including development of transportation master plans, evaluation of proposed land-use changes, initial design of transportation facilities, evaluation of air quality impacts, and assessment of future transportation needs. However, these tools were not designed to evaluate travel management strategies, such as ITS, ICM, and operational strategies. Travel demand models have only limited capabilities to accurately estimate changes in operational characteristics (such as speed, delay, and queuing), resulting from implementation of these operational strategies. These inadequacies generally occur because of the poor representation of the dynamic nature of traffic in travel demand models. Examples of travel demand modeling tools are CUBE, TransCAD, and EMME/2.

- **Microscopic simulation models –** Microscopic simulation models simulate the movement of individual vehicles, based on theories of car-following and lane-changing. Typically, vehicles enter a transportation network using a statistical distribution of arrivals (a stochastic process); and are tracked through the network over small time intervals (e.g., one second or fraction of a second). Typically, upon entry, each vehicle is assigned a destination, a vehicle type, and a driver type. In many microscopic simulation models, the traffic operational characteristics of each vehicle are influenced by vertical grade, horizontal curvature, and superelevation, based on relationships developed in prior research. The primary means of calibrating and validating microscopic simulation models is through the adjustment of driver sensitivity factors. Computer time and storage requirements for microscopic models are fairly large, usually limiting the network size and the number of simulation runs that could be completed. Because of the detailed representation of the traffic network found in these models and because of their ability to model traffic control strategies (such as ramp metering or traffic signal pre-emption), these tools are well-suited for modeling ICM strategies such as accommodating/promoting cross-network diversions. Examples of microscopic simulation models are VISSIM, Paramics, and AIMSUN.

- **Mesoscopic simulation models –** Mesoscopic models combine properties of both microscopic and macroscopic simulation models. As in microscopic models, the mesoscopic models' unit of traffic flow is the individual vehicle, and they assign vehicle types and driver behavior, as well as their relationships with the roadway characteristics. Their movement, however, follows the approach of macroscopic models and is governed by the average speed on the travel link. Mesoscopic model travel prediction takes place at an aggregate level, and does not consider dynamic speed/volume relationships as reflected in queue lengths and the temporal distribution of congestion. As such, mesoscopic models provide less fidelity than microsimulation tools, but are superior to travel demand models, in that, mesoscopic models can evaluate dynamic traveler diversions in large-scale networks. Examples of mesoscopic simulation models are Dynasmart-P, Dynasim, Transmodeler, and Dynameq.

Existing ICM AMS tools were evaluated for their ability to model ICM operational strategies, including information sharing/distribution; improving operational efficiency at network junctions and interfaces; accommodating and promoting cross-network diversions; and managing corridor demand and/or modifying capacity. Detailed definitions of ICM approaches and strategies are available in the ICM web site in the Phase I documents. Table 2.1 presents a summary comparison of travel demand models, microscopic simulation models, and mesoscopic simulation models.

Table 2.2 presents a summary evaluation of existing analysis tools' ability to model ICM strategies. In summary:

- Every tool type represents a tradeoff between geographic scope and level of resolution (scale vs. complexity). Less detailed tool types are tractable for large networks, while more detailed tool types are restricted to smaller networks. Depending on corridor size and the types of analyses required, all tool types are potentially valuable for ICM AMS.
- Microscopic and mesoscopic simulation models are capable of modeling traveler information strategies, while travel demand models do not have this capability. However, the limited geographic scale of microscopic simulation model implementations makes them less effective choices for traveler information evaluations that involve more than just changeable message signs. The most significant trip choices are made pre-trip or very early in longer trips, and mesoscopic simulation models are more effective than other tool types in evaluating pre-trip and en-route traveler information. Desired capabilities in ICM AMS are more than the capabilities found in existing tools.
- "Improve operational efficiency…" refers to system optimization strategies, such as freeway ramp metering and arterial traffic signal coordination. Microscopic simulation models are effective at analyzing these strategies. Mesoscopic simulation models are less effective, and travel demand models do not have this analysis capability.

Table 2.1 A Comparison of Existing Traffic Analysis Tools

	Travel Demand Models	Mesoscopic Simulation Models	Microscopic Simulation Models
Geographic Coverage	Regional network/ metropolitan area 	Subregional network 	Small subarea networks 
Demand	Static O-Ds	Time-dependent O-Ds	Dynamic O-Ds
Traffic Control	No signal setting or geometric information needed	Approximate signal settings & phasing schemes needed	Detailed signal settings & phasing schemes needed
Analysis	User equilibrium based on volume-delay functions	User equilibrium based on simulation-based dynamic traffic assignment	Behavioral modeling based on car-following of individual vehicles
Advantages	Available from local MPO; can analyze mode shift	Can analyze subregional dynamic diversion	Can analyze operational strategies, such as ramp metering and traffic signal coordination
Limitations	Not sensitive to operational strategies; not capable of analyzing regional dynamic diversion	Fairly new in the traffic analysis business; not capable of analyzing mode shift	Limited in geographic scope due to computational and calibration complexity

Table 2.2 Summary Evaluation of Existing Analysis Tools' Ability to Model ICM Strategies

Ability to Model ICM Approaches and Strategies	Microscopic Simulation Models	Mesoscopic Simulation Models	Travel Demand Models	ICM AMS Desired Capabilities
Information sharing/distribution	+	++	–	+++
Improve operational efficiency of network junctions and interfaces	+++	++	–	+++
Accommodate cross network route shifts	++	+++	+	+++
Accommodate cross network modal shifts	+	–	++	++
Response to congestion pricing	+	++	+	+++

+ The specific tool is much less capable of analyzing the relevant ICM strategy.
++ The specific tool is less capable of analyzing the relevant ICM strategy.
– The specific tool is not capable of analyzing the relevant ICM strategy.
+++ The specific tool is capable of analyzing the relevant ICM strategy.

- Travel demand models are better than other existing tools in estimating mode shift, but microscopic and mesoscopic simulation models are better at estimating route shifts. In fact, mesoscopic tools can estimate regional dynamic diversion of traffic, while microscopic tools can estimate route shift at a smaller geographic scale. Also all travel demand models are capable of analyzing mode-shift, while this capability is very limited in macroscopic simulation models and non-existent in mesoscopic simulation models.
- Finally, mesoscopic simulation tools are better at analyzing traveler responses to congestion pricing, but the ICM AMS desired analysis capability is more than what is offered by existing tools.

3.0 Performance Measures and Analysis Approach

The AMS methodology includes the capability to convert all impact/ performance measures to non-mode specific measures such as person trips. These mode-independent performance measures will be produced by an interface tool that can translate AMS model components outputs into non-mode-specific performance measure output. Since ICM is multimodal, the operational impacts need to be measures beyond the traditional network-based measures. The AMS framework outputs will be converted to performance measures, such as person travel time or trip reliability, in order to evaluate and compare operations among the alternative paths and properly portray the collective corridor-wide performance.

The AMS methodology is flexible enough to accommodate the analysis needs of corridors in a range of urban areas across the nation. For example, corridors in the nation's largest metropolitan areas may have broad and complex corridors served by multiple layers of transit operations. Corridors in smaller or developing markets may have simpler corridors with more limited transit operations. Certain types of analysis may not be relevant in particular jurisdictions, just as complex feedback between classes of analytical models may not be required in some corridors.

The performance and benefit-cost framework outlined in this chapter establishes traffic analysis goals and objectives; and sets expectations, needs, and issues related to the corridor study analysis performance measures, expected output, and project prioritization/cost-benefit requirements. The following objectives of this framework are to ensure that performance measures and analysis methods:

- Are consistent across different types of corridors, such as the ones described above;
- Are consistent across levels of analysis, including existing/future for short- and long-term strategies;
- Are consistent across different transportation modes; and
- Take into account recurrent and non-recurrent congestion.

This chapter presents:

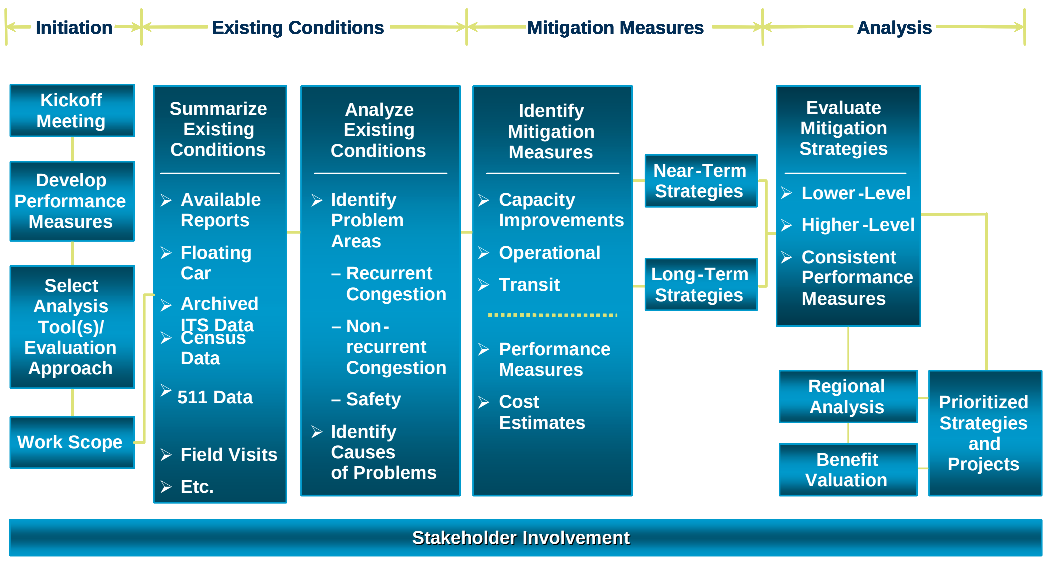
- A list of recommended *performance measures* for use in ICM AMS;
- A *framework to enable a consistent assessment* of existing conditions, application of performance measures, and analysis considerations;

- An *output format* for the ICM AMS corridor studies; and
- A *prioritization/cost-benefit framework*.

3.1 Corridor Analysis Approach

Figure 3.1 provides an overview of the ICM AMS corridor analysis approach. It describes the process that should be followed in the AMS of Pioneer Site corridors.

Figure 3.1 Overview of the ICM AMS Analysis Approach



The following steps are involved in this process:

- **Kickoff meeting –** In this meeting, the analysis team will establish communication channels, protocols, and data and information sources; discuss the scope of work, schedule, and budget; and obtain a thorough understanding of the goals for the analysis. Also in this meeting, appropriate performance measures and analysis tools will be selected for the corridor.
- **Data collection and analysis of existing conditions –** In this step, the analysis team will collect and analyze all information necessary to understand existing traffic conditions in the study area, and identify specific causes of problems. Data include the following:
  - ***Geometric data –*** Number of lanes on the freeway and parallel arterials; and basic geometric information, such as lane and shoulder widths, transit service, and configurations of key intersections on parallel arterials.
  - ***Existing traffic performance data*** for all modes, including peak-period traffic volumes on the freeway and parallel arterials, vehicle occupancies,

truck percentages, transit ridership, congestion data, delay data, travel time data, and accident and incident data.

– Information from ***corridor studies*** currently underway or recently completed to compile a list of projects and strategies that have been planned or programmed.

– A ***field review*** of each travel mode within the study corridor.

The data will be analyzed to determine causes of existing *recurrent* traffic congestion problems in the corridor. Locations of freeway bottlenecks will be identified, as well as other locations that may constitute mobility constraints in the corridor, such as freeway ramps or arterial intersections. The data also will be analyzed to quantify the magnitude of *non-recurrent* congestion in the corridor. The results of the existing conditions analyses will be summarized in an Existing Conditions Technical (ECT) memorandum. At a minimum, the ECT memorandum will include a description of the roadway and transit network, including a map showing the corridor study network; and a detailed description of existing traffic performance on the corridor with specific explanations of the causes of congestion problems.

- **Develop ICM strategies and projects –** In this step, the analysis team will refine the ICM strategies developed for the corridor. The proposed strategies will be segregated into short- and long-term implementation timelines, consistent with the Concept of Operations documents developed at Pioneer Sites. For the identified mitigation strategies, the analysis team will develop performance measures and prepare planning-level cost estimates. The list of strategies and projects then will be summarized in a technical memorandum.

- **Evaluation of congestion mitigation strategies and projects** – In this step, the analysis team will evaluate the ICM strategies and projects making use of AMS framework described in previous chapters. The analysis is intended to identify locations of freeway bottlenecks, changes in aggregate congestion levels in the corridor, and changes in peak-period travel times and delays. Based on the analysis, a prioritized list of recommended measures will be developed, including a narrative explaining the rationale for the prioritization. A technical memorandum will be produced summarizing the results of the analysis; and a prioritized list of ICM strategies, including recommendations for any modifications to proposed projects and strategies.

3.2 Performance Measures

This section provides details on the proposed performance measures to be used in the evaluation of ICM strategies. To be able to compare different investments within a corridor, a consistent set of performance measures should be used.

The following are primary objectives of the proposed performance measures:

- Provide an understanding of existing traffic conditions in the study area;
- Demonstrate the ability of ICM strategies to improve corridor mobility, throughput, reliability, and safety based on current and future conditions;
- Prioritize individual investments or investment packages within a given corridor for short- and long-term implementation; and
- Prioritize individual investments or investment packages among corridors based on cost-effectiveness and benefits to the corridor.

As much as is feasible, the primary performance measures should be reported for existing and future conditions, and should be easily calculated to evaluate any proposed improvement scenarios. To the extent possible, the measures should be reported by:

- **Mode –** Single-Occupancy Vehicles (SOV), High-Occupancy Vehicles (HOV), transit, freight, etc.;
- **Facility type –** Freeway, expressway, arterial, local streets, etc.;
- **Jurisdiction –** Region, county, city, neighborhood;
- **Corridor-wide;** and
- **Peak-periods and by hour of the day**.

The proposed performance measures focus on the following four key areas:

1. **Mobility –** Describes how well the corridor moves people and freight;
2. **Reliability –** Captures the relative predictability of the public's travel time; and,
3. **Safety –** Captures the safety characteristics in the corridor, including crashes (fatality, injury, and property damage).

Mobility

Mobility describes how well the corridor moves people and freight. The mobility performance measures are readily forecast, making them useful for future comparisons. There are two primary types of measures proposed to quantify mobility: 1) travel time and 2) delay. Other proposed measures that are commonly used to describe mobility are volume-based measures derived from distance and travel times, such as total vehicle-miles traveled (VMT), person-miles traveled (PMT), vehicle-hours traveled (VHT), and person-hours traveled (PHT). Person-hours of delay (PHD) can also be used as a mobility measure. Descriptions of these performance measures, including how they can be calculated and caveats surrounding their use, are provided below.

Travel Time

Travel time is defined as the average travel time for the entire length of the corridor or segment within a study corridor by facility type (e.g., mainline, HOV, local street) and by direction. Travel times should be computed for peak periods and by hour, and used in calibrating traffic analysis tools for AMS.

When developing real travel time data, any gaps in the detection system will have to be accounted for. In cases where there are very limited data, field observations, as well as input from local agencies, will have to be utilized to validate assumptions and analysis conclusions of the ICM study teams. Some additional data collection will have to be performed when critical to the analysis.

Where gaps exist in ITS system coverage, probe vehicle travel times can be used as being representative of the travel time over the gap. A field observation may also reveal that travel times over the section missing detection is at free-flow speeds – meaning that probe vehicle runs may not have to be done.

Travel times are inputs to the subsequent measures: delay and reliability.

Delay

Delay is defined as the total observed travel time less the travel time under non-congested conditions, and is reported as either vehicle-hours or person-hours of delay. Delays should be calculated for freeway mainline and HOV facilities, transit, and surface streets.

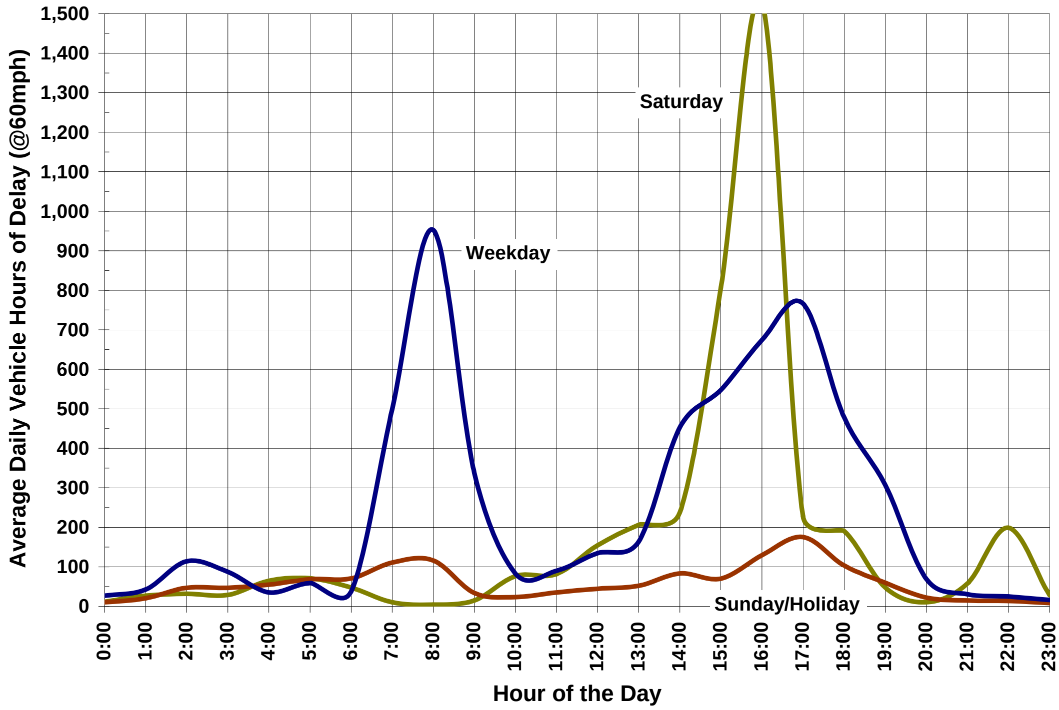
Many transportation agencies define the freeway congested speed threshold as 35 mph, because this is in the speed range at which traffic flow breaks down and becomes stop and go. Vehicles traveling at freeway speeds above 35 mph are not considered to experience any delay. Delay is calculated by using the following formula:

$$\left(\text{Vehicles Affected per Hour}\right)\times\left(Dis\tan ce\right)\times\left(Duration\right)\times\left[\frac{1}{\left(\text{Congested Speed}\right)}-\frac{1}{\text{35mph}}\right]$$

Many agencies use a freeway lane capacity 2,200 vehicles per hour per lane (vphpl). 2,000 or 2,200 vphpl are commonly used by engineers as the design capacity, or the bottleneck capacity of an urban freeway lane. Figure 3.2 shows an example summary of average daily delay on a hypothetical corridor.

For arterials and surface streets a similar threshold is needed to separate congested speed from free flow – the speed limit or the 85th percentile travel speed can be used to make the calculation applicable to arterials and surface streets.

Figure 3.2 Example Average Daily Delay by Day of Week and Time of Day



VMT, PMT and RPMT, VHT and VMT, and PHD

Vehicle and person-miles or hours traveled (VMT and PMT) and person hours of delay (PHD) are relatively straightforward calculations once travel times and delays are established. VMT is computed by segment by time period as the flow × the segment length. Along a corridor, multiple segment VMT can be summed to arrive at the corridor-level VMT. PMT is simply VMT × average vehicle occupancy. Where transit ridership and vehicle occupancy data are available, PMT can be calculated for a segment by multiplying ridership by distance. In this case, total PMT is:

(Total Autos) × (Segment Length) × (Average Auto Occupancy) +
(Total Transit Ridership) × (Segment Length)

If specific transit ridership is not available, PMT can be computed as:

(Total VMT) × (Average Vehicle Occupancy)

As with VMT, PMT can be aggregated from the segment level to the corridor level. It is advised to use household survey vehicle occupancy data with caution, since it is based on a sample size that may not be factored appropriately for corridor-level analyses.

PHD is computed by multiplying vehicle hours of delay times average auto occupancy. Autos should be computed as total vehicles less transit vehicles, if possible. For transit, estimate total transit ridership during the peak period and multiply it by delay per transit vehicle hours of delay, where applicable (i.e., distinguish between HOV and mainline speeds to use for transit travel times). If transit-specific data is not available, multiply vehicle hours of delay by average vehicle occupancy gathered from other sources.

A multimodal performance measure that can useful in ICM AMS is "Reliable PMT" (RPMT) – this measure can help summarize transit, arterial, and freeway performance into one measure that describes corridor performance. The "Reliable" part of RPMT can be derived by comparing the PMT for a certain scenario to a target maximum or optimal RPMT (RPMT*). This can be calculated analytically by loading a simulation network incrementally to some maximum throughput level before systemwide decline. An acceptable RPMT could then be defined as an RPMT that does not deviate more than x percent from RPMT*. RPMT is not an observable field measure; however, high RPMT is likely associated with values of observable field measures like travel time, travel time reliability, and bottleneck throughput.

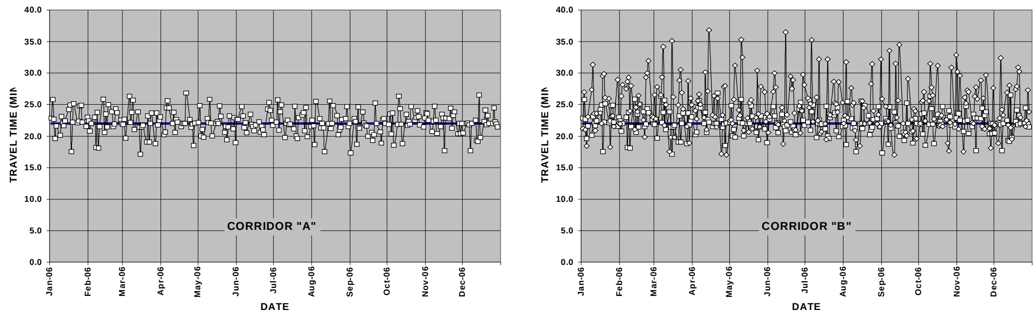
Reliability

Reliability captures the relative predictability of the public's travel time. Unlike mobility, which measures how many people are moving at what rate, the reliability measure focuses on how much mobility varies from day to day. Analysis techniques that can be used to forecast travel time reliability include the use of simulation models (e.g., performing multiple runs of the same forecast scenario, while adjusting flows and/or other input variables); or the ITS Deployment Analysis System (IDAS) methodology; or the Highway Economic Requirements System (HERS) methodology; or the TTI "buffer index" method.

To illustrate the importance of the reliability measures, Figure 3.3 shows two hypothetical corridors of the same length having the same average weekday travel time of around 22 minutes (i.e., they have the same level of mobility). However, Corridor "B" on the right side of the figure has a much wider day-to-day variation in travel time, and is less reliable than corridor "A." Even though they both experience the same ***average*** level of mobility, it is very likely that the travelers on Corridor "B" will remember those days where the travel time exceeded 35 minutes much more than the travelers on Corridor "A" will remember those few days where their travel time barely exceeded 25 minutes.

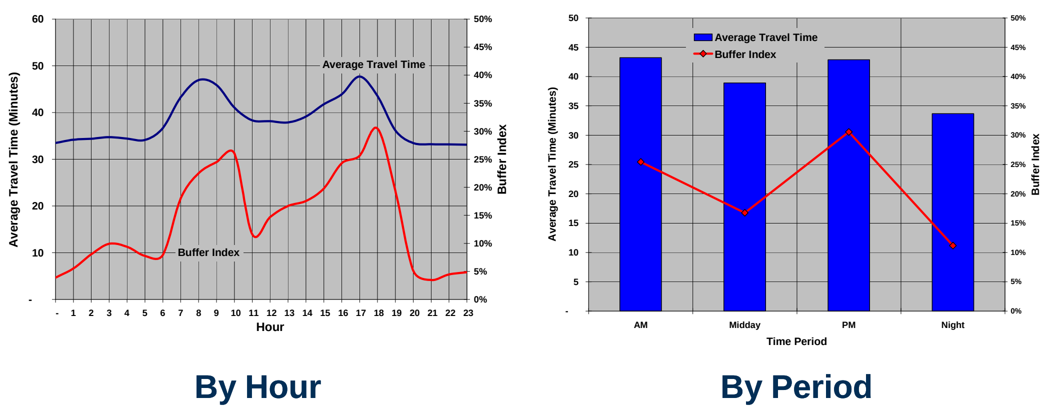
The "buffer index" method can be used to estimate reliability in conjunction with other measures, such as the standard deviation of travel time or using other percentile measures (e.g., the 85th percentile travel time). The buffer index is defined as the extra time (or time cushion) that travelers must add to their average travel time when planning trips to ensure on-time arrival. On-time arrival assumes the 95th percentile of travel time distribution.

Figure 3.3 Illustrative Difference Between Mobility and Reliability



The buffer index is fairly easy to communicate to the general public. It also is presented as a percentage, which makes it comparable among the different corridors and modes. Figure 3.4 illustrates two ways to present the buffer index. The first chart in the figure shows the average travel time and the buffer index by hour of the day. The second chart on the right averages the travel time over the four periods of the day (a.m., p.m., midday, and evening/early morning).

Figure 3.4 Different Ways to Present the Buffer Index



For example, a buffer index of 30 percent for a corridor of 10 miles has the same relative reliability as a 30 percent buffer index for a corridor of 20 miles. The FHWA has a web site with more detailed information on how to apply the buffer index for planning purposes and provides links to additional resources at http://ops.fhwa.dot.gov/publications/tt_reliability/.

To illustrate, a buffer index of 40 percent means that, for a trip that usually takes 20 minutes, a traveler should budget an additional 8 minutes to ensure on-time arrival most of the time:

Average travel time = 20 minutes

Buffer index = 40 percent

Buffer time = 20 minutes × 0.40 = 8 minutes

The average travel time can be estimated as described above in the travel time calculation discussion from above. The 95th percentile travel time can be obtained by sorting each day's travel time for the given hour. The buffer index is the difference between the 95th percentile travel time and the average travel time for the year divided by the average travel time:

$$BufferIndex = \frac{([95thPercentileTravelTime] - [AverageTravelTime])}{[AverageTravelTime]}$$

Safety

For the safety performance measure, it is suggested to use the number of accidents and accident rates from accident databases linked to highway databases. The highway database contains description elements of highway segments, intersections and ramps, access control, traffic volumes and other data. Accident databases contain specific data for accidents on state highways. Each accident record contains a ramp, intersection, or highway post mile; and includes other data, such as the following:

- Location;
- Time and date;
- Severity;
- Primary collision factor;
- Environmental information (e.g., weather);
- Roadway conditions;
- Type of collision;
- Number of vehicles involved;
- Party type;
- Condition of party;
- Actions of party; and
- Casualties per party.

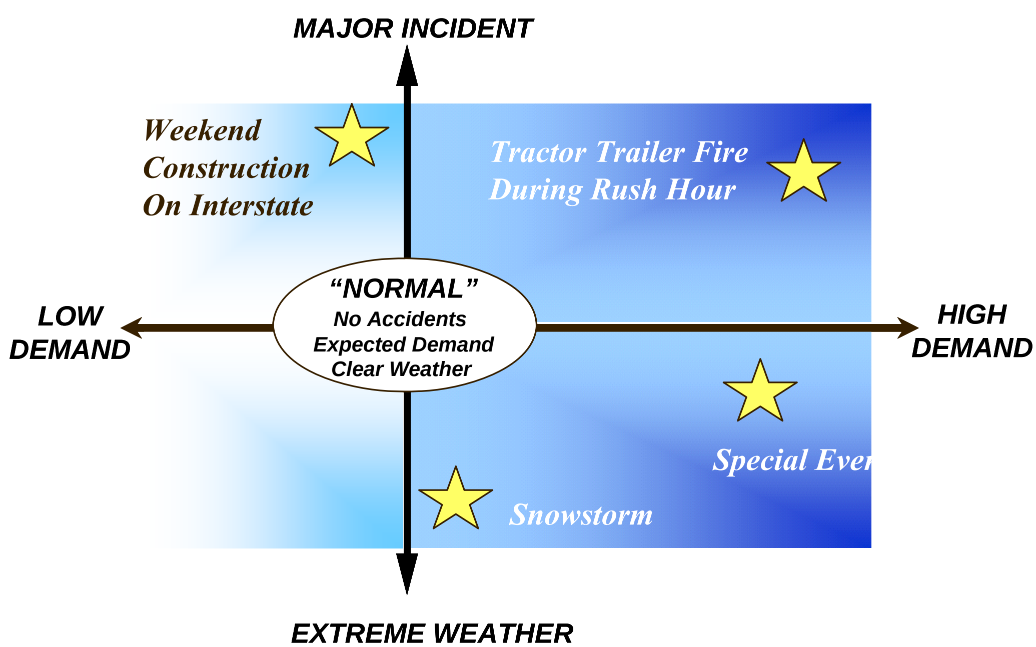
Safety is a fairly difficult measure to forecast. There are some tools available that estimate the potential reduction in accidents, given certain types of improvements. For the purpose of ICM AMS, safety analysis can be conducted qualitatively using expected levels of improvement in safety as a result of deploying mitigation strategies (e.g., major improvement, minor improvement, none, slightly worse, etc).

3.3 Analysis of Non-Recurrent Congestion

Collectively, all the tools in the ICM AMS framework are capable of supporting the analysis of both recurrent and non-recurrent corridor scenarios. The non-recurrent scenarios that will be supported include major and minor incidents (unplanned), special events, weather, and work zones. These non-recurring scenarios entail various combinations of increases of demand and decreases of capacity. The relative frequency of non-recurrent conditions is also important to estimate in this process – based on archived traffic conditions. Otherwise, resource allocation may be drawn towards highly unlikely events.

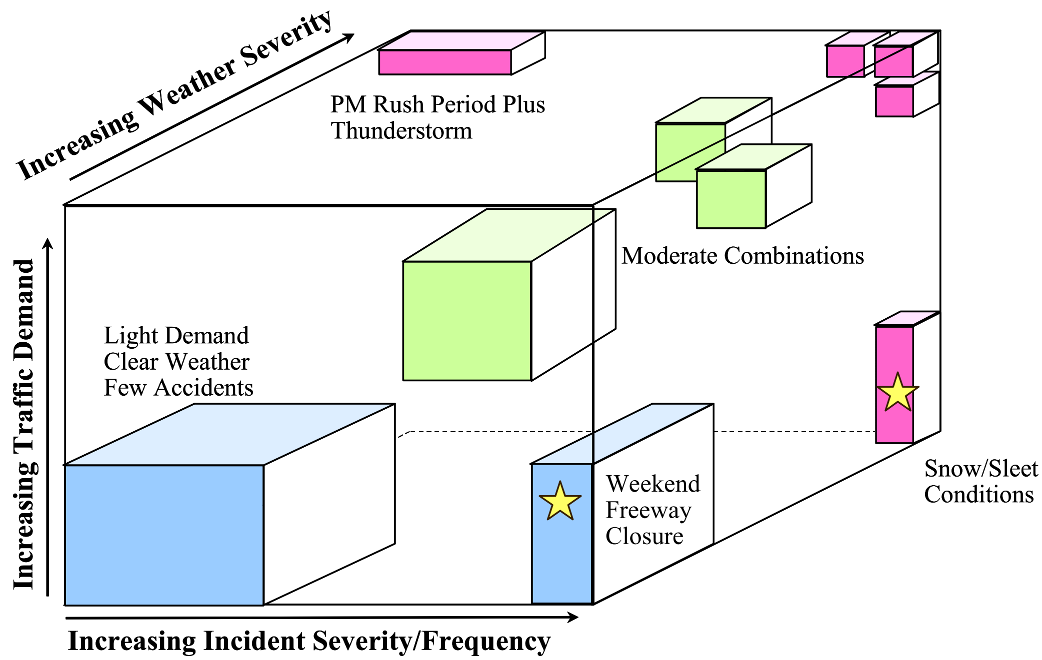
Figure 3.5 depicts this approach: key ICM impacts may be lost if only "normal" travel conditions are considered; the proposed scenarios take into account high and low travel demand, incidents, work zones, and weather conditions. These are sources of variation in the performance of the transportation system. Possible analysis scenarios are depicted in Figure 3.6.

Figure 3.5 Key ITS Impacts May Be Lost If Only "Normal" Conditions Considered



Source: Wunderlich, K., et al., Seattle 2020 Case Study, PRUEVIIN Methodology, Mitretek Systems. This document is available at the FHWA Electronic Data Library (http://www.itsdocs.fhwa.dot.gov/).

Figure 3.6 Sources of System Variation: Classifying Frequency and Intensity



Source: Wunderlich, K., et al., Seattle 2020 Case Study, PRUEVIIN Methodology, Mitretek Systems. This document is available at the FHWA Electronic Data Library (http://www.itsdocs.fhwa.dot.gov/).

3.4 ANALYSIS APPROACH – EXISTING CONDITIONS

This section outlines the general approach for evaluating existing conditions. There are "rules of thumb" that should be applied where possible:

- Use available collected data or field observations to characterize existing traffic conditions; and
- Define the study area and analysis timeframe so as to contain traffic congestion.

The timeframe for analysis should focus on weekday peak-period conditions. Weekends should be assessed where such an analysis would influence projects or strategies to be used, or where weekend conditions vary considerably from the weekday.

Peak-period analyses should be performed at a minimum, and hourly estimates should also be used where appropriate data are available. Mid-day and off-peak periods would be of interest, if data are readily available. If after an assessment of the availability of existing traffic data the study teams determine that data gaps exist, the analysis teams should make a recommendation for additional data collection.

In addition to corridor-wide performance for existing conditions, individual bottlenecks should be evaluated to determine their overall contribution to corridor congestion. Once bottlenecks are identified field observations need to be performed to determine and document the cause of the bottlenecks.

Existing and future corridor conditions should also be assessed for arterials in addition to freeways. Mean speeds and average traffic volumes can be used to describe arterial traffic performance, for both the baseline and mitigation strategies.

3.5 Analysis Approach – Future Conditions

Two analysis levels are recommended for the analysis:

1. First, in comparing alternatives, a low-level/screening analysis should be used to screen out non-viable alternatives; and
2. Second, viable alternatives that emerge from the screening analysis should be assessed using higher-level, more detailed analysis.

Analysis Timeframe

In conducting the analysis, the study area and analysis timeframe should be defined so as to contain congestion both spatially and temporally. The primary focus in ICM AMS traffic analyses is on peak weekday periods – not only peak-hour conditions. Weekends should be assessed where the analysis would potentially influence the selection of projects or strategies.

If assumptions need to be made for peak spreading in future traffic conditions, the analyst can check the reasonableness of future queues and travel demand, and make peak-spreading assumptions that would result in queues and delays that would be acceptable by the traveling public. The peak-spreading approach should be thoroughly documented and applied to both future baseline and alternatives so that benefits of the improvements can be demonstrated in a consistent way across alternatives.

Analysis of ICM Strategies

The identified ICM strategies will be segregated into short- and long-term implementation timelines. The identified strategies should then be grouped into analysis scenarios. Figure 3.7 shows the desired organization of analysis scenarios and results.

- At the start of the corridor analysis, an Existing Conditions Baseline will be established and calibrated to replicate observed traffic performance;
- Using travel demand model forecasts and model calibration characteristics identified in the Existing Conditions Baseline, future baselines will be established, including Future Baseline 1 (for a near-term future year) and Future Baseline 2 (for a longer-term future year);

- For each of the analysis, horizons analysis scenarios will be developed using short- and long-term ICM strategies; and
- For each scenario and for each performance measure, analysis results will be report absolute values and differences between each scenario and its corresponding baseline.

Figure 3.7 Example Analysis Scenarios

Analysis Timeframe	Baseline	Scenarios 1, 2, … (Separate Analysis	Difference in Performance Measures Between Baselines and Scenarios
Existing Conditions	Existing Baseline	Short-term ICM Strategies	
Near-term Future Conditions	Future Baseline 1	Mix of short- and long-term ICM Strategies	
Long-term Future Conditions	Future Baseline 2	Long-term ICM Strategies	

Cost Estimation

For the identified mitigation strategies, the analysis team should prepare planning-level cost estimates, including life-cycle costs (capital, operating, and maintenance costs). Costs should be expressed in terms of the net present value of various components. The analysis team can use consistent percentages for soft costs, such as design and contingency costs. Also, the FHWA Cost Database can be used to assist in producing capital and operating and maintenance (O&M) costs for ICM strategies.

3.6 Output

The output of each ICM corridor analysis should be a well written narrative of the identified problems and recommended solutions, and a clear and concise description of an implementation sequence and schedule for project and strategies for any given corridor. In addition to the narrative, output and reports should be graphical to the extent possible, and then tabular. Output performance measures must be consistent across corridor analyses, existing and future conditions, and mitigation strategies and scenarios.

Each corridor report should include the following chapters:

- **Corridor description –** A description of the corridor roadway and transit network, including a map showing the corridor study network and a detailed description of existing traffic performance on the corridor with specific explanations of the causes of congestion problems.
- **Analysis methodology –** A description of performance measures and methodology employed for corridor analysis, including assumptions, data and tools/models used, and model calibration characteristics.
- **Existing conditions –** Analysis results for existing conditions, including causes of existing *recurrent and non-recurrent traffic* congestion problems in the corridor, locations of freeway bottlenecks, and other locations that may constitute mobility constraints in the corridor, such as freeway ramps or arterial intersections.
- **ICM strategies –** A description of viable short- and long-term ICM strategies for the corridor.
- **Future conditions –** Analysis results for future conditions, including causes of future *recurrent and non-recurrent* traffic congestion problems in the corridor, changes in aggregate congestion levels in the corridor, changes in peak-period travel times and delays, and locations of freeway bottlenecks. For all identified mitigation strategies, analysis results for all performance measures and planning-level cost estimates.
- **Cost-benefit analysis** – A prioritization effort based on cost-benefit analysis providing a basic comparison of cost-effectiveness across all identified ICM strategies and projects. This analysis will estimate the economic value of project impacts, benefits, and costs in a consistent analysis framework. A possible method to be employed in this analysis includes IDAS.
- **Recommendations –** A prioritized list of recommended ICM strategies, including a narrative explaining the rationale for the prioritization. A summary of results of the traffic operations analysis and a prioritized list of congestion relief measures, including recommendations for any modifications to proposed projects and strategies.

4.0 AMS Methodologies

Three findings emerge from the analysis of capabilities found in existing AMS tools:

1. Each tool type has different advantages and limitations, and is better than other tool types at some analysis capabilities. There is no one tool type at this point in time that can successfully address the analysis capabilities required by the ICM program. An integrated approach can support corridor management planning, design, and operations by combining the capabilities of existing tools.
2. Key modeling gaps in existing tool's capabilities include: a) the analysis of traveler responses to traveler information; b) the analysis of strategies related to tolling/HOT lanes/congestion pricing; and c) the analysis of mode shift and transit.
3. Interfacing between travel demand models, mesoscopic simulation models, and microscopic simulation models presents integration challenges that can be addressed by identifying interface requirements that focus on: a) maintaining the consistency across analytical approaches in the different tools, and b) maintaining the consistency of performance measures used in the different tool types.

The proposed generic AMS methodology encompasses tools with different traffic analysis resolutions. Three classes of simulation modeling approaches – macroscopic, mesoscopic, and microscopic – are considered essential components of a general AMS methodology. To conduct the analysis of a corridor where ICM approaches and strategies may be implemented, the AMS capabilities need to provide for the interaction of various aspects of macroscopic-, mesoscopic-, and microscopic-level analysis capabilities.

The individual modeling approach developed for a specific corridor might involve significant tailoring of the general methodological approach. Depending on the scope, complexity, and questions to be answered within a specific corridor, there may be more or less emphasis on each of the three general model types and their interaction.

Developers of traffic analysis tools have recently started moving towards integration of analysis tools of various scales (macroscopic, mesoscopic, and microscopic) within one analysis framework. For ICM AMS purposes, there are two major limitations in this tool-specific integrated analysis approach:

1. This type of integrated "super model" is one size fits all. Pioneer Sites already have most models that are needed for ICM AMS – conducting the AMS in an integrated model framework would be more expensive than the

proposed approach and would take more time to implement, because a new super-model would need to be created from scratch for each Pioneer Site.

2. Many of the new commercially available integrated tools are too new as research concepts for practitioners to pursue now for ICM AMS. Many of these integrated tools have not been fully debugged and are frequently challenged when applied in complex settings.

Different ICM applications will call for different levels and forms of model integration. For example, assessing the operational efficiency at network junctions and interfaces requires the integration of mesoscopic and microscopic models; whereas, assessing modal shifts calls for the use of all three classes in a coherent manner (i.e., using macroscopic models for demand estimation, mesoscopic models for flow re-distribution, and microscopic models for traffic control optimization).

The proposed ICM AMS methodology will be adapted for and implemented on the Test Corridor. Emphasis has been placed on choosing a methodology that provides the greatest degree of flexibility and robustness in supporting subsequent tasks for the Test Corridor and AMS support of Pioneer Sites.

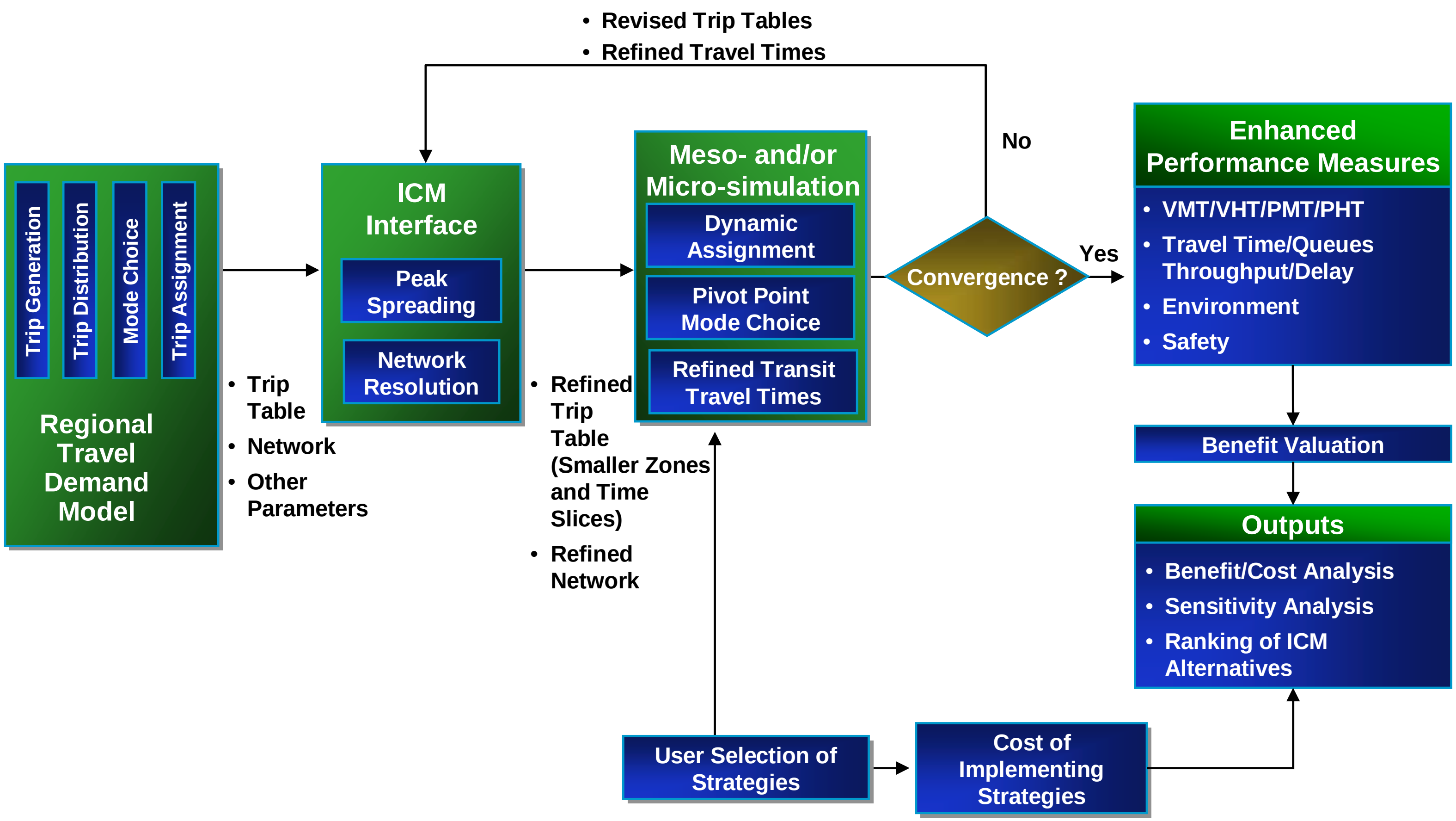
This chapter outlines a range of potential analytical approaches for the assessment of corridor operations in general, and how those methodologies can be adapted to address the specific requirements of individual corridors.

4.1 AMS Framework

The proposed 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 (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 proposed methodology also includes the development of 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/benefit-cost module. Figure 4.1 presents a summary depiction of the proposed analysis framework.

In the AMS framework, macroscopic, mesoscopic, and microscopic traffic analysis tools will interface with each other, passing trip tables and travel times back and forth until convergence is achieved between consecutive iterations that produce travel times and number of trips that differ less from one iteration to the next. Once convergence is achieved, performance measures will be calculated and benefits (such as travel time savings) will be evaluated and compared to deployment costs to produce benefit-cost ratios associated with each scenario/ alternative. With the help of benefit-cost information, alternatives can be ranked and a roadmap can be produced outlining the implementation timeline for ICM strategies. Following is a description of the components of the AMS framework.

Figure 4.1 AMS Framework



4.2 Macroscopic Travel Demand Forecasting Models

These models typically used in metropolitan planning applications have a role in AMS corridor analysis. The structure of these models supports the analysis of mode choice using mode-specific trip tables identifying trips from a traffic analysis zone to another. To adapt this trip table capability for ICM AMS purposes, a simple pivot-point mode choice model will be developed to estimate shifts due to ICM strategies. The mode choice and trip table manipulation capabilities will be able to understand most prevailing trip table formats and output trip tables in a format readable by mesoscopic-level analysis tools. The expected result from mode choice analysis and trip table manipulation will be a corridor-based trip table or tables that takes into account basic trip impacts associated with corridor conditions, current operations, or operational changes that need to be reflected at the trip table level.

4.3 Mesoscopic Simulation Models

Models at the mesoscopic level are needed to support analysis of the dynamic impact of ICM strategies that try and induce shifts of trips from one network to another, such as pricing, corridor-specific traveler information (pre and during trip), and peak spreading. The mesoscopic models will accept and use manipulated macroscopic-level trip table information. The mesoscopic models will also to support input concerning the effects of various control strategies from the microscopic level and transit operational information that can be used to account for the impact of transit alternatives. A dynamic pricing analysis capability that works at the mesoscopic level will also support the analysis of various ICM pricing strategies, including pricing of toll facilities, parking, and transit. Most mesoscopic analysis tools are able to re-estimate the trip table provided by the macroscopic level, and provide the re-estimated trip table information in a format conducive for use at a microscopic analysis level. The re-estimation of trip tables can use archived data from detectors to check for validation purposes.

4.4 Microscopic Simulation Models

These models support the evaluation of the operational control aspects of ICM strategies, such as the retiming of signals to accommodate trip shifts from other networks; strategies that coordinate the timing of ramp meters and adjacent signals; the coordination of arterial signal timing, transit priority, and connection protection (in various combinations); and the alternative uses of managed lanes, including such strategies as conversions to bus only operations. The interactions will account for coordination with transit operations, especially rail, which will be represented through transit travel times, schedules, or both in the analysis in order to understand the corridor impacts of implementing roadway/transit cross-network ICM strategies.

Microscopic simulation analysis will output detailed travel times that can be used to augment the mesoscopic simulation analysis. This augmentation entails the conversion of operational impacts identified at the microscopic level into adjustment factors at the mesoscopic level. These factors can support the modification of the mesoscopic analysis, such that the impacts of the operational control aspects of ICM strategies can be analyzed in conjunction with the trip management/shifting aspects of those strategies.

4.5 Representation of Mode Shift and Transit Services

A known gap in the analysis of ICM is the performance and impacts of transit services when integrated in a corridor with adjacent facilities. The requirements described above for all the modeling levels require input of transit travel times in order to account for the impacts of transit in each level of the analysis. Transit travel times need to be calculated and provided by network segment and at key decision points in the corridor. This will support comparison of network and modal alternatives and facilitate the analysis of traveler shifts among different transportation modes. This analysis gap is prevalent at the mesoscopic and microscopic simulation levels. Very few of these models can actually represent a transit network, estimate transit travel times, or dynamically adjust transit travel times at road segments and different decision points. On the other hand, travel demand forecasting models do represent transit, but are not effective at estimating accurate transit travel times (both static and dynamic travel times).

The key requirements addressed by the AMS methodology and proposed solutions are outlined below.

- **Demand –** The capability to estimate mode shift in an environment where macroscopic, microscopic, and mesoscopic models are being used. The proposed solution is the development of a simple pivot-point mode shift model that can work with trip tables from any travel demand model, and with accurate travel times estimated by microscopic and mesoscopic simulation models. This approach has the advantages of: 1) being model and vendor neutral; and 2) being universal enough, so it can be applied to all ICM and non-ICM corridors. Specific requirements for the analysis of short-term mode shift are addressed later in this chapter.
- **Supply –** The capability to represent transit networks at the mesoscopic and microscopic simulation levels. Some existing microscopic simulation models (VISSIM, and to a lesser extent Paramics) have the capability to represent transit networks and estimate accurate travel times. In most cases, these capabilities are recently developed and not error-free. In Pioneer Sites that

have these particular models in place, it would probably be cost-effective to use these models in the estimation of accurate transit travel times. In other ICM Pioneer Sites, a more universal approach can be employed where custom geographic information system (GIS) interfaces (based on travel demand model networks) can be used to represent transit networks and transit travel times are calculated off-line in a spreadsheet format. A depiction of this approach is shown in Figures 4.2 and 4.3.

Figure 4.2 Pivot Point Mode Shift Model – Level of Service and Mode Share Calculation

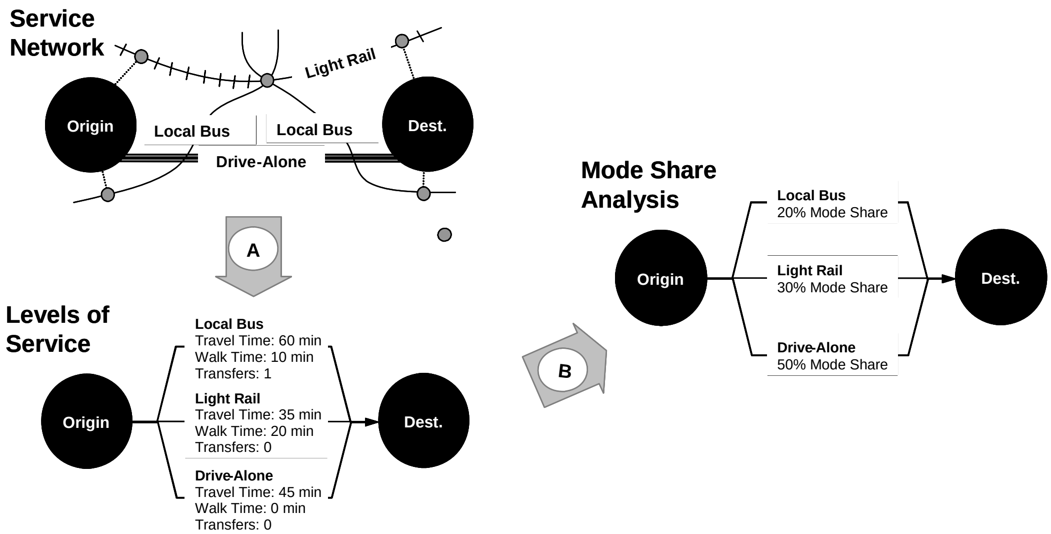
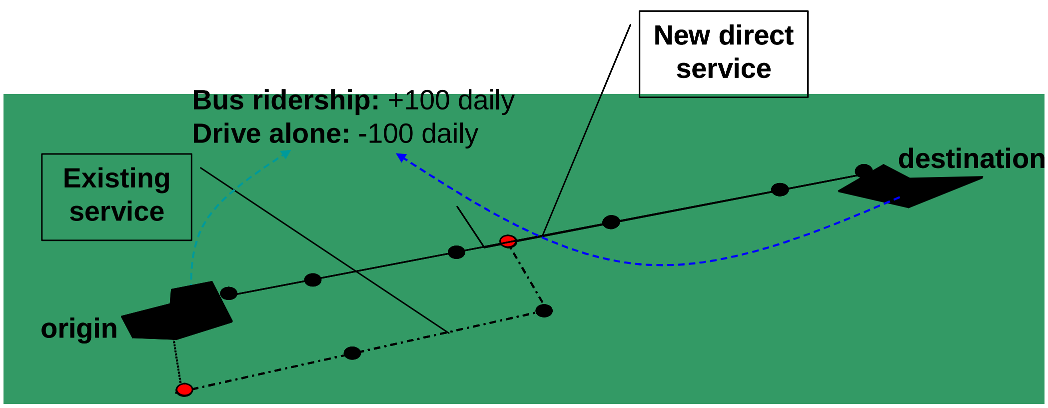


Figure 4.3 Pivot Point Approach



This type of dual approach can: 1) calculate transit travel times for each requested level of analysis given the corridor conditions or operations input; 2) can take input from each level of analysis to adjust transit travel times per segment and decision point; and 3) can generate output, such that it can be incorporated into the other tools as analysis adjustment factors. This approach supports the corridor analysis of transit in an ICM environment and provides the information necessary to account for the interrelation of impacts with the other operations in the corridor. This analysis feature also can be separated among all analysis levels, or consolidated with capabilities to support all analysis levels.

The “off-line” transit analysis method described above is capable of analyzing improvements to heavy and light rail, as well as improvements to bus transit. Furthermore, two microscopic simulation tools (VISSIM and Paramics) offer analysis capabilities for the transit supply side only (transit lines, transit stations, and other supply side characteristic) and can be used to estimate accurate transit travel times. Finally, transit analysis capabilities currently are being added to Dynasmart-P (a mesoscopic simulation model) in research efforts by two universities, including the University of Arizona and Southern Methodist University.

Short-Term vs. Long-Term Mode Shift

In the ICM analysis, environment mode choice variables need to address both short- and long-term mode shifts. These traveler behaviors have similarities, but are also different enough to warrant special and separate consideration.

- **Short-term mode shift –** Travelers will be presented with information on delays at certain parts of the transportation network, and will then consider changing their route of travel, their mode of travel, and their time of travel in response to these delays and away from their habitual or baseline choices.
- **Long-term mode shift –** Travelers consider shifting modes based on historical (not real time) information on travel times and other modal characteristics. Elasticities to switch modes tend to be lower (in absolute value) in the short term.

Characteristics of short-term mode shift as compared to long-term mode shift include the following:

- Travelers have limited awareness of modal alternatives for a specific trip or tour;
- Travelers may have limited information on the availability of modal alternatives (locations of stops, schedules, etc.);
- Travelers may have constraints or circumstances that strongly influence the mode required to complete activities in the current trip or tour;
- Travelers may have constraints on rescheduling of activities that might be required, depending on the transit schedule; and
- Travelers have behavioral inertia.

Evidence of short-term dynamic mode choice indicates limited shift to transit. Based on a review of a small number of available stated-preference studies on the subject, approximately one-half of a percent to two percent of commuters would switch to public transit in a major incident using pre-trip or en-route traveler information.

Variables influencing mode choice are listed below. Variables in *italics* are more important for short-term mode shift, while variables in standard typeface are common to short- and long-term mode shift.

- Travel time difference between auto and transit;
- Travel time uncertainty/variability;
- Travel costs (including parking, fare, etc.);
- Walk access time, auto access time;
- In-vehicle time;
- Wait time/headways;
- Transfer time;
- Number of transfers;
- *Availability of parking at transit stations*; and
- *Traveler knowledge of modal options*.

A typical mode choice equation describing the share of trips absorbed by transit is as follows:

Transit share = f (Travel time difference between auto and transit, Travel costs, Access time, Number of transfers, Transfer time, Wait time, Headways, …)

The structure of the proposed mode shift pivot-point model will be similar across long- and short-term mode shift. However, in the case of short-term mode shift, there will be additional variables influencing mode choice, such as availability of parking at transit stations and traveler knowledge of modal options.

4.6 Modeling Traveler Information

Travelers have multiple possible responses to congestion and mitigating ICM strategies: route diversion, temporal diversion, mode change, changing travel destination, or canceling their trip are some of these traveler responses. These responses depend on when travelers receive information about congestion (pre-trip or en-route); and on what information they receive, including congestion warning, delay estimate, recommended diversion route, etc.

Evaluation studies (see U.S. Department of Transportation (DOT) ITS Joint Program Office – ITS benefits Database) have revealed that traveler responses to information vary widely. Examples are presented below.

In response to pre-trip traveler information:

- 15 percent of 511 callers changed route based on information (Boston); and
- 7 percent of travelers changed route and 5 percent changed both departure time and route due to telephone traveler information system (San Francisco).

In response to en-route traveler information:

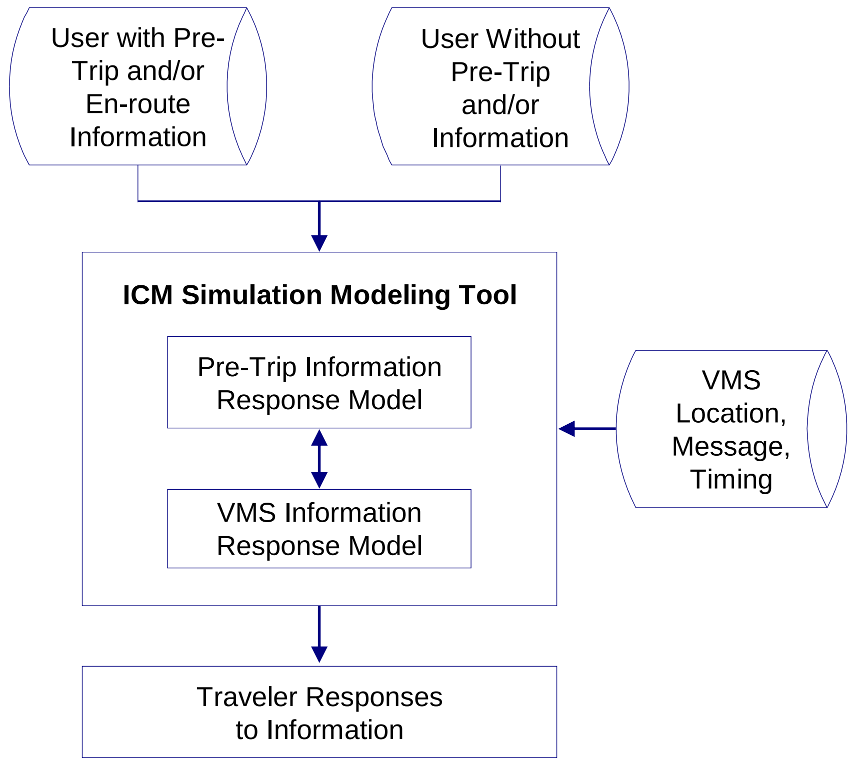
- 20 percent of callers switched route due to telephone traveler information (San Francisco);
- 40 percent of callers reported diverting based on variable message signs (VMS) information (Orlando);
- 5 to 10 percent travelers diverted due to VMS information (Long Island); and
- 1 percent of travelers divert due to VMS message (Hampton Roads).

Traveler information is disseminated by television, radio, the Internet, highway advisory radio (HAR), telephone-based traveler information (such as 511), and changeable message signs (CMS). The key traveler information characteristics influencing traveler responses include accessibility to traveler information (including media providing traveler information, market penetration, and the travelers' response to information); the quality of traveler information; and the location of CMS.

Traffic simulation models currently model **pre-trip information** as follows: based on habitual/baseline choices and on their knowledge about alternative choices, trip-makers adjust their travel route, departure time, or transportation mode based on received pre-trip information. Doing so requires modeling an explicit trip assignment based on a targeted on-time arrival. This on-time arrival-based assignment is applicable primarily to commuting trips, and other trips with different purpose (shopping trips, social/recreational trips) may be subject to departure-based assignment. Therefore, a feedback loop to adjust the trip-maker's departure time and/or mode is needed for ICM.

For **en-route information**, most simulation models currently have the capability to model CMS and general "radio" type of information for trip-makers to access. Simulation models (mesoscopic and microscopic) analyze the impacts of traveler information by separating travelers into "informed" and "uninformed" portions of the trip tables characterizing travel patterns in the study area. Market penetration can be taken into account by separating the trip tables into these portions based on existing and projected levels of traveler accessibility to traveler information. In response to an incident, "uninformed" travelers are "locked" onto their historical paths, while "informed" travelers are free to choose different routes, models, or times of travel. For modeling the impacts of **CMS**, simulation models use a version of "select link" analysis, in which travelers that traverse a link where a CMS is present are tracked forward to their destination, and are given the option to consider other alternatives (such as changing route, mode, or their destination). Figure 4.4 depicts these two approaches.

Figure 4.4 Modeling Traveler Information Strategies



This approach is functional enough to be used in ICM AMS for estimating responses to and impacts of traveler information. However, this approach will be supplemented and enhanced, because relatively little is known about 1) the effect of the quality of information on traveler responses; 2) how to take into account the availability of ubiquitous traveler information on the radio; and 3) the factors influencing mode shift based on traveler information. The enhancements will include the following:

- Utilizing more than two sets of traveler accessibility to information. For example, trip tables can be separated into four categories, including "fully informed all the time," "fully informed x minutes after the occurrence of an incident," "partially informed," "informed only by in-vehicle radio," and other categories.
- Conducting sensitivity analysis on the results by varying the percentage of travelers who fall in the categories listed above, or by varying other parameters that affect traveler information, such as quality of information and traveler responses.

The following two types of challenges will need to be addressed in this analysis approach:

1. **Establishing baseline traveler choices in each Pioneer Site –** In each Pioneer Site, available information on a) past traveler choices during major incidents

will be used to establish these baselines; and b) utilization of available traveler information services.

2. **Ensuring analytical consistency between Pioneer Sites –** Assumptions used across Pioneer Sites must be consistent with local reality and with general assumptions made for all Pioneer Sites.

An alternative option of modeling traveler information using HOWLATE is described in Appendix A. If archived data exist for the corridor sufficient to conduct a traditional HOWLATE analysis (Option 1 in Appendix A), then such an effort may be quite valuable and could be conducted in the timeframe allowed for the ICM AMS effort. The results could be used to demonstrate capability in ATIS analysis, which would be helpful to the ICM effort as a whole.

4.7 Modeling Tolling, High-Occupancy Toll Lanes, and Congestion Pricing

Several congestion pricing strategies can be part of ICM. These include the following:

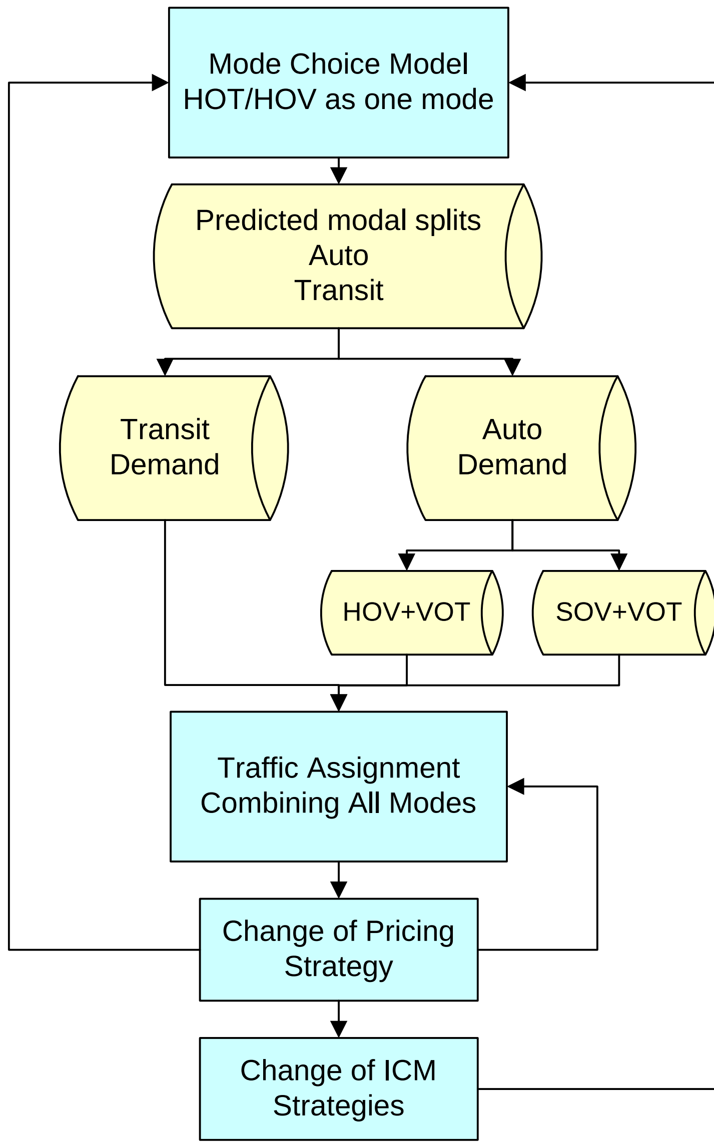
- Conventional road tolls, using a fixed fee for driving on a particular road;
- Time-variable congestion pricing (i.e., a fee that is higher under congested conditions than uncongested conditions);
- Cordon fees (i.e., fees charged for driving into a particular area); and
- High-occupancy toll (HOT) lanes (i.e., high-occupancy vehicle (HOV) lanes that accommodate a limited number of single-occupancy vehicles (SOV) for a fee).

To model these different congestion pricing strategies, the ICM AMS framework will need the following analysis capabilities:

- Dynamic traffic assignment, so that travelers can divert to and from another mode, route, or time of travel in response to congestion or to congestion pricing strategies;
- The ability to evaluate changes in the Value of Time (VOT) – this parameter can be uniform across all travelers, or it can be different across different zones, or vehicle classes;
- The ability to evaluate changes in toll rates – the rates can vary by vehicle class or by time of day; and
- The ability to model operations at toll plazas and other tolling locations for both manual and electronic toll collection.

Existing simulation models have the ability to model both regular time-invariant, as well as time-dependent tolls, HOV lanes, and HOT lane utilization. However, these models do not provide the congestion pricing capability that is responsive to congestion or to the level of service in the HOT and/or general-purpose lanes. An effort may soon be underway to enhance Dynasmart-P and add the congestion pricing capability. Alternatively, a Federal Highway Administration (FHWA) spreadsheet analysis capability can be used to vary the tolls based on congestion levels; the FHWA spreadsheet can be found at "Value Pricing – Evaluation of Toll Options Using Quick Response Analysis Tools."

Figure 4.5 Mesoscopic Simulation Modeling for ICM Congestion Pricing Strategies



4.8 Interface Requirements

This chapter defines the linkage mechanisms required to establish consistency between the modeling resolutions of the AMS candidate tools. The interfaces described in this chapter are methods commonly used by practitioners in establishing connections between different analysis tools.

In general, three types of interfaces are required to allow communications between macroscopic travel demand models, mesoscopic simulation models, and microscopic simulation models:

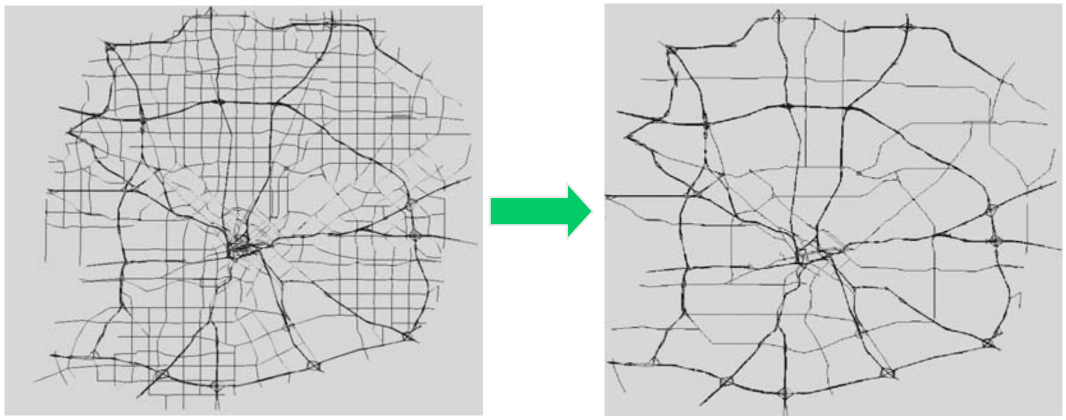
1. An interface focusing on network features;
2. An interface focusing on the temporal distribution of trips; and
3. An interface focusing on the refinement/aggregation of model traffic analysis zones that generate and attract travel demand.

For example, the interface between a travel demand model and a microscopic simulation model requires that uniform peak-period travel demand from the travel demand model is transformed into a dynamic travel demand that changes every 5 to 15 minutes. This interface further requires that there is compatibility between the zonal structures and networks in the two model types. Interface components are further explained in the following sections.

Network Interface

Most simulation-based traffic network modeling tools do not adopt the logic of centroid connectors for demand loading. In some tools, zonal demand is distributed over roadway links in a zone in proportion to the length of each link in this zone. If a vehicle is assigned to a trip generation link, this vehicle is directly loaded (considering capacity constraints) into this link at the appropriate time interval. The AMS network interface would be required to eliminate all centroids and centroid connectors from the starting travel demand model. In addition, the interface will need to allow the analyst to represent the network at any desired level of detail. Figure 4.6 illustrates a case in which all links that are marked as non-major arterials are eliminated from the roadway network.

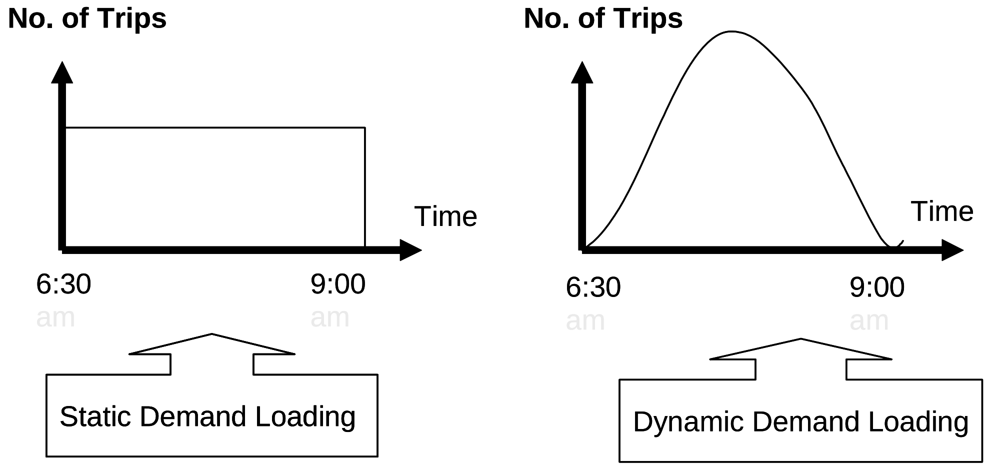
Figure 4.6 A Roadway Network at Two Spatial Resolution Levels



Temporal Distribution Interface

Travel demand models provide trip demand data for the study area in terms of total number of trips between all origin-destination pairs (O-D matrix) for different time periods, such as morning peak period, evening peak period, and off-peak period. These models provide no information on how demand between O-D pairs varies within any of these time periods. In these models, a constant, flat demand generation rate over the analysis period is assumed. However, in reality, demand generation rates vary significantly over the different departure time intervals within a given analysis period. This temporal distribution interface will provide the capability to represent travel demand dynamics over the analysis period. As shown in Figure 4.7, the interface would convert the constant demand generation rate into a time-varying rate. The pattern of this time varying rate would be an input to the interface. If no information on the pattern were available, the interface would use a default symmetric triangular pattern.

Figure 4.7 Static Versus Dynamic Travel Demand Loading Patterns for a Given O-D Pair



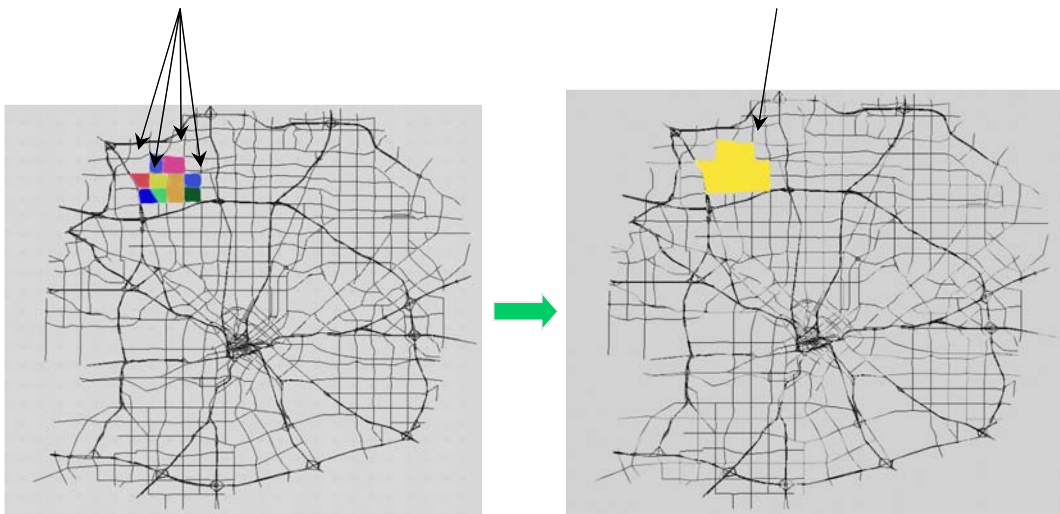
Zonal and Demand Interface

Simulation-based dynamic traffic assignment tools require intensive shortest path computations and storage from all nodes in the network to all zone centers. As the number of destination zones in the network increases, the running time of these simulation models significantly increases. Furthermore, the size of traffic analysis zones in travel demand models is typically much larger than zone sizes in simulation models. These different levels of zonal resolution mandate the development of an interface that would link the zonal representations of different tools. Finally, when extracting a piece of a travel demand model network to create a microsimulation model network, external zones may need to be aggregated and zones at the border of or within the microsimulation area may need to refined.

This interface will provide the capability to represent the zoning system of the study area at any user-specified level of aggregation. As illustrated in Figure 4.8, based on their spatial locations, the interface would aggregate several zones into one big zone or disaggregate one big zone into smaller zones. The O-D demand matrix associated with the new zoning system would also be generated.

Examples of model interfaces are presented in Appendix B.

Figure 4.8 Example of Zonal and Demand Aggregation



5.0 Summary, Conclusions, and Next Steps

The objective of the ICM initiative is to demonstrate how ITS technologies can efficiently and proactively manage the movement of people and goods in major transportation corridors. The objectives of the "ICM – Tools, Strategies, and Deployment Support" project are to refine Analysis Modeling and Simulation tools and strategies; assess Pioneer Site data capabilities; conduct AMS for up to four Stage 2 ICM Pioneer Sites; and conduct AMS tools post-demonstration evaluations. Efforts under this project focus on analyzing the ICM systems proposed by the Stage 2 Pioneer AMS Sites, and evaluating the expected benefits to be derived from implementing those ICM systems. The overall benefits of this effort include the following:

- Helping decision-makers identify gaps, evaluate ICM strategies, and invest in the best combination of strategies that would minimize congestion and improve safety;
- Helping estimate the benefit resulting from ICM across different transportation modes and traffic control systems; and
- Transferring knowledge about analysis methodologies, tools, and possible benefits of ICM strategies to the Pioneer Sites and to the entire transportation community.

This document provides a discussion of potential ICM analytical approaches for the assessment of generic corridor operations. The AMS framework described in this report is based on the analysis of advantages and deficiencies of existing tools, and the identification of cost-effective and low-risk strategies to integrate existing tools into an internally-consistent and flexible system approach that is able to support various ICM functional requirements. This document outlines a range of potential analytical approaches for the assessment of corridor operations, and includes a description of the proposed methodological approaches.

At the outset of this effort, existing candidate AMS tools were evaluated and compared for their ability to model ICM strategies and other requirements. Findings from this evaluation reveal that existing models share certain common features, but vary widely in their implementations and data requirements. Most existing tools do not fully integrate the *representation of transit services* with other auto-based traffic flow and facilities. Also, most of these tools are designed to model *recurrent* congestion conditions. Modeling *non-recurrent* congestion conditions requires integration with macroscopic travel demand models and possibly other special modeling techniques. In summary:

- Every tool type represents a tradeoff between geographic scope and level of resolution (scale vs. complexity). Less detailed tool types are tractable for large networks, while more detailed tool types are restricted to smaller networks. Depending on corridor size and the types of analyses required, all tool types are potentially valuable for ICM AMS.
- Microscopic and mesoscopic simulation models are capable of modeling traveler information strategies, while travel demand models do not have this capability. However, the limited geographic scale of microscopic simulation model implementations makes them less effective choices for traveler information evaluations that involve more than just changeable message signs. The most significant trip choices are made pre-trip or very early in longer trips, and mesoscopic simulation models are more effective than other tool types in evaluating pre-trip and en-route traveler information. Desired capabilities in ICM AMS are more than the capabilities found in existing tools.
- "Improve operational efficiency…" refers to system optimization strategies, such as freeway ramp metering and arterial traffic signal coordination. Microscopic simulation models are effective at analyzing these strategies. Mesoscopic simulation models are less effective, and travel demand models do not have this analysis capability.
- Travel demand models are better than other existing tools in estimating mode shift, but microscopic and mesoscopic simulation models are better at estimating route shifts. In fact, mesoscopic tools can estimate regional dynamic diversion of traffic, while microscopic tools can estimate route shift at a smaller geographic scale. Also, all travel demand models are capable of analyzing mode-shift, while this capability is very limited in macroscopic simulation models and non-existent in mesoscopic simulation models.
- Finally, mesoscopic simulation tools are better at analyzing traveler responses to congestion pricing, but the ICM AMS desired analysis capability is more than what is offered by existing tools.

Three findings emerge from the analysis of capabilities found in existing AMS tools:

1. Each tool type has different advantages and limitations, and is better than other tool types at some analysis capabilities. There is no one tool type at this point in time that can successfully address the analysis capabilities required by the ICM program. An integrated approach can support corridor management planning, design, and operations by combining the capabilities of existing tools.
2. Key modeling gaps in existing tool's capabilities include: a) the analysis of traveler responses to traveler information; b) the analysis of strategies related to tolling/HOT lanes/congestion pricing; and c) the analysis of mode shift and transit.

3. Interfacing between travel demand models, mesoscopic simulation models, and microscopic simulation models presents integration challenges that can be addressed by identifying interface requirements that focus on: a) maintaining the consistency across analytical approaches in the different tools, and b) maintaining the consistency of performance measures used in the different tool types.

The proposed generic AMS methodology encompasses tools with different traffic analysis resolutions. Three classes of simulation modeling approaches – macroscopic, mesoscopic, and microscopic – are considered essential components of a general AMS methodology. To conduct the analysis of a corridor where ICM approaches and strategies may be implemented, the AMS capabilities need to provide for the interaction of various aspects of macroscopic-, mesoscopic-, and microscopic-level analysis capabilities. The proposed 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 (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 individual modeling approach developed for a specific corridor might involve significant tailoring of the general methodological approach. Depending on the scope, complexity, and questions to be answered within a specific corridor, there may be more or less emphasis on each of the three general model types and their interaction.

In the traffic analysis marketplace, there are suites of tools developed by software vendors that offer some of the proposed analysis capabilities within a single modeling framework. While it might have been simpler to mandate the use of a single unified model/tool, this would: 1) make the transferability of this methodology more difficult; 2) not take into account the models available at the different Pioneer Sites and require more resources for the AMS; and 3) violate the vendor-neutrality principle outlined in Chapter 1.0.

The following key components of the AMS methodology and additional insight into its applicability to different types of corridors include:

- Different ICM applications will call for different levels and forms of model integration. For example, assessing the operational efficiency at network junctions and interfaces requires the integration of mesoscopic and microscopic models; whereas, assessing modal shifts calls for the use of all three classes in a coherent manner (i.e., using macroscopic models for demand estimation, mesoscopic models for flow re-distribution, and microscopic models for traffic control optimization).

- The proposed ICM AMS methodology will be adapted for and implemented on the Test Corridor. Emphasis has been placed on choosing a methodology that provides the greatest degree of flexibility and robustness in supporting subsequent tasks for the Test Corridor and AMS support of Pioneer Sites.
- The proposed methodology includes the development of a simple pivot-point mode shift model and a transit travel time estimation module to support comparison of network and modal alternatives, and facilitate the analysis of traveler shifts among different transportation modes.
- The proposed methodology also includes the development of linkage mechanisms required to establish consistency between the modeling resolutions of the AMS candidate tools. Three types of interfaces are generally required to allow communications between macroscopic travel demand models, mesoscopic simulation models, and microscopic simulation models: 1) an interface focusing on network features; 2) an interface focusing on the temporal distribution of trips; and 3) an interface focusing on the refinement/aggregation of model traffic analysis zones that generate and attract travel demand.

5.1 Next Steps

Next steps in the ICM AMS project are summarized as follows:

- In Task 2.4, the AMS methodology will be customized and refined for the Test Corridor. This refinement will involve testing of various components on actual or hypothetical corridor settings so as to validate the correctness of the integrated tools. This step will ensure that the integration does not cause undesired effects, and will address and resolve any modeling or data issues before the integrated model is implemented on the Test Corridor.
- In Task 2.5, the refined methodology will be applied to the Test Corridor. The purpose of this task is to demonstrate the depth and scope of the analyses that will be conducted as part of the ICM Stage 2 Pioneer AMS Sites. The AMS methodology will be implemented to evaluate a number of ICM strategies; calibrate/validate the AMS tool; produce performance measures for each strategy by mode, jurisdiction, and facility type; and tally the results. We will document the results of the Test Corridor AMS activities and findings in a draft and final report. The report will detail the AMS approach, results, lessons learned, and comment on possible limitations of tools with respect to each of the ICM strategies.
- In Task 2.6, we will refine the ICM operational strategies based on the results of the Test Corridor AMS in Task 2.5, and propose additional methods to assess ICM strategies. In this task, we will assess the capabilities of AMS methodologies and support cost-benefit calculations for each strategy with the goal of establishing priorities for implementation.

- In Task 2.7, we will document the previously developed tools and strategies in a final report. The final report will document lessons-learned from the application of the AMS methodology on the test corridor, and will present the modified AMS methodologies. In addition to documenting the AMS methodologies, the documentation will include a categorization of AMS tools and interfaces to be used in different corridor settings; for different ICM strategies to be modeled; for different types of analysis scenarios; desired performance measures allowing for consistent comparison of ICM strategies; recommended validation/calibration steps and targets; the relative capability of the AMS activity to support benefit-cost assessment for the successful implementation of ICM; potential risks and applicability; and schedule/ budget guidelines for ICM AMS activities. This information will be organized in a way that can be useful in determining Decision Point #2 – Site Application Feasibility, and in the development of the Phase 4 – Technology Transfer activities.
- In Task 4, we will model the selected Stage 2 Pioneer AMS Sites and analyze their proposed ICM corridor strategies. For each of up to four selected Stage 2 Pioneer AMS Sites, we will: 1) develop site-specific AMS plans; 2) assemble/collect data; 3) assemble available tools, including travel demand models, macro-, meso-, and micro-simulation models, apply any additional tools that may be needed, and build interfaces among these tools using Task 2 methodologies; 4) calibrate/validate the baseline models; 5) test ICM strategies using the calibrated models; 6) produce performance measures for each site and scenario; and 7) for each site, prepare a Stage 2 Pioneer AMS Site Assessment Report, detailing the approach, results and lessons learned, and presenting the possible benefits of implementing the proposed ICM strategies.

Appendix A. Additional Options for ATIS Evaluation in ICM/AMS

Karl Wunderlich, Noblis

The current proposal to deal with traveler information centers on a *sensitivity-testing approach* manipulating a series of parameters in traffic simulation to reflect various proportions of travelers changing mode, trip departure, and route choice. The advantage of such an approach is that it is relatively simple to implement with most traffic simulation models and avoids the need to develop a complex travel behavior model. Aggregate system-level performance measures can be directly obtained from simulation outputs. The disadvantage of this kind of simple approach is that it is likely to be too coarse to identify the effects of incrementally improved traveler information services. Further, since the sensitivity must be performed on trip decisions (e.g., varying mode choice by origin-destination) it cannot clearly differentiate between service users (who may use information to confirm that sticking with usual choices is preferable) and non-users (who may divert or make other uniformed decisions based on unexpected conditions).

Alternative, complementary methods could be considered to provide a more robust representation of traveler behavior. This appendix describes one possible approach using software and techniques developed as a part of the Heuristic On-Line Web-Linked Arrival Time Estimation (HOWLATE) development program over the last six years [1, 2, 3, 4, 5, 6, and 7].

HOWLATE resources could be brought to bear for ATIS (Advanced Traveler Information Services) impact analysis in several ways, depending on several key factors:

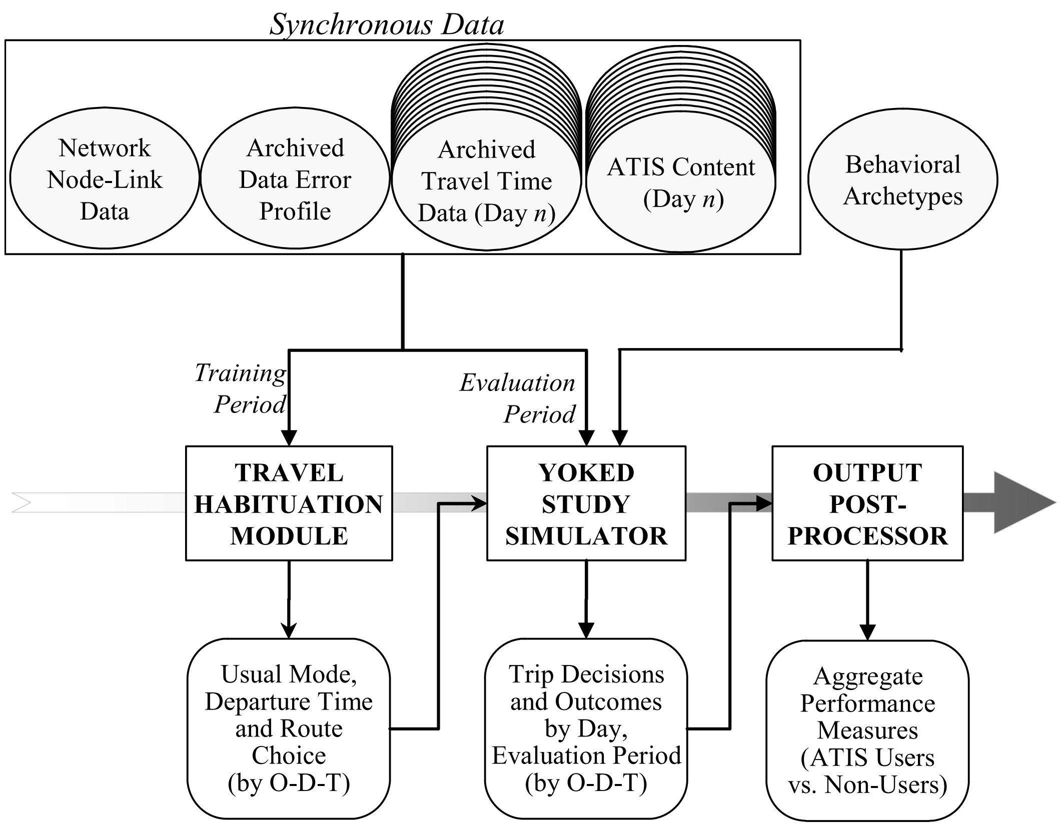
- Type(s) of traveler information services to be evaluated;
- Targeted market segments of these services (e.g., commuters vs. tourists);
- Projected market penetration for various traveler information services;
- Quality and availability of archived data; and
- Capability of a selected traffic simulation to represent pre-trip and en-route choices.

This appendix presents two options for utilizing HOWLATE resources for improved ATIS modeling in ICM. The options are presented in ascending order of complexity. It should be stressed that these options represent potential complementary or enhanced analyses within the simulation-based ICM AMS methodology and not a replacement to the methodology.

OPTION 1: HOWLATE WITH ARCHIVED DATA

The first option is a complementary analysis based on archived travel time data and traveler information content (Figure A.1), and corresponds to the traditional HOWLATE evaluation method used in previous studies. No direct link or interaction with a traffic simulation is required. This option assumes that quality travel time data can be obtained for all modes and integrated with an archive of synchronous traveler information content. Further, the average error in the travel time data has been measured and its distribution known. Finally, a file describing multimodal network structure in terms of links and decision nodes must be available. This network file is not as complex as a simulation network file, it is just a representation of the various routes, and modes a traveler must consider getting from trip origin to trip destination. Detailed characteristics such as link capacity or number of lanes are not required. However, for each link in the network, there must be a corresponding travel time available describing the actual travel time to traverse the link, every five minutes. For best results, a minimum of 100 days of synchronous travel time and ATIS content are required. This large set of days is broken into two mutually exclusive datasets, one for establishing usual travel choices for regular commuters in the corridor and one for the evaluation of the benefit of the traveler information services under a representative set of congestion conditions.

Figure A.1 HOWLATE with Archived Data



In the first analytical step in HOWLATE, synchronous data for the training period is fed into the Travel Habituation Module (THM), which identifies usual mode, departure time, and route choice for all of the possible origin-destination-time of arrival triplets in the network. For large metropolitan networks, this may entail upwards of 100,000 triplets in the network considering 15-minute target time of arrival increments. For each triplet, the THM finds the time of departure, mode and route with the minimum generalized disutility that results in on-time arrival at some specified threshold (typical values: 85 to 95 percent). Generalized disutility is based on work by Small *et al.* [8], and is a monetized combination of travel time, late schedule delay (minutes late), and early schedule delay (minutes early). HOWLATE does not currently take into account fares or tolls, but this can be extended with minimal effort. These usual choices, along with a file describing average travel times on the multimodal network are carried forward to the evaluation phase.

In evaluation, days from the archive are fed into the yoked study simulator for analysis. Here, each triplet is associated with a simulated non-user (control) subject who ignores information and sticks to the usual choices every day. Using the archive of travel time data, the yoked study simulator simply adds up the elapsed retrospective time accumulated by the non-user along each link in the time-dependent network. This implies that arriving at an intermediate node later in the rush period may cause even more delay as recurrent congestion builds on the latter portions of the trip. A simulated traveler information user (experimental) subject is also associated with each triplet, who will react to provided information based on a behavioral archetype. The archetype can be scripted to consider only certain choices (e.g., no early departures, but will consider a change to mode) and consider certain types of information (e.g., pre-trip consultation of a congestion map).

Using the rules from the archetype and the ATIS content, the yoked simulator assembles a travel experience and time of arrival at the trip destination based on conditions actually observed on all the links in the trip. Pre-trip and en-route choices are generated as simulator moves forward in time. Regardless of the type of user, trip decisions and trip outcomes are recorded for each day for each of the many possible triplets. In previous HOWLATE studies, the ATIS users deviate from usual choices at rates proportional to the amount of unexpected variation in conditions, and quite often arrive more consistently on time with smaller travel budgets than non-users. Comparisons can be made between non-users and ATIS users on the individual yoked pair by day, or aggregated in a post-processor.

Because no traffic simulation is involved in the process (only simple re-creation of conditions from an archive), the HOWLATE engine is computationally efficient. Roughly 5,000 simulated yoked trials can be conducted every second on a low-end PC. This allows the quantification of ATIS user benefits across large networks, and also allows for the rapid evaluation of multiple archetypes.

Major HOWLATE analyses have involved the processing of several hundred million simulated yoked trials.

Option 1: Limitations

There are several *limitations to the use of HOWLATE with archived data (Option 1)* for ICM, however. First, Option 1 is a purely retrospective approach and cannot be tested in future conditions significantly different from the current state of operations (e.g., instituting congestion pricing for the first time). It also assumes that significant archives of travel time data exist for the corridor. Second, Option 1 is valid for prospective (future) ATIS services only if the number of ATIS users is small enough that resulting congestion patterns are unaltered. For the evaluation of current services, this is not an issue, even if market penetration is high (e.g., the HOWLATE study on broadcast radio traffic reports). As a rough rule of thumb, market penetrations under 6 percent generally do not result in significant changes in congestion patterns.

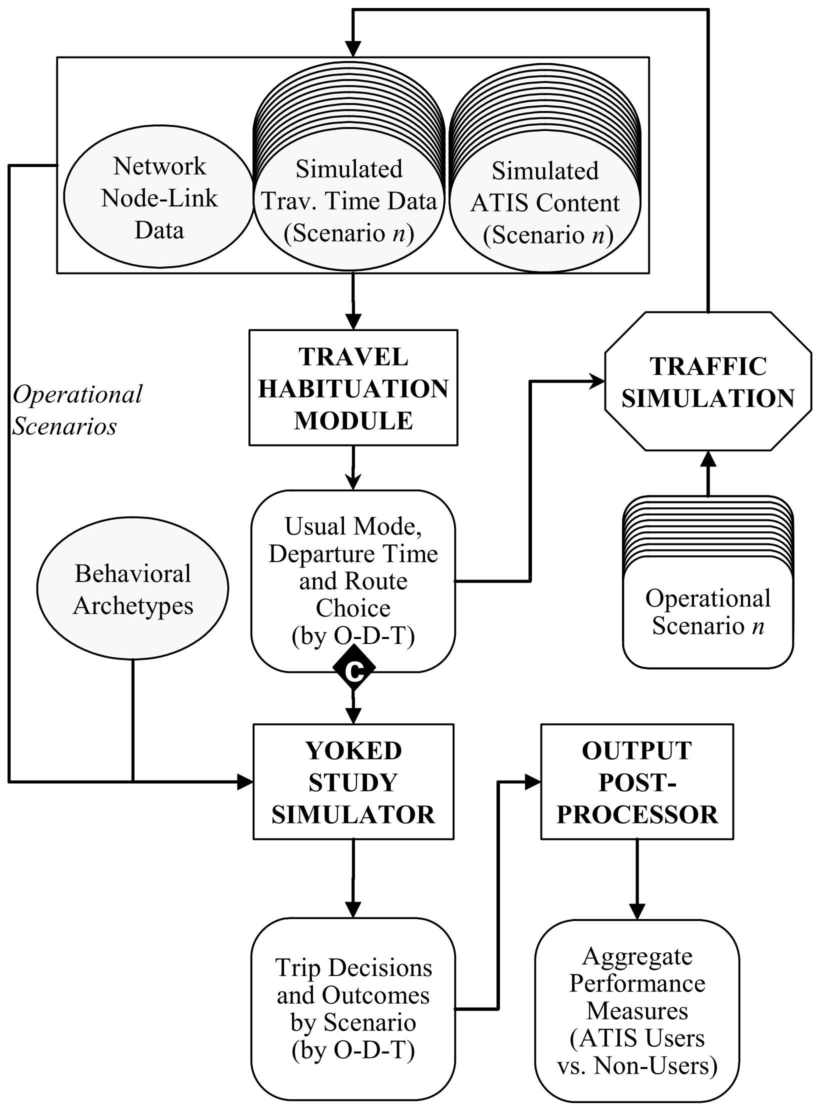
Option 1: Advantages

The *advantage of Option 1* is that it is a relatively low-cost, high-payoff extension to a corridor analysis if travel time and other data are already being collected for the purposes of performance management or traffic simulation modeling. Results of the HOWLATE study can be used to guide a more precise depiction of user response than simple range testing. For example, if benefits for a pre-trip service are geographically concentrated non-uniformly for longer trips in the corridor that have a good alternative, then user density can be non-uniformly distributed over the network in a more realistic fashion. The simulation analysis is enhanced not only by non-uniform distribution of traveler information usage, but also providing a resource of experiential data to draw on within the simulation analysis when trip decisions must be made in response to traveler information (e.g., modeling of variable message signs or broadcast traffic reports).

OPTION 2: HOWLATE WITH SIMULATION (SOFT FEEDBACK)

In this option (graphically illustrated in Figure A.2), individual modules of the HOWLATE software are utilized to incorporate more realistic traveler behavior in response to traveler information with limited feedback to a traffic simulation. This option is more complex than Option 1 because HOWLATE is applied iteratively in conjunction with a traffic simulation, but allows for higher market penetration ranges (6 to 25 percent) to be evaluated. The traffic simulation must be jointly calibrated with the travel habituation module so that there is at least a modicum of consistency between usual route selection and operational

Figure A.2 HOWLATE with Simulation – Soft Feedback



conditions. This option is less complex than Option 1 in terms of archived data, however – all the travel time can be provided from a traffic simulation. This option is only valid with simulated ATIS content, which can be generated from the simulation outputs using relatively simple rule sets (e.g., speeds between 30 mph and 40 mph are coded as yellow on the congestion map, for example). Another key requirement is that the traffic simulation is run through a set of scenarios that reflect the range of conditions typically seen in the corridor (that is, combinations of variations in travel demand, incident patterns, and weather impacts). Because the THM needs a range of conditions over which to find a preferred usual trip departure time, mode and route choice, these conditions and their probability of occurrence must be provided as input.

The THM finds a set of choices and these are input back into the traffic simulation. If the set of selected usual routes is relatively stable from iteration to iteration, then we can declare a rough state of convergence (denoted in Figure A.2 with a "C"). Note that we have a soft convergence criterion, that is, the use of traveler information may have impact in particular scenarios (say, a major incident), but the market penetration rate is low enough that these relatively rare events do not change habitual behavior significantly.

Once some kind of acceptable convergence criterion is reached, then the stable conditions (travel times by scenario) and usual decisions (habitual decisions) can be used as input to the yoked study simulator to identify outcomes by scenario. Output can be processed using the existing post-processor to generate aggregate performance measures by user vs. non-user. In addition, the traffic simulation outputs themselves will provide system-level performance measures.

Limitations

The technique is untested, so there is technical risk associated with its implementation. Further, there is a technical risk that even the proposed "soft" feedback loop will not result in convergence. The TRANSIMS effort has struggled for several years to force "hard" convergence in large metropolitan networks based on a single simulation run representing normal conditions with near-zero indifference thresholds. Soft feedback is more tolerant, but does not guarantee convergence. Triplets with significant flow rates may have to be broken up into lower flow components and fitted with different disutility distributions to avoid unstable bang-bang control issues. This observation is valid for both ATIS users and non-users since the decisions they make influence the congestion conditions. The complex feedback at the simulation level must also be reconciled with feedback loops to other regional models, which may result in the need for multiple convergent solutions at the simulation level. The representation of en-route choice consistent with the assumptions of the THM will depend on the flexibility and capability of the individual traffic simulation used in the analysis.

Advantages

The advantage of such an approach is that if a convergent solution can be identified, then the system and user-level benefits from ATIS can be assessed in whatever range of conditions the ICM program wants to explore.

Summary and Recommendations

This appendix presents two options for incorporating analytic assets from the HOWLATE traveler information impacts evaluation effort into ICM analysis. The goal of providing these options for consideration is to provide a more robust analysis of traveler information impacts for ICM, a recognized need in the program and in the field of traffic simulation.

Given the technical risks associated with Option 2, it is unclear that an effort to pursue this unproven method in the early phase test corridor would be wise. However, if the archived data exist for the corridor sufficient to conduct a more traditional HOWLATE analysis (Option 1) then such an effort may be quite valuable and could be conducted in the timeframe. The results could be used to demonstrate capability in ATIS analysis, which would be helpful to the ICM effort as a whole. Depending on success, need and a longer timeframe to explore the technical risks, the more complex Option 2 may be a useful notion to reserve for consideration in later phases of the project.

REFERENCES

Wunderlich, K., M. Hardy, J. Larkin, and V. Shah, *On-time Reliability Impacts of Advanced Traveler Information Services (ATIS): Washington, D.C. Case Study*, prepared by Mitretek Systems for FHWA, 2001 (Document #13335 on the ITS Electronic Document Library, http://www.its.dot.gov/welcome.htm).

Jung, S., J. Larkin, V. Shah, A. Toppen, M. Vasudevan, and K. Wunderlich, *On-time Reliability Impacts of Advanced Traveler Information Services (ATIS), Volume II: Extensions and Applications of the Simulated Yoked Study Concept*, prepared by Mitretek Systems for FHWA, March 2002. (EDL #13630).

Shah, V., S. Jung, J. Larkin, A. Toppen, M. Vasudevan, and K. Wunderlich, *Accuracy and Coverage Implications for Advanced Traveler Information Services (ATIS) Benefits, Volume III: Extensions and Applications of the Simulated Yoked Study Concept*, prepared by Mitretek Systems for FHWA, May 2003. (EDL #13859).

Vasudevan, M., K. Wunderlich, A. Toppen, and J. Larkin, *Making the Most of Limited Data in Evaluating Advanced Traveler Information Systems by Experimental Resampling*, In Transportation Research Record 1897, pp. 1-8, 2004.

Vasudevan, M., K. Wunderlich, J. Larkin, and A. Toppen, *Comparison of Mobility Impacts on Urban Commuting: Broadcast Advisories Versus Advanced Traveler Information Services*, In Transportation Research Record 1910, pp. 38-45, 2005.

Shah, V., K. Wunderlich, and J. Larkin, *Time Management Impacts of Pre-Trip ATIS: Findings from a Washington D.C. Case Study*, In Transportation Research Record 1774, pp. 36-43, 2001.

Vasudevan, M., and K. Wunderlich, *Quantifying Serenity Benefits from Use of Advanced Traveler Information Services (ATIS)*, prepared by Mitretek Systems for the FHWA, October 2004.

Small, K., R. Noland, and D. Lewis, *Valuation and Travel-Time Savings and Predictability in Congested Conditions for Highway User-Cost Estimation*, NCHRP Report #431, National Academy Press, Washington, D.C., 1999.

Appendix B. Examples of Model Interfaces

This Appendix contains examples of interfaces that have been developed to assist in the integration of different types of models outlined in the AMS Methodology. The specific examples apply to steps followed in interfacing travel demand models and microsimulation models. These are just examples of interfaces developed for specific projects – they should not be construed as the recommended approaches to interface different types of models for AMS. These examples are provided here for illustrative purposes.

CREATE SUBZONE TRIP TABLE

This section outlines the steps involved in creating a subzone trip table suitable for use with a traffic microsimulation model. First, a daily trip table is created by identifying the outline of the analysis subarea and running the full-scale travel demand model to identify the origins and destinations of link flows traversing the subarea boundaries. The zones outside the subarea are aggregated to entry and exit points along the cut-line (external stations) and the zone and network geography inside the subarea are refined to match the traffic microsimulation network. The daily trip table is assigned to the subarea network. The daily assigned volumes are used to determine the time of day the trips occur.

Daily trip tables are used as the input to the time of day analysis because in most travel models peak period trip tables are often based on static factors derived from base-year surveys. Most often they are not sensitive to peak-spreading due to congestion that is likely to occur in future year analysis.

WINDOW THE ANALYSIS SUBAREA

Decide where the cut-lines will be for the analysis subarea. The subarea should include alternate routes for congested corridors. Links that cross the cut-lines should be identified in the traffic assignment step of the travel demand model as "select links." This will ensure that the origins and destinations for traffic on these links are saved to be used when aggregating the zones outside the study area. If the analysis area is very large, it may help to identify the select links by geographically intersecting a polygon of the subarea with the road network.

Run the Travel Demand Model

Run the travel demand model in full to estimate travel demand and link volumes for the base year. Additionally, the origins and destinations for the "select links" will be saved and used in the next step for aggregating zones outside the subarea. The output from this step is the daily trip table by trip purpose as well as the origins and destinations by trip purpose for each of the links crossing the subarea boundary.

Aggregate Zones Outside Subarea

Trips with an origin or destination that lie outside the windowed subarea need to be allocated to external stations along the subarea boundary. Trip origin and destinations should be aggregated to the external station that corresponds to the link that was used to cross into the subarea. The output from this step is the daily trip table windowed to the subarea. If possible, separate trip tables should be maintained by vehicle type and trip purpose.

Add detail to Subarea Zone System

Traffic analysis zones (TAZs), represented in the network by *centroid* nodes, are the origins and destinations of all trips. Centroids can also be thought of as the sources and sinks of vehicles in the models. All centroids (and their corresponding TAZs) should be numbered the same in all model networks and represent the same geographic area. Centroids are connected to the network by *centroid connector* links that determine the point where traffic is loaded on the network. Load points should be consistent for both the macroscopic and microscopic models.

Traffic microsimulation models are very sensitive and require a detailed treatment of traffic loading points onto the network. Travel demand models using static traffic assignment are not as sensitive and therefore often have multiple access points aggregately represented by a single centroid connector and loaded on to a single point on the network. Therefore, it is necessary to distribute the assigned trips from a single macroscopic-level zone in the travel demand model among all the access points used in the traffic microsimulation model. To maintain consistency between the travel demand model and the traffic microsimulation model, each loading point that exists in the microsimulation model should correspond to one zone/centroid in the travel demand model. Additionally, the zone/centroid numbering schema should also be the same between the models. Therefore, many of the Travel Demand Model zones will need to be broken up into subzones. There are two methodologies that can be employed depending on the availability of data (or they can be used in tandem).

In the first methodology, trip tables can be split from zones to subzones based on zonal characteristics. For example, the number of trips originating from the zone can be allocated to each subzone based on the proportion of zonal houses in each subzone and the number of trips terminating in a subzone can be determined by the proportion of employment that exists in that subzone relative to the other subzones contained in that zone. If little or no socioeconomic data are available at this detailed level, then subzone areas can be used to allocate trips from zones to subzones. However, using the relative area can produce illogical results for some trip purposes and where the areas are not proportional to the density of land use (i.e., a field and a lake with one house next to a subdivision).

The second methodology is to run traffic assignment on the regular zones (not the subzones), but with several centroid-connectors attached to each centroid – one for every subzone. The trips can choose where to load on to the network and the proportion of trips using each centroid connector can be used to distribute trips amongst the subzones. This method makes the most sense to use for zones where there is a lot of internal connectivity and vehicles have many options about where to load on to the external street network.

The end product from this step is the daily trip table – the number of trips originating and terminating in each subzone and external station by trip purpose and vehicle type.

ZONE INTERFACE

Two levels of communication between the macroscopic and microscopic model must be accomplished in this step. First, the macroscopic model must emulate the number and location of centroids and load-points (centroid-connectors) of the microscopic model. Second, the vehicle demand between origins and destinations must be transferred from the macroscopic model to a format that can be read by the microscopic model.

The macroscopic model can import the geography of the microsimulation model network. However, often human judgment must be used as to how to break up the zones into subzones. This will likely include the use of aerial photos to determine logical split points.

Vehicle demand predicted by the macroscopic travel demand model is represented by the following characteristics and can traded between the demand model and traffic microsimulation model in a columnar data format for easy importation to the traffic microsimulation model:

- Time period start time,
- Time period end time,
- Origin centroid/TAZ,
- Destination centroid/TAZ, and

- Number of vehicle trips between the origin and destination during this time period.

Ideally, the vehicle trips would be stratified by (and have separate columns for):

- Vehicle type (passenger car, heavy truck, etc.); and
- Trip purpose/direction (Home to work, shopping to home, etc.).

ADD DETAIL TO THE SUBAREA NETWORK

Traffic microsimulation models often have very detailed networks compared to macroscopic travel demand models: both the number of links that are coded, as well as the number of attributes on the link. Additionally, traffic microsimulation models have very detailed representations of signalized intersections. Often this level of detail is not possible in the macroscopic travel demand model because of the sheer size of the network and the required amount of data entry. By mapping the two networks spatially, a correspondence can be developed between them.

NETWORK INTERFACE

A relationship between the network characteristics in the microsimulation model and the demand model will facilitate the information flow both for feedback (level of service parameters), as well as reasonableness checking.

Links

Links in both the macroscopic and microscopic model networks are referred to by a unique *i* (link origin), *j* (link destination) combination (in some model platforms the letters A and B are used). They have the following characteristics at a minimum that should be commonly defined between the models:

- *i*, link origin node.
- *j*, link destination node.
- *Facility Type/Functional Class* (Freeway, Expressway, Major Arterial, etc.).
- *Capacity*, the maximum link flow achieved at LOS E. The microsimulation network does not have a deterministic capacity. However, details on lane-width, facility type, number of lanes, and area type can be used to either calculate a capacity to be used by the macroscopic model or to alter or verify a capacity that is already coded on the macroscopic network. If turning movement capacities are regularly exceeded in the macroscopic travel demand model, then separate links for each lane group may be coded in the network to constrain the volumes.
- *Free-flow speed*.

- *Number of lanes*.
- *Length*, the actual length of the roadway, including curves that may not be well represented in the macroscopic network.

Several other variables exist in the microsimulation network and may be used to help determine the capacity used in the demand model. They include the following:

- *Lane width*,
- *Gradient*, and
- *Turn bays*.

Additionally, the following level of service attributes will be added:

- *Volume by vehicle class,* number of vehicles that pass through the link for the time period by vehicles class (i.e., single occupancy vehicle, trucks, etc.);
- *Average Link Delay*; and
- *Queue Length*.

The level of service attributes will be used to feed back information to the macroscopic model. The macroscopic model can use this to predict peak spreading.

Nodes

Node numbers in the subarea travel demand model should match the node numbers in the traffic microsimulation model. This will enable the LOS characteristics of links to be easily transferred from the microsimulation model to the demand model. Nodes all have the following characteristics:

- *Node number*;
- *X-coordinate*;
- *Y-coordinate*; and
- *Node type*, an intersection, zonal centroid, etc.

If a node is an intersection then it will have numerous characteristics that are grouped by turning movement, described in the next section.

Turning Movements

There are five attributes that define a turning movement:

- *Start time period;*
- *End time period;*
- *A-node*, the last node traversed before entering the intersection;

- *B-node*, the intersection node; and
- *C-node*, the next node traversed after leaving the intersection.

There are several attributes that characterize a turning movement:

- *Turning movement capacity*.
- *Turning penalties*, can specify if a turning movement is not allowed or can specify a time-penalty associated with the movement that is static or a function of the volume and capacity. The turning movement delays from the traffic microsimulation model can be input here as well.
- *Volume*, and
- *Level of service* (i.e., control delay).

ASSIGN SUBAREA VEHICLE TRIPS TO SUBAREA NETWORK

Once the daily subzone trip table and the subarea network have been created, assign the daily subzone trips to the subarea network. Once the time period profile is determined, an hourly trip table should be assigned to the subarea network to make sure there are no links or turning movements over capacity. Further refinements to the network including turn-movement capacity constraints may be necessary if problems arise.

TIME-OF-DAY MODEL

Choice models that produce trips by time period are not as common in practice, but use traditional logit choice estimation techniques to apportion trip tables by purpose to various time periods. Choice models spread the number of trips that occur in the peak period based on an assessment of congestion, level of service, purpose and socioeconomic or density variables.

The objective of the time-of-day choice models is to provide sensitivity to traveler's temporal decisions with respect to socio-demographic and trip characteristics. This sensitivity to temporal decision-making is expected to have significant impacts on forecasting results, as peak period travel is more likely to be occurring in saturated conditions. Fixed time period factors provide realistic estimates of peaking characteristics under current conditions, but are not sensitive to changes in travel behavior as congestion increases or demographics shift.

The time-of-day choice models are applied to produce probabilities that trips will occur in different discrete time periods. These probabilities are then applied to trip tables for each purpose to produce trip tables by time period and purpose. This process is very similar to how mode choice models are estimated and applied. The sum of the resulting time period trip tables will equal the total daily trips.

Capturing the variations in travel by time of day is essential to predicting transportation system performance to congestion pricing and ITS technologies, and air quality impacts of the transportation sector. This is also necessary to predict traffic volumes at very disaggregate time periods and thereby replicating the reality of traffic assignments accurately. This is critical to integrate travel demand or planning models to simulation models. A vast amount of transportation research has been conducted to study travel demand by time of day. Much of this research has been limited to observing trends in service usage, such as vehicular volumes and the number of person trips. While important to understanding past and present usage patterns, these types of studies are less valuable for predicting future travel by time of day given changes in transportation service availability, quality, and policy. Possibly the behavior least accounted for in travel forecasting is "peak spreading" (e.g., persons rescheduling their travel from daily periods of high demand to the portions of the day where travel takes less time and is more reliable). Travel surveys and other monitoring activities have documented the correlation between decreasing service quality (congestion) and longer peak periods. Also, many planning agencies need to test the effectiveness of policy initiatives specifically targeted at shifting travel demand to off-peak periods.

The Matrix Varigator[1] approach is a trip table refinement procedure that applies a unique temporal distribution to each O-D pair, where appropriate temporal distributions are based on the amount of congestion that is present between each pair. This approach has been applied at the corridor level with some reasonable success. The procedure assumes that the degree of peak spreading that is likely to occur between any O-D pair depends on the amount of congestion that is present along the shortest travel path for each O-D pair. The distributions used here are approximations based on a previous study[2] that developed a set of temporal distributions that varied by the ratio of the daily volume to hourly capacity (AADT/C). These distributions were manually estimated as a simple means of moving demand from peak hours to off-peak hours as congestion increases.

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[1] Simons, C., 2006, *I-285 Matrix Variegator: A Practical Method for Developing Trip Tables for Simulation Modeling from Travel Demand Modeling Inputs*, presented at the 85th Annual Meeting of the TRB, Washington D.C., January 2006.

[2] Margiotta, R., H. Cohen, and P. DeCorla-Souza, 1999, *Speed and Delay Prediction Models for Planning Applications*, Sixth National Conference on Transportation Planning for Small- and Medium-Sized Communities, Spokane, Washington.

Another method that facilitates peak spreading[3] but on a systemwide basis has been implemented by the Volpe National Transportation System Center (VNTSC) within a modeling framework applied in evaluating Intelligent Transportation Systems (ITS). This peak spreading approach considers the systemwide excess travel demand and delay and distributes excess travel demand between the individual travel hours that comprise the peak period. This approach is neither link-specific nor trip-specific, which is one of its serious limitations. Also, since it was designed to model the travel impacts of ITS deployment, it assumes that a significant amount of travel information is available to travelers and thus the traveler's temporal response to congestion can be modeled on a systemwide basis rather than on a trip-specific or link-specific basis.

One of the most essential modeling component to the analysis, modeling, and simulation methodology is the time-of-day choice model that provides sensitivity to traveler's temporal decisions with respect to sociodemographic, travel conditions, and cost of travel. This sensitivity is needed to effectively evaluate ITS and pricing strategies and improve forecasting results. So in the time-of-day choice models, the inclusion of more temporal details or time periods will make the models more sensitive to congestion pricing. Most of the prior time-of-day choice modeling studies considers time as a discrete variable, that is, the various time choices are represented by several temporally contiguous discrete time periods such as a.m. peak period, off-peak period and p.m. peak period. There are several drawbacks of using such an approach to model time-of-day choice.[4] The use of discrete time periods requires a pre-determined partitioning of the day into time intervals, the characteristics of which may or may not be the same in the future. This might preclude the analyses of potential future congestion pricing strategies during time periods which are smaller than those used in the base year. Also, the discrete choice structure considers the time points near the boundaries of intervals as belonging to one or the other of the aggregate time periods. But in reality, two closely spaced time points on either side of a discrete interval boundary are likely to be perceived as being similar rather than as distinct alternatives. So either many finer discrete time intervals have to be specified to obtain a reasonable time resolution, which might not be very practical as this will involve estimating many parameters, or a distinction should be made between adjacent discrete time periods.

CS recently completed an FHWA research project on time-of-day models that resulted in a methodology for time-of-day choice models that for trip-based models and another for activity-based models. These were tested and validated

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[3] Volpe National Transportation Systems Center, 1994, *IVHS Benefits Assessment Model Framework.* Final Report, Cambridge, Massachusetts.

[4] Bhat, C. R., and J. L. Steed, 2002, *A Continuous-time Model of Departure Time Choice for Urban Shopping Trips*, Transportation Research Part B (36), pp. 207-224.

in case studies in Denver and San Francisco. The trip-based time-of-day modeling method was applied to a pricing scenario in the Denver region. Tolls were assumed on a (currently toll-free) 20-mile section of a circumferential freeway. Tolls were highest in the two peak periods (0.2 to 3.5 hours long), with lower tolls in shoulder periods (1 to 3.5 hours) and lowest tolls in the off-peak periods. The time-of-day choice method estimated trips by time of day for half-hour periods. The application of the model for this scenario showed a modest amount of peak spreading resulting from the implementation of the period-based tolls.

The tour-based time-of-day modeling method was applied to a pricing scenario for downtown San Francisco. The time-of-day choice method estimated trips by time of day for half-hour periods. A hypothetical $4.00 toll was applied for all auto trips entering downtown San Francisco during the a.m. peak period (6:00 to 9:00). Although it is impossible to separate all of the effects of the pricing, it is apparent that the largest effect appears to be on mode choice. About 20 percent of the reduction in downtown trips is due to people choosing not to travel downtown at all. About 70 percent of the total, is due to changes is mode, and about 10 percent of the reduction appears to be due to time-of-day shifts. These results seem reasonable, as many downtown travelers, such as commuters to work, may not have the flexibility to change their times of travel.

For the Washington State DOT, CS updated the time-of-day choice models by dividing the five main periods (a.m. peak, midday, p.m. peak, evening, and night) into 30-minute subperiods, in order to model peak-spreading behavior [5]. In addition to auto travel time variations between periods, the model has also been structured in such a way that it will be sensitive to auto travel cost differences between periods, for instance to emulate time-of-day-specific congestion pricing. The new time-of-day choice models were estimated for eight trip purpose/direction combinations, using a new set of 32 alternatives.

Outputs of Time-of-Day Choice Model

The time-of-day choice models produce the choice probabilities that measure the magnitude or the ratio of vehicle trips made in a time interval to vehicle trips in the given base period, which is usually a day. These probabilities or ratios are applied to vehicle trip tables after the trip distribution modeling step. Based on the number of time-of-day choice models, the trip tables can be broken into the following categories:

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[5] Kuppam, A. R., M. L. Outwater, M. Bradley, L. Blain, R. Tung, and S. Yan, 2005, *Application of Time-of-Day Choice Models Using EMME/2 – Washington State DOT Congestion Relief Analysis*, presented at 19th International EMME/2 User's Group Conference, Seattle, Washington, October 19-21.

- O-D – Trip tables after trip distribution are subjected to the time-of-day choice models to produce the time-of-day shares for every possible O-D pair in the travel model. The O-D level disaggregation of trips is very important for any travel model that requires integration with a simulation model.
- Trip purposes – The models that were estimated as part of the FHWA study are home to work, home to non-work, non-home based, work to home, and non-work to home. The disaggregation of time-of-day choice models largely depends on the trip purposes included in the travel model, and also the data availability at the trip purpose level from the surveys.
- Direction – These models have to be estimated for both directions of a trip, onward and backward, as both of the segments of a trip are usually in different time periods or intervals.
- Time interval – The finer the time intervals, the better the representation of reality and the estimation of a number of important travel performance measures, including speeds, congestion, and emissions.
- Mode of travel – The time-of-day choice models are usually estimated for auto trips and the different auto modes typically modeled are single occupant vehicles (SOV) and high-occupancy vehicles (HOV).

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