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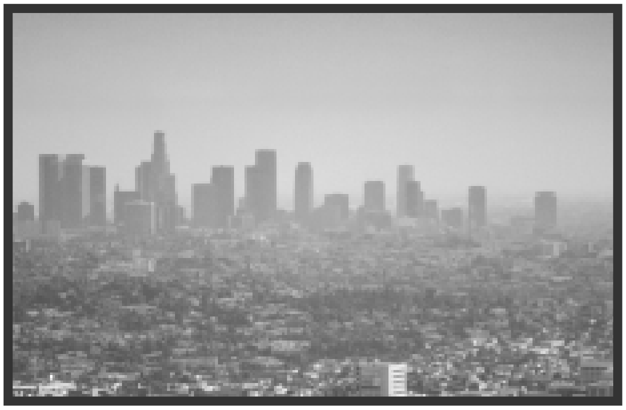
Assessing the Emissions and Fuel Consumption Impacts of Intelligent Transportation Systems (ITS)



Assessing the Emissions and Fuel Consumption Impacts of Intelligent Transportation Systems

Energy and Transportation Sectors Division
Office of Policy
U.S. Environmental Protection Agency

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FOREWORD

Intelligent Transportation Systems (ITS) include a broad range of transportation improvements, such as traffic signal control, freeway management, transit management, incident management, and regional multimodal traveler information services. ITS has generated considerable enthusiasm in the transportation community as a potential strategy for reducing highway congestion, improving highway safety, and reducing environmental impacts associated with motor vehicle travel. Some policy makers, however, are concerned that induced travel associated with ITS may partially offset the potential emission benefits of improved traffic operations. As a result, methodologies are needed to evaluate the full traffic and emissions implications of ITS deployment.

This study describes the types of modeling approaches needed to capture the short- and long-term transportation, emissions, and fuel consumption impacts of ITS deployment. It describes needed progressions in modeling approaches, including developments in travel demand, traffic simulation, and modal emissions modeling. The study identifies a framework for modeling the impacts of specific ITS components and discusses data issues relevant to an evaluation of ITS impacts.

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CONTENTS

EXHIBITS

1. Introduction

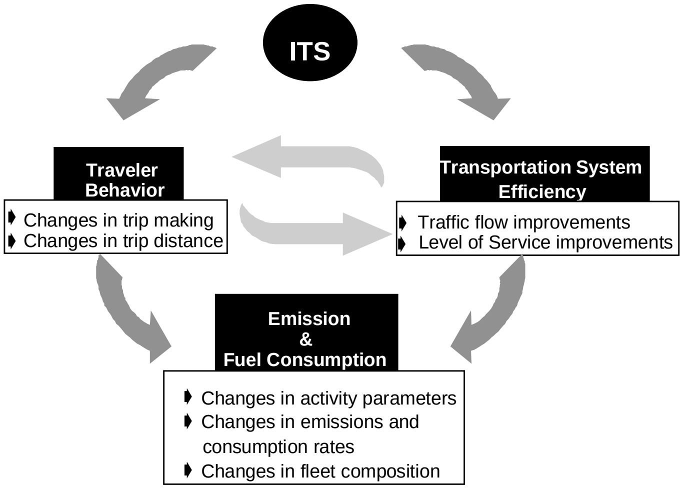
Intelligent Transportation Systems (ITS) have generated considerable enthusiasm in the transportation community as a potential strategy for reducing highway congestion, improving highway safety, enhancing the mobility of people and goods, promoting economic productivity, and reducing the environmental impacts associated with motor vehicle travel. However, as state and local governments across the country proceed with the deployment of ITS services and technologies, some policy makers are concerned that the detrimental emission effects of increasing the number of vehicle trips and miles traveled may partially offset the potential emission benefits of improved traffic operations and system efficiencies. The objective of this study is to describe the types of modeling approaches needed to capture the short- and long-term transportation and emission/fuel consumption impacts of ITS deployment.

As illustrated in Exhibit 1, the deployment of ITS user services can be expected to affect the following general parameters, which can be thought of as deployment outcomes:

- traffic flow along specific links of the highway network
- the number of trips (vehicle or person) by time-of-day and mode along specific links
- trip distance for specific origin and destination (O-D) pairings.[1]

These general parameters are interrelated and encompass most of the factors that characterize transportation system performance and traveler behavior. For example, the integration of traffic management and traveler information systems may affect travel behavior as users of the system adjust their departure times, destinations, mode choices, and/or route choices in response to a more complete information set. Adjustments in these variables determine the number of trips and traffic flow along links, as well as trip distances across O-D pairings. Likewise, traffic signal control, freeway management, and incident management may

Exhibit 1
Tracing the Emissions and Fuel Consumption Impacts of ITS



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[1] Note that at the aggregate level (i.e., for a specific transportation network) the number of vehicle trips and trip distances combine to determine vehicle miles of travel (VMT). Likewise, traffic flow is normally characterized by average travel speed, which determines travel time. VMT and speed are important activity-based indicators of trip emissions and fuel consumption. However, changes in average travel speed will not capture the full effects of ITS deployment on motor vehicle emissions and fuel consumption as the operating profile of the vehicle itself (i.e., accelerations and decelerations) is often more important.

affect volume-to-capacity ratios, vehicle hours of travel and delay, average trip speeds, vehicle modes of operation, and other indicators of traffic flow along specific links. As traffic flow improves on a specific link, the number of trips along that link may increase as travelers adjust to changing traffic conditions. These effects may in turn impact trip distances.

A methodology for evaluating the emissions and fuel consumption effects of ITS must address all potential deployment outcomes, including the potential for induced travel effects. Induced travel is defined as: 1) trips that people would like to be able to take, but that they forgo because of associated delays and excessive travel time; 2) increases in motor vehicle trips resulting from mode shifts; and 3) increases in vehicle miles of travel (VMT) stemming from increases in the distances of trips. Significant improvements in the transportation system (usually, increases in roadway capacity) that lower users' perceived costs of travel (primarily by reducing travel times) can induce additional vehicle miles of travel (VMT), therefore increasing emissions and fuel consumption.[2] Thus, a methodology will need to evaluate the impacts of modified traveler behavior that may, in some cases, reduce or negate potential emission benefits from improved traffic flow.

Mapping the deployment of specific ITS elements to transportation system performance, travel behavior parameters, and, subsequently, to emissions and fuel consumption impacts is a challenging exercise, as many of the effects attributable to ITS will be multidimensional. Although progress has been made in enhancing or developing new travel demand, traffic simulation, and emissions models, more must be done to accurately assess the short and long-term emissions and fuel consumption impacts of ITS.

The remaining sections of this report describe potential modeling processes for estimating the impacts of ITS infrastructure (Section 2); and review developments in travel demand, traffic

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[2] The magnitude of changes in demand as a result of changes in price is summarized by the elasticity of demand. *Elastic demand* implies that a change in user cost (i.e., price) leads to major increases in travel. *Inelastic demand* implies that a change in price leads only to minor changes in the amount of travel. In the short run, the demand for travel is relatively inelastic, since travelers cannot readily alter their existing housing and employment locations. Consequently, changes in the perceived user cost of travel have a relatively small impact on travel demand. In the long run, however, households have the capability to select different housing and employment locations and to alter their behavior in other ways that may increase the demand for travel (as represented by the number and length of trips).

Recent work by the Institute of Transportation Studies at the University of California, Berkeley, shows that the elasticity of VMT with respect to capacity at the county level is 0.62, while the elasticity at the metropolitan level is 0.94. The increased VMT from a capacity expansion is estimated to be realized within two years at the county level and within four years at the metropolitan area level. This means, for example, that a one percent increase in capacity at the county level is expected to result in a 0.64 percent increase in traffic two years after the expansion project has been completed. (Source: Hansen, Mark. *The Traffic Inducement Effect: It's Meaning and Measurement, Transportation Research Circular, no. 481*, Transportation Research Board, National Research Council) simulation, and modal emissions modeling (Section 3). The appendix summarizes the types of data that must be collected to accurately assess the impacts of ITS.

2. ITS Evaluation Methodology

Decision makers rely on distinct models to address the broad range of transportation issues at the local, regional, and state levels. Metropolitan Planning Organizations (MPOs), for example, execute short- and long-term planning activities with the help of travel demand models that forecast the effects of alternative strategies on congestion within a regional transportation network. In contrast, transportation engineers typically use traffic simulation models to address road, link, or intersection-specific traffic issues and to develop site-specific improvement plans. Meanwhile, air quality and transportation planners estimate vehicle emissions using emission factor models (specifically MOBILE and EMFAC) that rely on aggregate activity estimates provided by conventional travel demand models.

Quantifying the emissions and fuel consumption impacts of ITS deployment will require a methodology that accounts for or resolves the significant imperfections of existing mobile source emissions models, travel demand models, traffic simulation models, and traveler behavior analysis. These deficiencies are summarized below.

- EPA’s MOBILE emissions factor model cannot accurately estimate the effect of traffic flow improvements on trip emissions (e.g., the effect of changes in the speed profiles of trips that are outside the scope of the Federal Test Procedure, or FTP).

- Conventional four-step travel demand models cannot account for 1) the impacts of changes in perceived travel costs on travel demand, 2) the long-term effect of transportation investments on land use patterns (both of which are relevant to assessments of induced demand), 3) the impacts of congestion relief on trip generation, and 4) the impacts of pre-trip information on mode or route choice.

- Conventional traffic simulation models focus on sub-area phenomena, but must be able to simulate traffic at the network level to account for the impacts of ITS system integration across traffic analysis zones (TAZ) and/or jurisdictions.

- Conventional travel demand, traffic simulation, and emissions/fuel consumption models are not linked and therefore do not ensure analytic consistency across spatial and temporal dimensions.

The purpose of this section is to present the types of modeling approaches needed to assess the emissions and fuel consumption impacts of ITS. First, shortcomings characterizing conventional emissions and transportation models are explored in more detail, and a conceptual modeling platform is described. Second, specific analytic methods are presented for each component of ITS deployment in metropolitan regions. Finally, the data needs associated with a comprehensive evaluation of ITS emissions and fuel consumption impacts are summarized.

2.1 Needed Progressions in Methodology

Analysis of the transportation and travel impacts of ITS deployment requires a modeling approach that integrates travel demand models with traffic simulation models. Traffic simulation models are needed to analyze the effects of specific ITS elements (e.g., advanced traffic signal control or ramp metering) on facility performance, while travel demand models are needed to assess the impacts of user services that affect traveler behavior. Furthermore, the effects of ITS deployment on facility-specific level-of-service must also be captured at the regional level, thereby requiring feedback mechanisms between traffic simulation and travel demand models. Once an integrated transportation modeling platform is developed, emissions and fuel consumption models can be linked to this platform to assess the effects of ITS deployment on vehicle emissions and fuel consumption.

2.1.1 Emissions Models

Motor vehicle emissions are highly dependent on the modal activity of a given trip. Power enrichment (acceleration) and motoring (deceleration) events are discrete vehicle operating modes that are each capable of producing significant emissions. High vehicle emissions during rapid vehicle acceleration result from enrichment of the engine’s fuel-air mixture, which achieves maximum engine power but creates high levels of unburned hydrocarbons and carbon monoxide. Laboratory tests have indicated that high acceleration rates are significant contributors to instantaneous emission rates, and that in some cases one sharp acceleration can cause as much pollution as the entire remaining trip.[3] Likewise, the poor combustion caused by rapid throttle closing (i.e., sharp deceleration) results in high emissions of unburned hydrocarbons and carbon monoxide. The fuel injection systems in most newer vehicles stop the addition of fuel during vehicle decelerations, but the resulting rapid throttle closing still causes a “spike” of unburned hydrocarbons and carbon monoxide.

The number of episodes of power enrichment and rapid throttle closing are a function of the smoothness of traffic flow. Vehicles operating in unsteady traffic may experience numerous rapid throttle-closing events without coming to a full stop or even sharply decelerating. These throttle closings, coupled with the accompanying accelerations, lead to high levels of emissions under stop-and-go or other variable speed conditions. Thus, ITS deployments that decrease speed

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[3] M. Barth, et. al. *The Development of a Comprehensive Modal Emissions Model: Operating Under Hot-Stabilized Conditions*. Transportation Research Board, Annual Meeting Paper No. 970706. January 1997.

variation by improving traffic flow can have important effects on a vehicle’s emission rate during a given trip.

Changes in the speed profiles of vehicle trips cannot be accurately accounted for in such widely used models as MOBILE and EMFAC. The baseline exhaust emissions data used in both models are based on a standardized driving cycle that was originally developed to duplicate the speed-time profile of a route in the Los Angeles metropolitan area in the late 1960s. New drive cycles are being constructed to represent a wider variety of functional class roadways and driving situations. A methodology that quantifies the emissions and fuel consumption impacts of ITS deployment must account for the impact of traffic flow improvements on vehicle operation events that are outside the envelope of drive cycles imbedded in MOBILE and EMFAC.

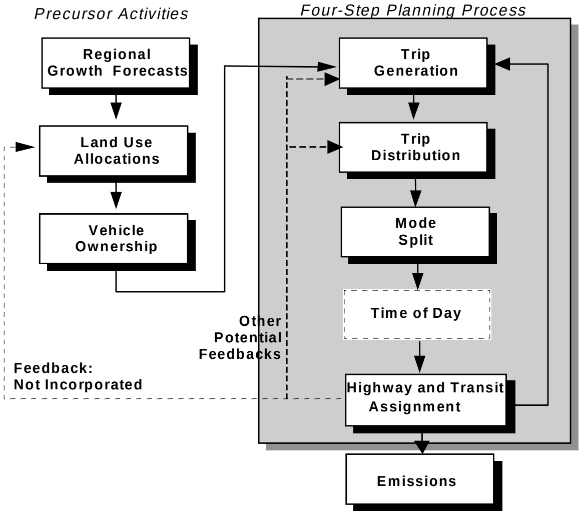
In response to this need, modal emissions models are being developed that can predict second-by-second tailpipe emissions under a variety of driving conditions. Calibration of such models requires test runs on freeways, arterials, collectors, and local streets, with instruments measuring the vehicle’s emissions by type, fuel consumption, and instantaneous speed variations. This calibration results in a correlation between emissions/fuel consumption and vehicle speed (acceleration/deceleration) under the entire spectrum of operating modes.

2.1.2 Travel Demand Models

Exhibit 2 shows the sequential forecasting process in a typical travel demand model. The transportation planning process is often referred to as the “four-step planning process.” The steps are summarized below.[4]

- *Precursor Activities: Land Use & Socioeconomic Projections*. Forecasts of future land-use patterns and socioeconomic demographics are the pre-step to transportation planning. In the traditional model, these independent variables influence trip generation rates. One major weakness in the sequential forecasting process is that land-use and socioeconomic distributions serve only as an input to trip generation but do not reflect changes due to improvements in the transportation system.

Exhibit 2
Traditional Transportation Planning Process



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[4] Schematic is based on that presented in EPA’s *Technical Methods for Analyzing Pricing Measures to Reduce Transportation Emissions*, EPA231-R-98-006. Description of the four-step process is gleaned from: Papacostas, C.S. and P.D. Prevedouros. *Transportation Engineering and Planning.* Prentice Hall, Englewood Cliffs, NJ. 1993.

- *Trip Generation.* As the first step of the traditional four-step process, trip generation deals with the decision to travel. It involves forecasting the number of person-trips that will begin from or end in each traffic analysis zone (TAZ) in the region on a typical day of the target year, estimated separately for a number of trip purposes (work, school, social and recreational, etc.). In this step, the number of trip ends (origins and destinations, or productions and attractions) in each zone are determined based on trip production/attraction rates associated with each land-use category and other characteristics.

- *Trip Distribution*. The second step involves the choice of destination, specifically the assignment of trips between trip-producing zones and trip-attracting zones to determine the trip volumes between all pairs of zones. Most travelers are attracted by zones that have higher levels of "attractiveness" (measured in terms of distance, travel time, and/or out-of-pocket costs). Common mathematical formulations of trip distribution include various growth factor models, the gravity model, and opportunities models.

- *Modal choice.* This third step involves the choice of travel mode. Factors that affect the mode selected include: trip characteristics (length of trip, time of day, orientation to CBD); trip purpose (home based work, non-work); transportation system characteristics (relative service level and costs associated with available modes); and trip-maker characteristics (auto-ownership, income). Models may also account for a transit-captive population.

- *Highway and Transit Assignment*. The fourth step involves the choice of route or paths between pairs of zones for each travel mode. Network assignment is used to forecast vehicular flows on the individual links that make up the transportation network. These estimates of link utilization can be used to assess likely levels of service and to anticipate potential capacity problems. A number of issues must be considered, including: average auto-occupancies, patterns of demand; assignment by time of day (to investigate performance during peak periods when capacity limitations become critical); and trip direction (e.g., flows during morning peak times are predominantly *toward* major activity centers).

Trips are assigned between nodes on the network by either minimizing individual user cost, called user equilibrium, or by minimizing overall cost to the system, called system equilibrium.[5] Speed post processing is used to modify highway speeds, which can be fed to transit assignment and also back to trip distribution and mode choice.

Using the data collected through travel surveys, traffic counts, and studies, these models are created, calibrated, and applied to evaluate the present system and analyze the future performance

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[5] Under user equilibrium users choose the route that minimizes their own travel times. Under system equilibrium users select routes such that they have equal travel times between the same origin-destination sets.

of the system. The calibrated results of the four-step process are used to identify the number of vehicle trips taken, vehicle miles traveled (VMT), and average speeds under varying infrastructure scenarios. These aspects of travel are used as inputs to EPA's MOBILE model and PART5 model in order to calculate the emissions impacts of infrastructure or other transportation projects.

Travel demand models were originally developed as a tool for planning both the location and size of new highway facilities. Some structural and theoretical aspects of travel demand models preclude a thorough analysis of ITS. In particular, assumptions of perfect knowledge of the system, presumed equilibrium condition, and lack of variation complicate the application of conventional travel demand models to ITS deployment evaluations.

To quantify the emissions and fuel consumption impacts of ITS deployment, models of trip generation, trip distribution, mode choice, and network assignment must be improved. For example, travel demand models are generally not responsive to corridor level, intersection, and communications related improvements or changes. These types of changes are usually analyzed using traffic simulation models. Traffic simulation models, however, may lack the behavioral underpinnings of travel demand models that are calibrated using regional travel behavior survey data.

2.1.3 Traffic Simulation Models

Traffic simulation models simulate the flow of traffic at a vehicular level, and some versions offer the option to simulate specific vehicle maneuverings such as acceleration, deceleration, weaving, start, and stop.[6]

Most of the existing microscopic traffic flow simulation models are designed for either a freeway system or a non-freeway network. A typical freeway traffic model simulates freeway segments and ramp segments. A typical non-freeway simulation model can simulate such road networks as arterials, collectors, and local streets. Outputs from these models include vehicle speed at specific link locations, moving delay, static delay, percent of total traffic in weaving mode, intersection delay, ramp delay, progression effectiveness, signal effectiveness, emissions, fuel consumption, volume to capacity ratios, and level of service. Such information can be used by vehicle

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[6] There are three types of traffic simulation models:

- macroscopic models such as FREFLO, NETFLO, and CORFLO
- mesoscopic models such as FRESYS, FREQ, Transyt, Passer, and HCM
- microscopic models such as FRESIM, NETSIM, CORSIM, HUTSIM, and INTEGRATION.

Microscopic models can keep track of each vehicle in the simulated network and include vehicle maneuvering models which be used to study the vehicle acceleration/deceleration characteristics under different levels of traffic flow. Examples of vehicle maneuvering models are TRANSIMS (under development), the Swedish VTI model, the German AUTOBAHN SIMULATOR model, INTEGRATION, and others.

maneuvering models to determine the speed-time profile of individual vehicles in a stream. The speed-time profiles can then be used by modal emissions and fuel consumption models to quantify trip emissions and fuel consumption.

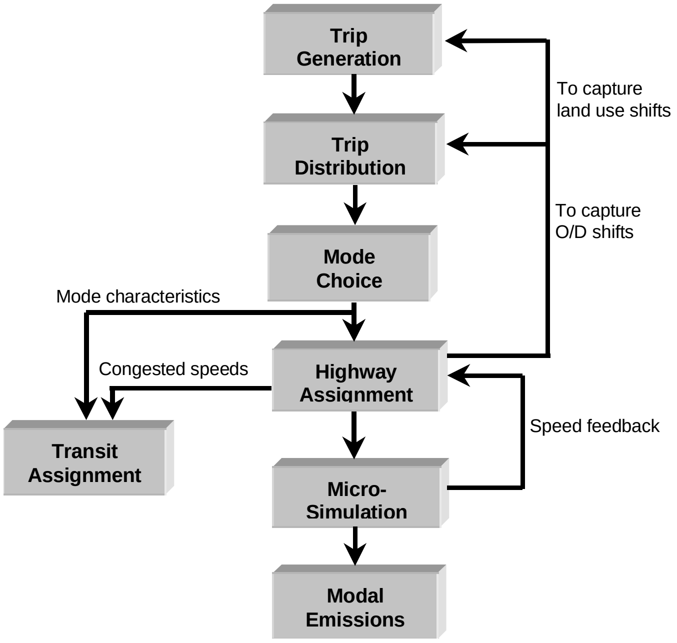
A central theme of ITS is the deployment of integrated information networks to support travel and increase utilization of the transportation infrastructure. This integration requires models that can simulate the effect of information on traffic flow at the corridor level and travel behavior at the regional level. Methodologies that quantify ITS impacts must be able to accept and interpret real time traffic data received from surveillance points along the network, and to represent real time demand and supply conditions along a corridor or over the entire regional network. As a result, use of a simulation model as a stand-alone tool would be an inadequate methodology for evaluating any ITS system.

2.1.4 Linking Travel Demand, Traffic Simulation, and Emissions Models

Exhibit 3 presents a generic methodology for linking transportation and emissions models. As shown in the exhibit, transportation models will require the following feedback loops:

- *Feedback from traffic assignment to trip generation*. The purpose of this loop is to capture the long-term effects of additional ITS-generated capacity on regional land use and trip making.
- *Feedback from traffic assignment to trip distribution*. The objectives of this loop are to: 1) provide speed-sensitive travel times for trip distribution, and 2) capture the long-term changes in destination (e.g., employment) or origin (e.g., housing location) due to ITS-generated capacity.

Exhibit 3
Linking Travel Demand, Simulation, and Emissions Models



- *Feedback from simulation models to traffic assignment*. The purpose of this loop is to provide more accurate travel time and congested speed estimates for traffic assignment, since most assignment models estimate link volumes based on congested speeds.

These model linkages and feedback loops make it possible to more accurately predict the emissions and fuel consumption impacts of ITS deployment. However, modeling individual ITS components may require a shift in emphasis to reflect the component's area of focus. For example, if examining traffic control systems, micro-simulation models may be used to capture the time savings that will be fed-back to the traffic assignment module of a travel demand model. The next section provides details on how specific ITS components can be modeled.

2.2 Modeling Specific ITS Components

Typically, the effects of transportation improvements on emissions and fuel consumption have been measured and analyzed using a combination of the following techniques:

- regional travel demand modeling
- microscopic traffic simulation, including vehicle maneuvering modeling
- emissions and fuel consumption modeling
- statistical analysis methods.

As discussed above, ITS evaluation methodologies must have the capability to produce emissions and fuel consumption impacts estimations that reflect a vehicle's mode of operation and level of acceleration/deceleration. Furthermore, a comprehensive, reliable, and executable ITS modeling methodology should have three primary characteristics.

- It should be flexible enough to allow the user to specify different parameter values, including implementation level and behavioral principles.

- It should be able to capture the dynamic mode and route choice effects of various ITS components.

- It should have the capability to simulate the driving patterns of each vehicle, yet provide output that can be handled by a reasonable amount of human and computing resources.

A generic modeling approach (such as the one presented in Exhibit 3) may not yield accurate results for all ITS components, as each component may have different traveler behavior and system performance repercussions. Some ITS components, such as freeway management systems, may have impacts that are predominantly corridor-level, rather than regional. Similarly, traffic signal control systems may impact performance in the short term (e.g., within six months of implementation) and in specific locations or corridors. In contrast, components such as multimodal traveler information systems may have predominantly regional impacts, but only after several years from the date of deployment. In this manner, the spatial and temporal dimensions and the expected impacts of a specific ITS component will determine the appropriate evaluation tool(s). Exhibit 4 summarizes the spatial, temporal, data, and modeling issues related to each of the nine components (plus system integration) of metropolitan-level ITS deployment initiatives.

Exhibit 4
Summary of the Spatial and Temporal Dimensions of ITS Components

	Region of Impact			Time of Impact			
ITS Element	Region/Transit System	Corridor/ Transit Line	Intersection/Park-and-Ride Lot/ Transit Stop	Instantly	Short Term (Less than 6 months)	Medium Term (6 mth. to 1 year)	Long Term (More than 1 year)
Traffic Signal Control		X	X	▨			
Freeway Management	X	X		▨			
Transit Management	X	X		▨			
Incident Management		X		▨			
Electronic Fare Payment	X	X		▨	▨		
Electronic Toll Collection		X		▨	▨		
Railroad Grade Crossings			X	▨	▨		
Emergency Management Services	X	X		▨	▨	▨	
Regional Multimodal Traveler Information	X			▨	▨	▨	▨
System Integration	X	X	X	▨	▨	▨	▨

Given that the spatial, temporal, and impact magnitude dimensions of specific ITS components may differ, a range of modeling approaches and analytic processes will be required. The following subsections present specific modeling platforms for each of the nine ITS components (plus system integration) listed in Exhibit 4. The underlying structure for each platform is the integrated modeling framework that is described in Exhibit 3. For several of the ITS components, specific analytic approaches are presented to illustrate ways in which the emissions and fuel consumption impacts of ITS can be assessed. The modeling approaches for each component rely on a modal emissions and fuel consumption model as the basis for impact assessments.

2.2.1 Traffic Signal Control

Exhibit 5 presents a framework for evaluating the emissions and fuel consumption impacts of implementing traffic signal control systems. As depicted in the flowchart, travel demand modeling, traffic simulation modeling, and modal emissions/fuel consumption modeling are linked to form a comprehensive process for evaluating the impacts of traffic signal control systems. The solid-line arrows represent the base case (*without*) scenario. The *with ITS* scenario is represented by the dashed-line arrows. The base case model uses land use/socioeconomic inputs in conjunction with highway and transit systems specifications to develop highway volumes and transit ridership estimates. These values are inputs to the traffic simulation models, which are used to develop vehicle speed-time profiles. The speed-time profiles and other vehicle operating characteristics are used in the modal emissions/fuel consumption model for generating estimates of emissions and fuel consumption impact. Arrows in bold and related text represent points in the modeling process that are expected to be influenced most by traffic signal control systems. Because traffic signal control systems are not expected to impact land use, the proposed modeling framework for the *with ITS* scenario does not include a feedback process to the trip generation step.

Bus and emergency vehicle signal preemption is expected to affect the shortest path travel time, even though the shortest path itself may not be impacted. Reductions in in-vehicle and out-vehicle travel times translate into modal shifts through the mode choice model. Thus, the ITS element is modeled in the travel demand modeling stage. Transit travel time savings may result in higher levels of transit ridership along the affected transit line(s). Traditionally, off-line techniques have been used for measuring emissions from and fuel consumption of transit vehicles. It may be possible to use the same off-line techniques for measuring the emissions and fuel consumption impacts related to buses and other transit vehicles.

Traffic Signal Control Systems have four components:

- signal coordination
- bus signal preemption
- emergency vehicle signal preemption
- arterial variable message signs.

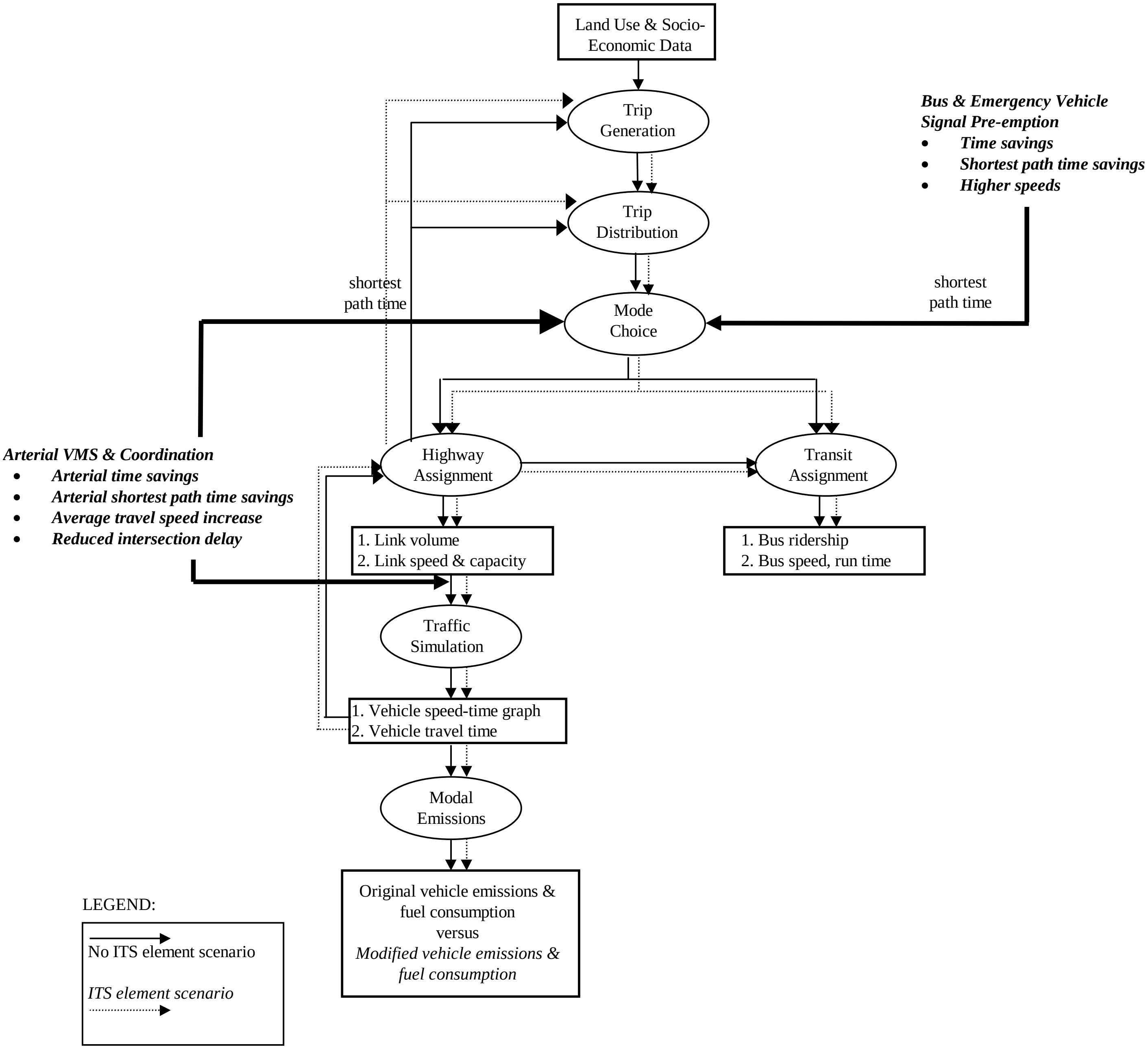
The following impacts are expected from these systems:

- reduced arterial travel times, implying an increase in average travel speed
- reduced stop/idle delay times for vehicles traveling on mainlines and at intersections
- better response to incidents and special events
- reduced bus round-trip times, implying increases in speed
- some mode shift to/from transit depending upon the strength of the impact
- reduced emergency vehicle response times
- increased safety at intersections

Arterial variable message signs (VMS) and signal progression can change highway assignment via shifts in route choice. Most travel demand models are not capable of accurately capturing route choice changes caused by minor travel time savings or signal progression. A more accurate way of modeling signal progression and arterial VMS is to use the network link volumes from traffic assignment as the starting point. The link volumes, travel time savings, and signal progression information serve as inputs to the simulation model. Such simulation models as TRAF-NETSIM/FRESIM and INTEGRATION can model route choice and provide the acceleration/deceleration characteristics of vehicles in the system for use in modal emissions models.

Any link-level traffic volume changes resulting from time savings must be captured by means of the feedback loops from the simulation model to highway assignment, and then from highway assignment to trip distribution. Any decreases in travel time due to signal control systems should be fed back to the trip generation and distribution steps.

Exhibit 5
Modeling Traffic Signal Control Systems



The installation of traffic signal control systems is expected on primary and secondary arterials in urban settings. With time, their coverage may extend to less urbanized areas. The magnitude of change in overall origin-destination travel times arising from deployment on primary and secondary arterials can be captured via the feedback from assignment to trip generation or trip distribution. There may be some route diversions, which may be captured through the feedback loop from simulation to the traffic assignment step.

2.2.2 Freeway Management

Freeway Management Systems have four components:

- ramp metering
- variable message signs (VMS)
- lane-control
- decision support systems, which provide freeway managers with options for adjusting freeway operations in real time.

The following impacts are expected from these systems:

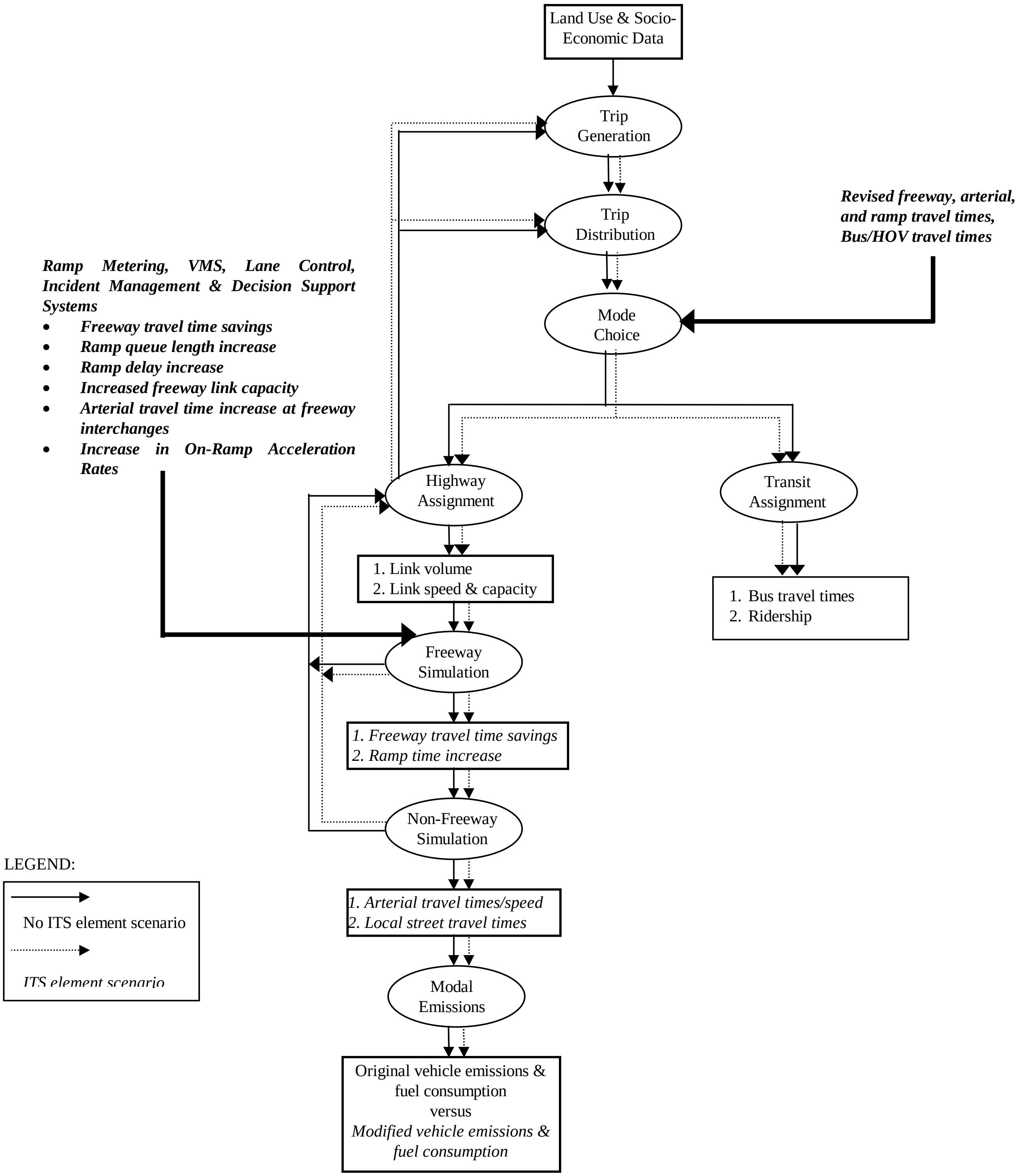
- reduced freeway travel times due to ramp metering
- increased ramp travel times and queues
- changes in acceleration -- ramp metering is expected to result in sharp acceleration events that produce high levels of emissions, possibly negating the benefits of reduced congestion on the freeway
- dynamic changes in freeway exit-points due to variable message signs, thus increasing freeway speeds
- better utilization of existing freeway capacity stemming from improvements in lane control
- reduced travel times on freeways that may be off-set by increases in single-occupant vehicle (SOV) travel
- increased travel times on arterials due to spillage of vehicles waiting to get on freeways
- increases in HOV travel resulting from HOV bypass to ramp metering
- longer through trips on freeways, given that such trips are typically favored over local access trips.

Exhibit 6 presents a methodology for determining the emissions and fuel consumption impacts of implementing freeway management systems. It shows that freeway management systems do not only affect the relevant freeway corridor, but also the entire region. This is because freeway management systems reduce freeway travel times while altering ramp and arterial delays. The size of reductions depends on the level of congestion on freeways and the placement of variable message signs (VMS) on arterials. Freeway management systems may have system-wide effects in terms of:

- land use shifts
- re-distribution of origins and destinations if travel time savings are significant
- mode shifts from HOVs to SOVs (and vice-versa) on freeways
- route changes from parallel arterials to freeways.

The flowchart presented in Exhibit 6 shows that the highway network and a region’s socio-economics are the primary inputs to the travel demand model. Freeway travel-time savings are not expected to influence transit travel times, except in the event of bus/HOV bypass at ramps or extensive freeway use by buses. Consequently, this methodology focuses on the highway assignment process. Output from the highway assignment process is fed into the freeway

Exhibit 6
Modeling Freeway Management Systems



simulation model. Traffic simulation modeling is divided into two sequential steps: 1) freeway simulation, and 2) non-freeway simulation. This is because changes in freeway and ramp travel times are expected to affect arterial travel times.

The freeway simulation process receives link volume and speed information from the highway assignment process. In addition, specific information on the nature of ITS deployments is provided. The output of freeway simulation is freeway link travel times, speed, ramp travel times, delay, spillage onto arterials in terms of vehicles per hour, and speed-time profiles for vehicles. Spillage information is then used as an input to the non-freeway simulation process, which then converts this into arterial travel time changes and delay time changes. Next, the freeway link time obtained from highway assignment is compared with the simulated freeway link travel time. If this difference is greater than a predetermined threshold (e.g., five percent), the simulated link times are fed back into the trip distribution step of the travel demand model. The feedback loop also contains information about arterial and ramp link travel times. This feedback loop does not directly connect the simulation model with trip distribution because the former processes information at the link level, while the latter processes information at the zone level. Traffic assignment processes information at both the link and zone levels, thereby providing a link between simulation and distribution. The feedback loop to trip distribution is used to capture increases in travel on freeways (stemming from route diversion or mode shift) arising from capacity increases.

In addition, a feedback loop to trip generation is required to capture long-term changes in land use patterns due to the deployment of freeway management systems. Once the modeled travel times are within acceptable limits, vehicle speed-time traces serve as inputs for a modal emission/fuel consumption model (or can be cross-referenced to emissions/fuel consumption look-up tables that reflect modal events). Emissions and fuel consumption estimates generated by this process can be compared subsequently to those under the base case scenario.

Overall, freeway management systems may have a significant impact on regional travel behavior and patterns. Induced travel as a result of changes in travel times can be captured through two feedback loops – one to trip distribution that will capture shifts in origins and or destinations, and another to trip generation to capture long-term land use and socioeconomic changes arising from significant improvements in the efficiency of the affected facilities.

2.2.3 Transit Management

Exhibit 7 presents a methodology for evaluating the emissions/fuel consumption effects of implementing transit management systems. These systems will directly impact transit route run times, out-vehicle and in-vehicle times, and transit route speeds. These impacts can increase the demand for transit services by shifting person-trips from other modes of travel. Transit in-vehicle times are expected to fall due to dynamic selection between options, which results in the shortest path between two stops. Transit management centers can relay information to buses and other vehicles about any diversions from the scheduled path between any consecutive stops.

The transit assignment process is used to produce line ridership estimates. These estimates are compared with observed ridership as part of a convergence test. If the two values are not statistically similar, the mode choice model is suitably modified to reflect improvements in the amount and quality of transit-related information. Once the mode choice model is re-calibrated and the convergence test is passed, a new transit trip table is generated. This trip table is subtracted from the total trip table to produce the highway trip table. The transit trip table is then assigned to the transit network, and the resulting line ridership, run times, and average speeds are used to produce bus speed-time profiles. The highway trip table, which is obtained by removing the transit portion from the total, is used for developing estimates of emissions and fuel consumption.

Transit Management Systems have three important components:

- user information dissemination
- automated scheduling
- automatic vehicle location (AVL).

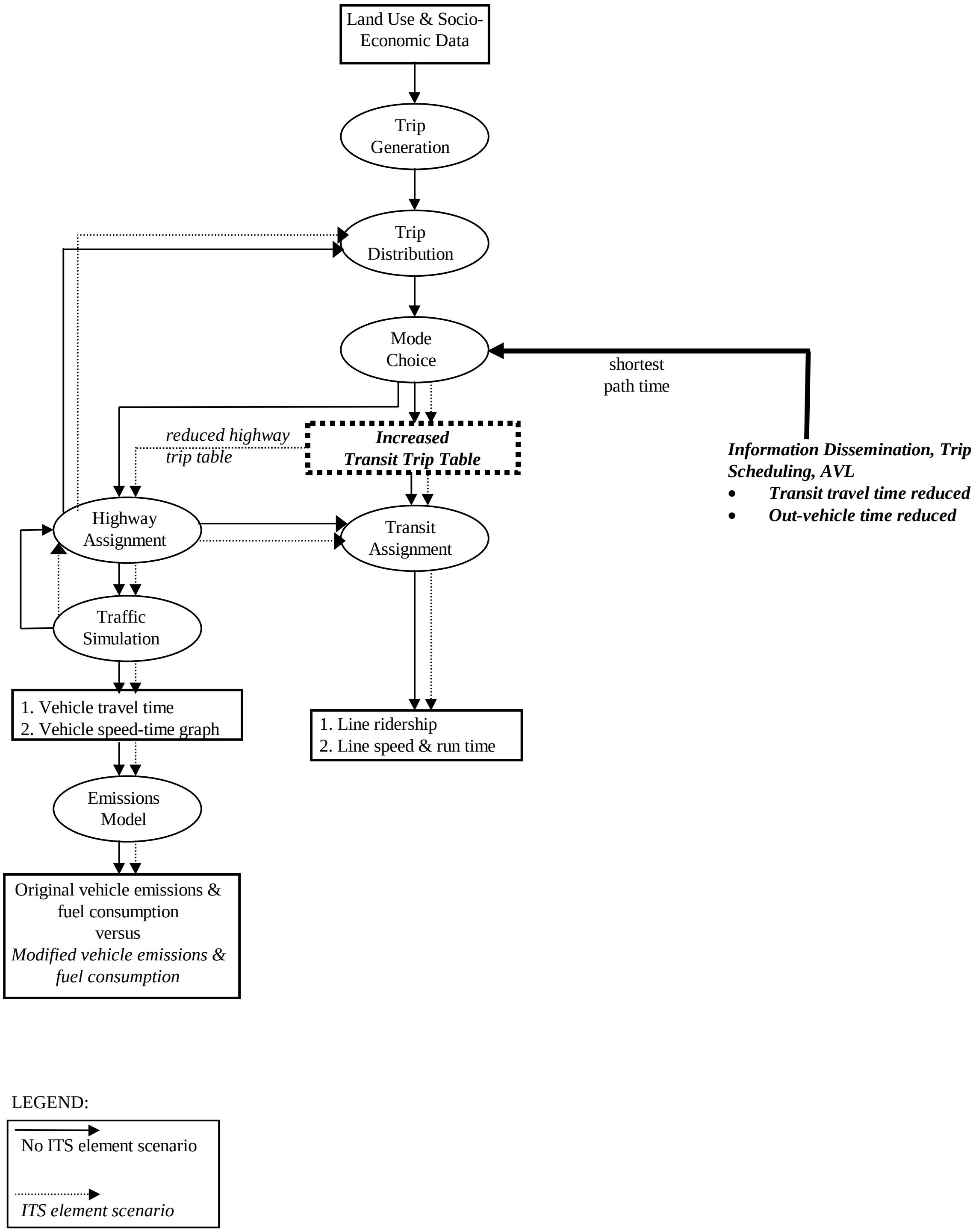
The following impacts are expected from these systems:

- decreased out-vehicle and in-vehicle times
- increased transit system reliability
- improved transit fleet utilization, which reduces operating expenses
- improved coordination between transit services such as bus transfers and bus-rail interface, promoting overall transit usage
- increased opportunity to provide fixed route deviation during non-peak periods
- reductions in labor intensive ridership data collection which reduces expenses.

Transit management systems are not expected to shift highway-related origin-destination pairs. Instead, minor changes in highway travel times are expected to change dynamic route choice. This is captured in the flowchart through the feedback loop from traffic simulation to highway assignment. A full re-calibration of the highway assignment procedure is not necessary because transit management systems are not expected to affect route choice. Therefore, the reduced highway trip table is assigned to the highway network. The resulting link volumes, speeds, and speed-time profiles are then used by a modal emissions/fuel consumption model to generate emissions and fuel consumption estimates.

In the short term, dynamic route diversion and time-of-day changes in tripmaking may cause mode shifts from single occupant vehicles to transit. Changing transit travel times can capture these mode shifts. In the long term, travel patterns will stabilize, resulting in equilibrium between the number of transit and non-transit person trips. However, total person trips are not expected to change as a result of improvements in the level of service of transit systems. Consequently, the induced demand effects of transit management systems are expected to be negligible.

Exhibit 7
Modeling Transit Management Systems



2.2.4 Incident Management

The incident management system evaluation methodology is presented in Exhibit 8. This methodology is similar to the freeway management systems evaluation methodology presented in Exhibit 6. The only difference is that instead of performing sequential freeway and non-freeway simulation, one combined traffic simulation module is sufficient.

Incident Management Systems have two important components:

- incident detection, verification, and response
- agency coordination.

The following impacts are expected from these systems:

- reduced incident response times
- increased travel reliability and changes in departure times
- reduced delays, especially those due to incidents on highways and freeways
- reduced highway travel times
- dynamic changes in destination, mode, and/or route choice.

Impacts from the deployment of incident management systems will be felt at the corridor level. The regional impacts of these systems are expected to be minor and short in duration. However, information on incidents may cause dynamic changes in the destination, mode, or route choice of travelers, particularly if there is a high frequency of serious incidents with major delays and unreliable travel times. Therefore, the travel demand model component of an incident management evaluation methodology must be able to capture the dynamic effects of incident management systems. In comparison to other ITS components, incident management systems usually address non-recurrent congestion, and therefore, the modeling methodology must account for the probability of incidents (by type of incident) to capture the variation in incident occurrence.

In order to capture potential short-and long-term induced demand effects of incident management systems, the modeling approach includes feedback from traffic assignment to trip generation and trip distribution. Incident management systems are expected to have a greater short-term effect on route and mode shifts than on long-term land use shifts.

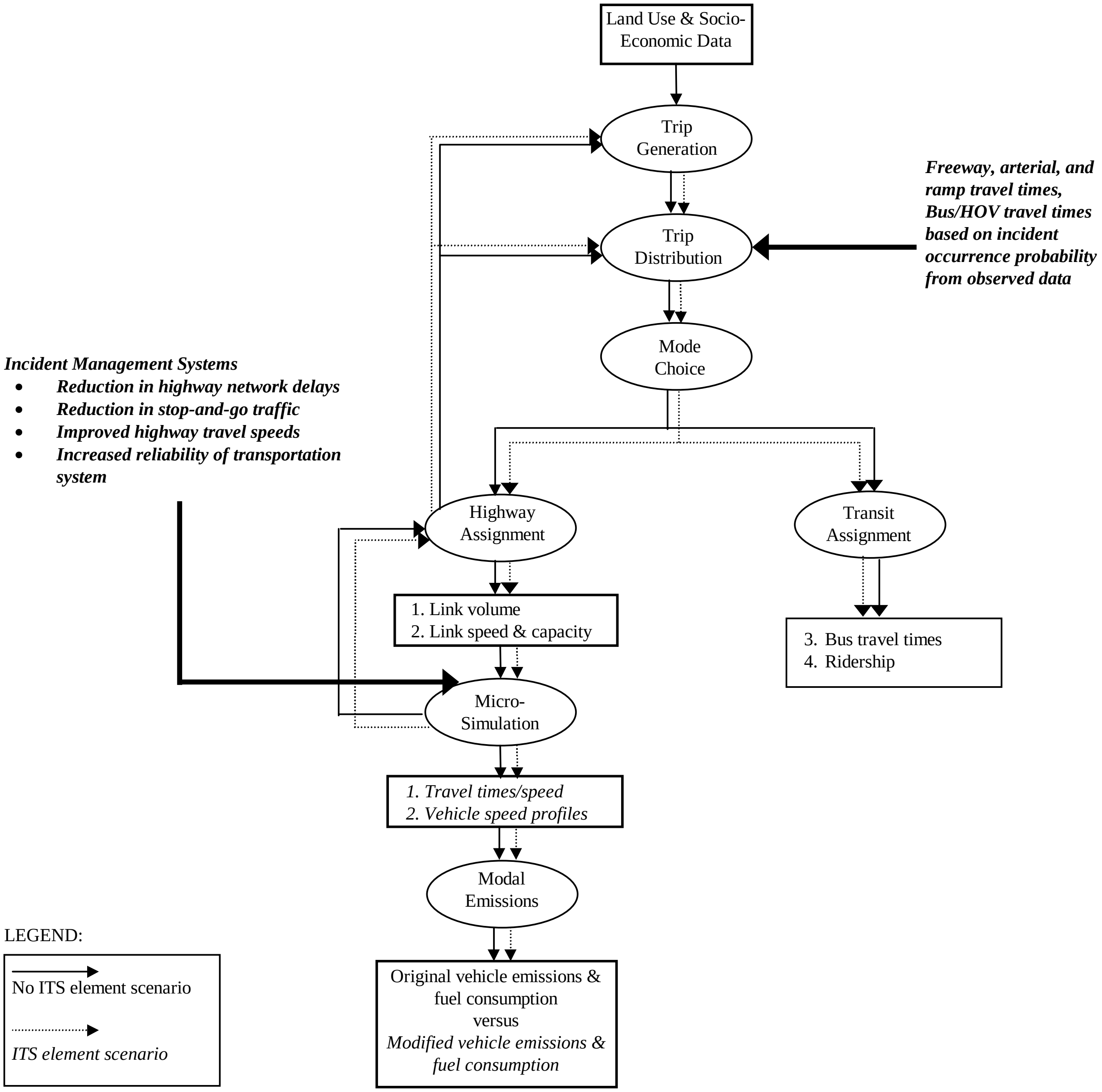
2.2.5 Regional Multimodal Traveler Information

Regional multimodal traveler information systems serve two primary functions:

- providing information about transportation services and performance of the system to users
- providing an information link between the various ITS components.

Information may be delivered to users through public channels such as kiosks, transit in-vehicle interfaces, television broadcast, radio broadcast, VMS, rideshare matching programs, and the Internet. Information may be provided by private companies in return for a fee. Such information would be available through cable television, auto navigation systems, and commercial vehicle

Exhibit 8
Modeling Incident Management Systems



routing and scheduling systems. Several different types of information will be available through regional multimodal traveler information systems:

- pre-trip planning information for both surface and air travel
- in-vehicle trip planning information especially in the case of unplanned events
- rideshare matching information
- mayday services information
- commercial vehicle routing and scheduling information.

The emissions and fuel consumption impacts of regional multimodal traveler information systems are driven by improvements in the quality and amount of information on traveler behavior at a microscopic level. Regional impacts associated with the level and quality of transportation information provided to the travelling public are expected to be realized in the medium to long term, since the habits and preferences of travelers may be relatively inflexible in the immediate or short term. The effectiveness of information dissemination, the user friendliness of information dissemination channels, the content of information, and user application of improved information for travel decisions will determine the magnitude of impacts.

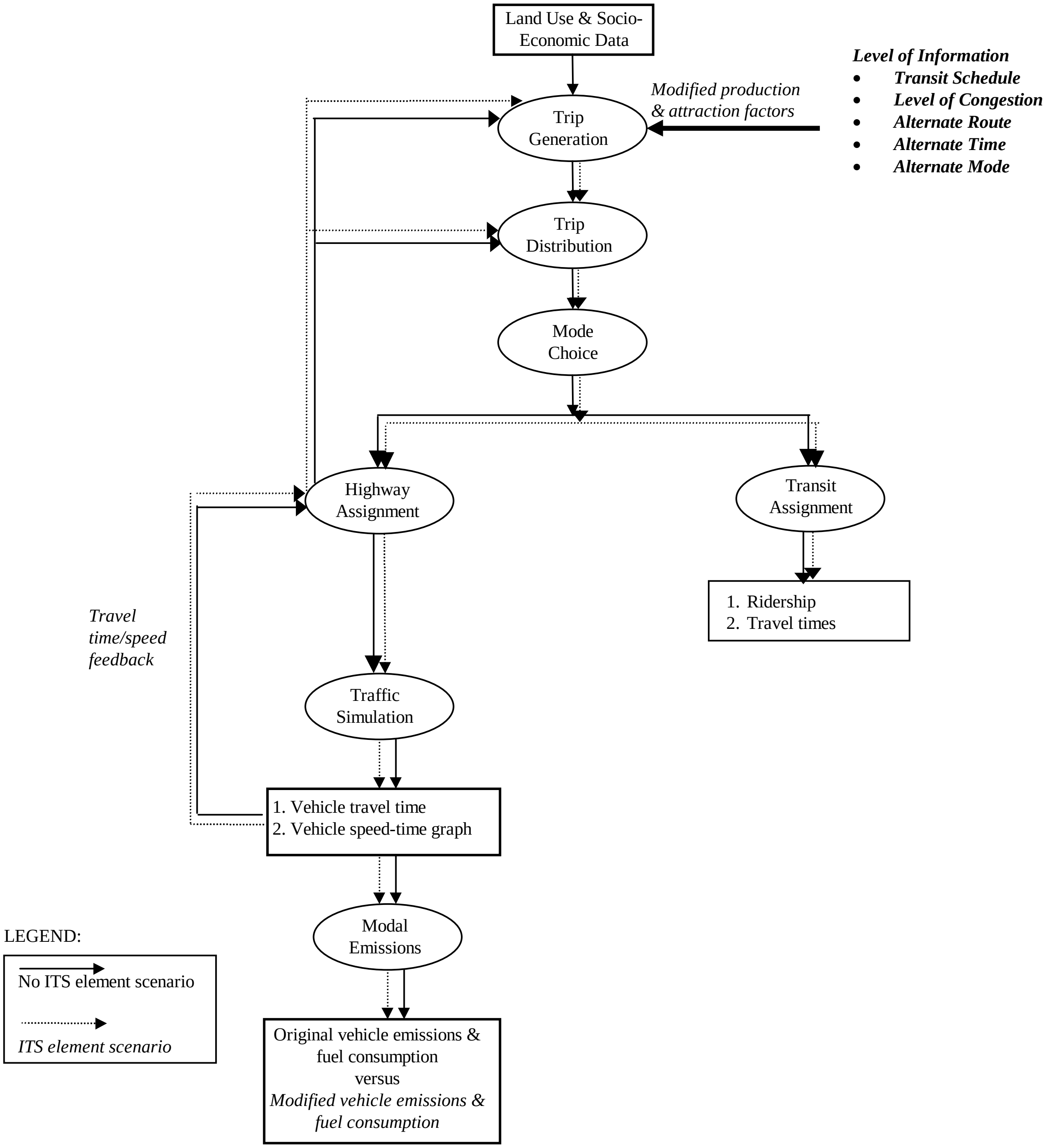
Exhibit 9 presents a methodology for evaluating the emissions/fuel consumption-related effects of implementing regional multimodal traveler information systems. It will be necessary to collect information on user acceptance by means of user surveys, market penetration research, stated preference surveys, and revealed preference surveys. It is expected that these systems will affect all decisions, including tripmaking, destination choice, mode choice, time of travel choice, and route choice. Thus, data will have to be gathered on these variables under the base case and the ITS scenario case.

Assuming that it is possible to survey users, the following information will be required to re-calibrate the four steps of regional travel demand models:

- trip production and attraction counts in select residential and non-residential localities
- origin-destination surveys on major highway and transit routes
- stated preference and revealed preference surveys for mode choice and time of travel choice behavior
- screen-line traffic counts and select link travel times.

Once the traveler behavior coefficients embedded in the travel demand model are adjusted to represent modified travel patterns, the modified travel demand model can be used for forecasting. Time of day choice can be modeled via an off-network method using travel demand management tools. A daily (24-hour) vehicle trip table can be input to a travel demand management model to

Exhibit 9
Modeling Regional Multimodal Traveler Information Systems



vary the percent of daily traffic occurring during any given hour of the day. This model will produce hourly trip tables that can be used in the traffic assignment step of the travel demand modeling phase.

Under the *with ITS* scenario (represented by the dashed line Exhibit 9), trip generation rates are modified to adequately reflect the effect of increased information on trip making behavior. Once modified trip productions and attractions are available, the trip distribution process must be re-calibrated using new friction factors between zone pairs. The calibrated trip distribution trip tables can then be used by the mode choice equations to determine mode shares. Stated preference and revealed preference surveys provide a basis for re-calibrating the coefficients of various mode choice parameters. The assignment process may be judged based upon the accuracy of the link volumes predicted by the process. Accuracy may be determined by a comparison with the observed screen-line volumes. If the assignment results are not close, trip generation can be modeled again.

Once link volumes and speeds are obtained from assignment, this information will be input into the traffic simulation package. The traffic simulation package, with link geometry data, is used to determine the operational characteristics of each individual vehicle. Feedback from simulation to assignment is used to fine-tune link-level travel times and speeds, which are fed into trip generation and/or distribution to capture ITS-impacted travel times. Speed-time profiles of vehicles can then be used by modal emissions/fuel consumption models to generate fuel consumption and emissions estimates. These estimates can be compared with those for the base case to determine the relevant impacts of regional multimodal traveler information systems.

Improvements in the quality and amount of travel information are expected to impact traveler behavior as users make travel decisions based on observed — rather than perceived — travel times and costs. In the long term, under the *with ITS* scenario, travel patterns are expected to stabilize at a higher level of demand. Differences in long-term demand levels between the *with* and *without ITS* scenarios can be modeled by using feedback loops from traffic assignment to trip generation. In this manner, the induced travel effects of multimodal traveler information systems can be assessed.

2.2.6 Other ITS Components

Other ITS components such as electronic toll collection and railroad crossing may be modeled based on local practices and data availability. Once all the individual components are in place, they must be integrated into one system that supports travel across all modes and regional boundaries. System integration is comprised of a set of protocols, methods, mechanics, and telecommunications elements that bring together the individual ITS components. Once integrated, the effect of individual components is expected to multiply several fold, thus making system integration an extremely important process in the implementation of ITS.

System integration has the four key dimensions:

- integration of information across ITS components such as transit management, freeway management information, emergency response management information, traffic signal control information, railroad grade crossing systems, and incident management
- integration of information across regions, such as coordination of signals between jurisdictions to ensure smooth traffic flow
- integration of transit management systems in abutting regions to ensure continuous service to users
- integration of incident management information across regions to provide the fastest possible response to an incident.

To determine the emissions/fuel consumption impacts of system integration, it is important to determine the inter-relationships between various ITS components. Exhibit 10 presents a schematic representation of these inter-relationships. It shows that ITS components are closely linked to each other either directly or through other components.

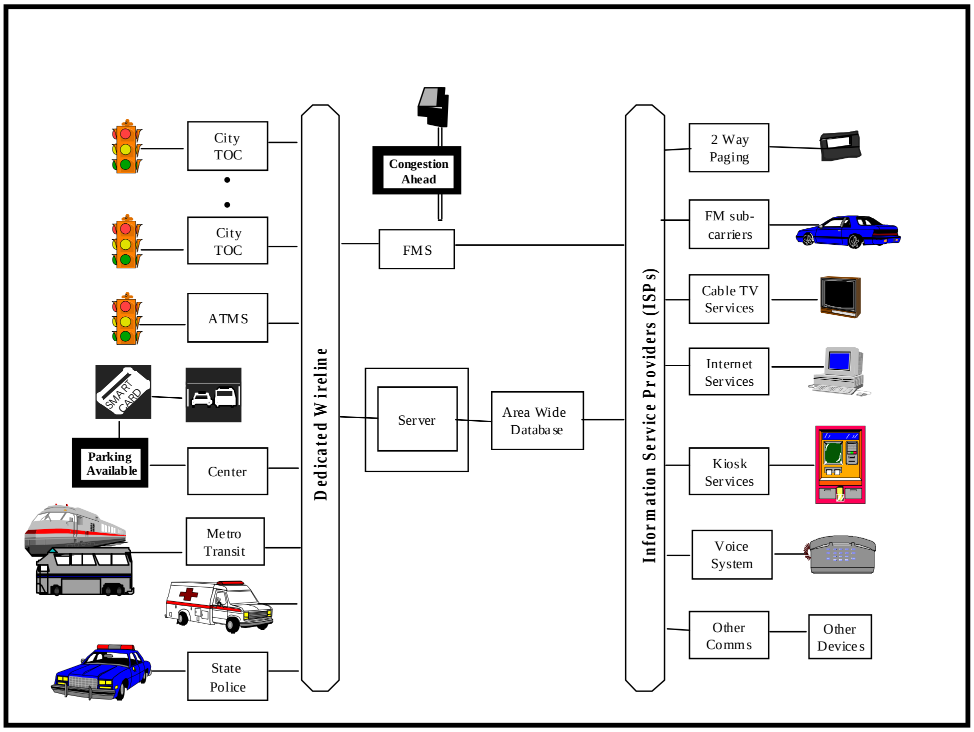
Multimodal traveler information is the most important component, as it connects all other components. Emergency and incident management systems are connected to freeway management systems (FMS), traffic management systems, and transit management systems through the regional information network. The regional information network consists of a dynamic database accessed by various means.

The methodology for modeling system integration brings together all the different ITS components discussed in the earlier sections of this report. Each ITS element is expected to have individual impacts. But when components are integrated, it is difficult to identify the individual impacts of each component. Several components are expected to have similar impacts, thus making the impact more pronounced; conflicting impacts are expected to nullify each other. One logical way to model this complex system is to include all the individual components in the methodology. The methodology will require re-calibration at almost every modeling step, as it is a combination of the enhancements detailed in Exhibits 5 through 9.

Thus, the difficult question to answer — especially for ITS implementation — is whether or not integration provides benefits that are greater than the sum of individual ITS components.

Operational efficiencies and inter-jurisdictional coordination may provide integrated benefits that result in better management of the transportation system. In terms of the impact on emissions and fuel consumption, only a comprehensive modeling approach can capture the benefits and/or costs of total system integration.

Exhibit 10
Relationships among System Integration Components



TOC: Traffic Operations Center
FMS: Freeway Management Systems
ATMS: Advanced Traffic Management System

2.3 Data Issues Relevant to an Evaluation of ITS Impacts

Extensive data support will be required to fully evaluate the emissions/fuel consumption impacts of ITS deployment. Data will be required for the *without* and *with* scenarios. The *without* scenario, referred to as the base case, may not include ITS elements. The *with* scenario builds on the base case by including ITS deployments and other transportation infrastructure development programs.

This subsection presents a detailed assessment of the types of data that are needed for an evaluation of the fuel consumption and emissions impacts of ITS deployment. First, results from an Expert Panel Session[7] are summarized to help guide the ITS modeling process. Second, an overview of a data collection, organization, and retrieval methodology is presented to guide the data needs assessment. Third, data needs are reviewed for each general category of the data collection process (e.g., transportation system, emissions and fuel consumption, and ITS deployment).

A central objective of the Expert Panel Session was to obtain input on the types of data needed to support the fuel consumption and emissions evaluation process and on the strategies needed to collect such data. The following general issues were raised by the panelists during the Session.

- A comprehensive inventory of ITS deployment initiatives must be developed for the relevant region. This issue is linked to the need for a well-defined evaluation baseline that will dictate data needs.
- Emissions and fuel consumption data must be evaluated using transportation planning information to assess the state of the region-specific transportation systems and travel patterns, and to identify information gaps that must be resolved.
- Supplementary data collection plans need to be designed to assist regions in the execution of primary and secondary data acquisition. Such plans should be based on a comprehensive assessment of data needs and alternative collection strategies.
- Newly developed survey instruments and other data collection strategies should reflect the entire spectrum of an ITS evaluation.

These issues are further discussed in the following subsections.

2.3.1 Data Availability

As part of their transportation and air quality planning processes, a given region or Metropolitan Planning Organization (MPO) has extensive information characterizing its transportation system, the manner in which the system is used by travelers, and the performance of the system in terms

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[7] An Expert Panel Session was convened on January 16, 1997 to gather information on the types of analytic tools that are available (or will be forthcoming) for quantifying the fuel consumption and emissions impacts of ITS deployment. The Expert Panel consisted of the following individuals: 1) Mohan Venigalla of EG&G Dynatrend/Volpe Center (now with Wilbur Smith Associates); 2) John German of EPA's Office of Mobile Sources; 3) Joon Byun of FHWA's Office of Environment and Planning; 4) Matthew Barth of the University of California at Riverside; 5) Ron Smith of the Los Alamos National Laboratory; 6) Jim Bunch of Mitretek; 7) Simon Washington of the Georgia Institute of Technology; 7) the late Greig Harvey of Deakin, Harvey, Skanardonis Associates; 8) Brian West of the Oak Ridge National Laboratory; 9) Bob Dulla of Sierra Research; and 10) Michael van Aerde of Queens' University (now with Virginia Polytechnic Institute and State University).

of air quality, safety, congestion, and other indicators. The following data sources and/or activities need to be reviewed to ensure that an evaluation process reflects site-specific conditions.

- The relevant region's transportation improvement program (TIP) should be reviewed to identify the system performance and traveler behavior impacts of other transportation projects that may be initiated within the ITS deployment time frame. This will ensure that ITS deployment impacts are not confused with impacts from other transportation investments.

- The relevant region's transportation and air quality planning processes should be reviewed to identify information gaps and opportunities for augmenting planned data collection activities. For instance, regions periodically execute travel surveys to collect data for input into travel demand models. Data from the most recent surveys could be used for the ITS modeling process.

Although regions may currently house useful information, much of the data needed for the evaluation process will need to be collected from primary and/or secondary sources.

2.3.2 Data Collection Plans

Given that the fuel consumption and emissions evaluation will require a modeling platform that integrates travel demand models with traffic simulation and fuel consumption/emissions models, data needs may not be met by current data collection activities at a relevant site. Significant resources will need to be devoted to data collection. In essence, data collection plans need to focus on the following needs.

- *Data characterizing vehicle operations at each site.* Some regions have already formulated plans to deploy probe vehicles to gather speed data along specially equipped facilities. Similarly, data that reflect spatial and temporal variability in vehicle operations can be collected by vehicle instrumentation. This will ensure that vehicle operations can be characterized at the desired level of specificity (e.g., on a second-by-second basis). Data collected from probe vehicles and vehicle instrumentation can be employed to calibrate the models used for the evaluation of the fuel consumption and emissions impacts.

- *Data on system market penetration.* A central focus of an ITS deployment plan may be the integration of traffic management systems with traveler information and public transportation systems. Consequently, data must be collected to assess the expected market penetration of traveler information services. Such an assessment is crucial for the estimation of route choice, mode choice, and induced demand impacts.

- *Data characterizing traveler behavior*. Given that many ITS deployment strategies may focus on traveler information systems, surveys may be used to collect information on traveler behavior, especially as it relates to pre-trip planning. The manner in which travelers will respond to more complete and improved travel information must be assessed using travel surveys. Surveys may also address traveler behavior changes stemming from congestion mitigation.

- *Defining a baseline*. The assessment of impacts stemming from ITS deployment depends largely on the analytic baseline from which differences in traveler behavior and system performance will be calculated. Baseline definition will dictate the types and quantity of data needed for the evaluation process. For instance, if the baseline is defined as September 1996, data on system performance and traveler behavior must be collected for the period between September 1996 and the evaluation date. This period will correspond to the "before" (or "without") ITS deployment scenario. These baseline data will then be compared to data collected during the evaluation period. In contrast, if the baseline is defined to capture ITS initiatives prior to September of 1996, data on the effects of those systems will need to be collected or constructed.

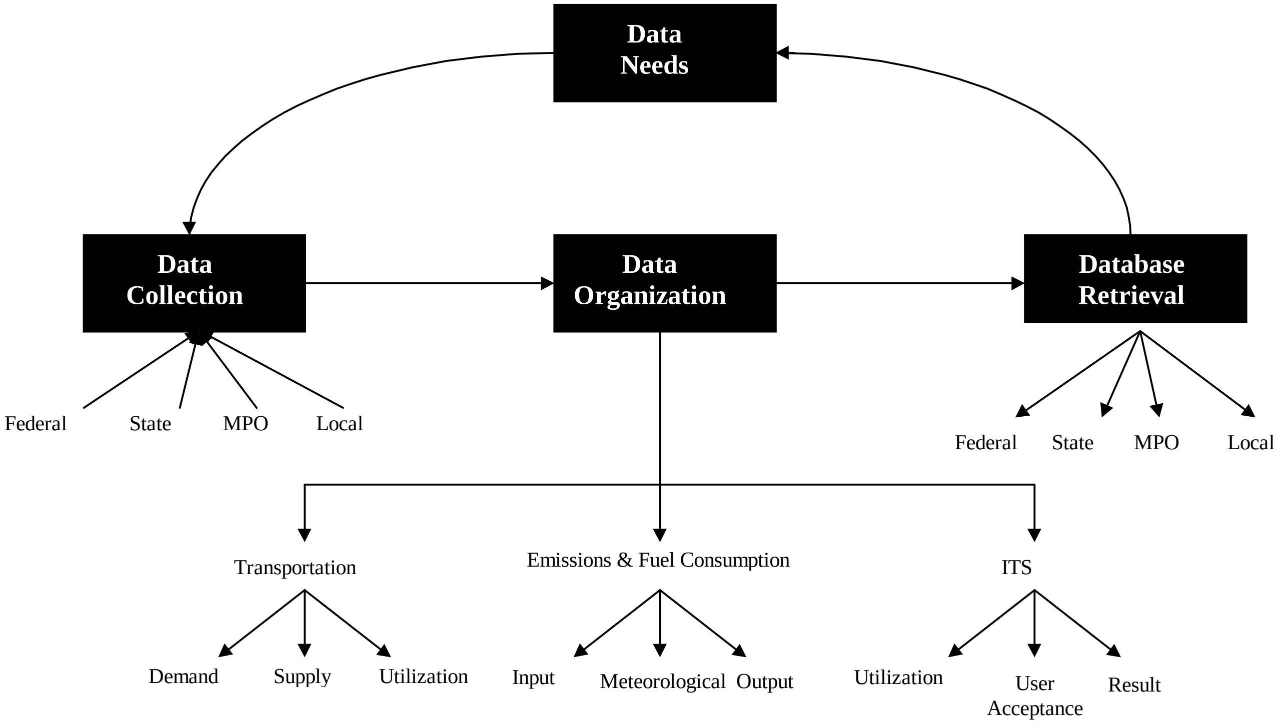
Although these data needs were identified during the Expert Panel Session many other general categories of data will be required for the evaluation process. The appendix details the type of data needed for an emissions and fuel consumption evaluation of ITS.

2.3.3 Overview of Data Framework

To effectively use information, it is necessary set up a data collection, organization, and retrieval framework. This will help in reducing the time and cost involved with acquiring accurate data, and will prevent any duplication of data collection efforts. Exhibit 11 shows a generalized data collection, organization, and retrieval framework that can be used to guide this process.

- *Data Collection.* Once data needs are defined, data can be collected by one or more planning agencies at the state, metropolitan planning organization (MPO), or local government levels. Data collection responsibilities may be shared or individually managed depending upon the data to be collected. Data collection characterizing a region's transportation system (such as roadway inventories) may be best performed at the state level, whereas census population data are available from federal sources. The MPO or the local planning agency may collect site-specific data on traffic signals, for example. Ultimately, the determination of the responsible party will be based upon economies of collection, geographic scope, resources, and data uses.

Exhibit 11
Data Collection, Organization, and Retrieval Cycle



- *Data Organization.* The manner in which data are grouped affects the efficiency and stability of the evaluation process. Data organization should start at the data collection level. Data should be collected so that little effort is expended in re-organizing them to the format shown in Exhibit 11. Data could be organized under three major groups: transportation, environment (i.e., emissions and fuel consumption), and ITS. Under each of the three major groups, data could be organized in three sub-categories. For example, the three transportation system categories could be demand, supply, and utilization; the three environment system categories could be input, meteorological, and output; and the three ITS categories could be utilization, user acceptance, and result.

- *Data Retrieval.* Data retrieval is directly related to data storage and access technologies. This implies data sharing and protocol checks among the involved agencies. The data retrieval system should be based on a platform that is both cost-effective and used widely. Sample methods are relational databases and GIS-based systems. Data retrieval processes should be secured to protect against damage to the data at source.

2.4 Summary of Methodologies

Evaluations of the transportation system efficiency, traveler behavior, and emissions/fuel consumption impacts of ITS deployments will require significant progressions in transportation and emissions/fuel consumption models. The modeling approaches presented in this section rely on an integrated platform that links regional travel demand, traffic simulation, and modal emissions and fuel consumption models. To date, such integrated models have not been developed, and their construction will require a significant amount of resources.

Consequently, the methodologies presented in this section delineate the types of analytic and modeling challenges that need to be considered by an evolutionary progression in state-of-the-art transportation and emissions/fuel consumption modeling. Future models must be able to capture the short- and long-term impacts of ITS deployment, including land use and induced travel effects. Likewise, future models will require highly disaggregate data on vehicle activities to capture many of the intricate system performance effects of ITS deployments.

The following section summarizes the research efforts to develop state-of-the-art transportation and emissions modeling. The methodology progressions that characterize these efforts are important to the eventual development of analytic procedures to accurately and reliably estimate the emissions and fuel consumption impacts of ITS.

3. Review of Research Efforts & Models

As part of developing this report, an Expert Panel Session was convened on January 16, 1997 to gather information on the types of analytic tools that are available (or will be forthcoming) for quantifying the fuel consumption and emissions impacts of ITS deployment. Input on two key issues was sought from the Panel members.

- What are the most effective analytic tools for assessing emissions and fuel consumption impacts?
- What types of data need to be collected to support modeling needs or impact assessment requirements?

The objective of the Session was *not* to achieve consensus on the specific elements of the modeling methodology, but rather to obtain input to help guide the development of analytic approaches for an evaluation effort. In this regard, the Session provided useful insight on the types of analytic processes that need to be employed to successfully estimate the emissions and fuel consumption impacts of ITS deployment. This insight has served as the basis for the methodologies presented in this report.

The objective of this section is to review current research that can be used to facilitate current and future evaluations of the emissions and fuel consumption impacts of ITS. The Session provided useful overviews of research activities in transportation and emissions modeling. However, to obtain detailed information on the modeling platforms and research timelines, follow-up telephone discussions and a literature review were conducted. Although numerous modeling efforts are underway across the country, this section focuses on the research programs and available models shown in Exhibit 12.

3.1 Models in Development

A review of each of the referenced models is provided in the following subsections. The model descriptions that follow include features currently available, as well as those proposed for the future. The distinction between proposed and available features should be noted when comparing the capabilities of various models, as features present in existing models may appear relatively weak when compared with proposed features of models that are not yet available. To adequately model the fuel consumption and emissions impacts of ITS, a modeling tool or a set of tools must be developed that incorporates some of the advanced features of the ongoing efforts.

Exhibit 12
Research Programs Reviewed in this Study

Model Type	Model Reviewed
Traffic Simulation Models	INTEGRATION Model FHWA's TRAF-NETSIM Model
Travel Demand Models	General Developments in Travel Demand Modeling Deakin, Harvey, & Skabardonis (DHS) STEP Model
Emissions Models	MOBILE6 UC Riverside's Modal Emissions Model Georgia Tech's GIS-Based Mobile Emissions Model
Combined Transportation Models	UC Berkeley's AIRQ Model TRANSIMS Mitretek System's Modeling Efforts

Consequently, continued developments in models that may be functional in the longer term (i.e., within three to five years) may become integral to modeling efforts around the nation.

3.1.1 INTEGRATION (v. 2.0) Traffic Simulation Model

INTEGRATION (v.2.0) is a microscopic traffic simulation and dynamic assignment model that has been proposed for use in the evaluation of ITS implementation. Version 2.0 traces the movement of individual vehicles on freeways and arterials to a resolution of one deci-second.[8] Incorporating a built-in traffic assignment algorithm, the model tracks, on a second-by-second basis, the spatial and temporal activities of up to 500,000 vehicles operating on a sub-area with a maximum of 10,000 links. INTEGRATION's ability to combine arterial and freeway movements sets it apart from most conventional traffic simulation models.

While INTEGRATION tracks vehicle positions and speeds to within one deci-second, the current fuel and emissions logic uses values averaged over a one-second period. Fuel consumption rates are calculated for three modes of vehicle operation: constant speed cruise, velocity change, and idle. For a given vehicle, the fuel consumption rate (in liters/hour) is modeled as:

- a function of travel speed for the *constant speed cruise* vehicle operation mode
- a function of initial and final speed for the *velocity change* operation mode
- a constant during the *idle* operation mode.

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[8] The name "INTEGRATION" comes from the model's ability to combine movements on arterials and freeways.

As part of the TravTek Route[9] Guidance experiment, the fuel consumption algorithm was calibrated using information collected from an instrumented 1992 Oldsmobile Toronado operating in Orlando, Florida. Using published EPA fuel consumption ratings by vehicle model and a procedure for decomposing EPA's highway and city driving cycles, the fuel consumption algorithm was generalized to reflect variances across the representative vehicle fleet. Fleet coverage can be expanded to model the fuel consumption of any gasoline-fueled, light-duty vehicle for which EPA fuel economy ratings are provided. In this manner, the basis for expansion is achieved using information obtained from the instrumentation of only one vehicle — the Oldsmobile Toronado — and secondary data to approximate the in-use vehicle fleet. Consequently, INTEGRATION does not truly characterize the in-use vehicle fleet, and does not account for fuel consumption and emissions attributable to medium- and/or heavy-duty vehicles.

Using relationships between fuel consumption and tailpipe emissions, a compatible emissions module has been developed and incorporated into the modeling platform. Specifically, correlation coefficients were developed between the fuel consumption rates for the 1992 Oldsmobile Toronado (at travel speeds of 0 mph, 19.6 mph, and 55 mph) and the HC, CO, and NOx emissions rates predicted by MOBILE5a for all 1992 gasoline-fueled vehicles traveling at the referenced speeds. Using curve-fitting techniques, curves describing emissions per gram of fuel consumed (as a function of average travel speed) were derived independently for CO, HC, and NO_x.[10] The effects of cold-start and hot-start operation and ambient temperature are modeled by correction factors applied to the fuel consumption rates calculated via the relationships specified above.

Neither the fuel consumption nor the emissions algorithm is sensitive to the levels of acceleration experienced by a vehicle during a specified trip. However, given that the traffic simulation component of the model traces vehicle operations on a second-by-second basis and speeds are updated every deci-second, routines that calculate levels of acceleration can be readily incorporated into the methodology.

Exhibit 13 depicts the approach for validating and calibrating the fuel consumption and emissions algorithms imbedded in INTEGRATION (v.2.0). The emissions algorithm is "reversed engineered" to mimic the drive cycle inherent in MOBILE5a. Thus, the current version of INTEGRATION will produce a different emission profile when using a drive cycle different from

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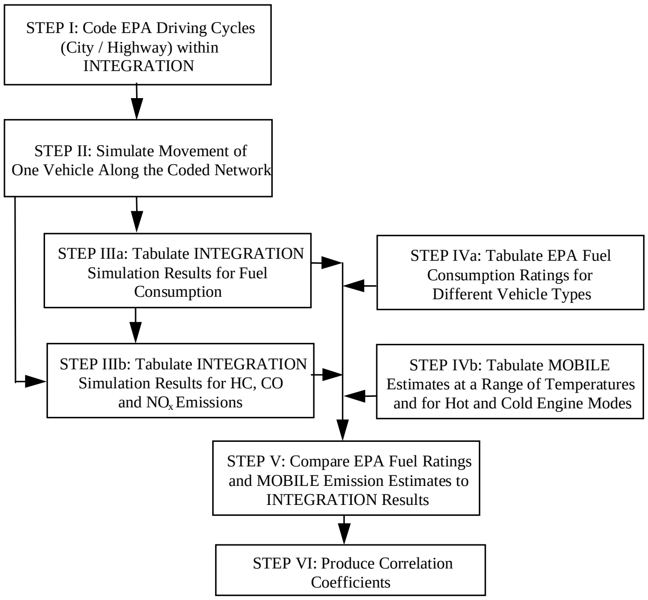
[9] Van Aerde, Michael and Baker, Mark, Department of Civil Engineering, Queen's University, Kingston, Ontario, Canada, *Modeling Fuel Consumption and Vehicle Emissions for the TravTek System.* Presented at IEEE-IEE Vehicle Navigations and Information Systems Conference (VNIS), 1993.

[10] Note that in predicting fuel consumption, INTEGRATION differentiates between vehicle models (e.g., a Honda Civic versus an Oldsmobile Toronado). However, the emissions to fuel consumption relationships imbedded in the model are not sensitive to different vehicle models and only reflect the 1992 model year.

the default used by MOBILE5a. Other characteristics of the fuel consumption and emissions modules of INTEGRATION are summarized below.

- Algorithms incorporate the effect of grade, and if regions have grade data at the sub-area level, they can be incorporated into the model.
- Every trip start is assumed to be a cold start, and as a vehicle progresses through the simulation, fuel consumption and emissions reflect changes in catalytic converter efficiencies.
- Trip segments are accounted for, but trip-chains are not; the algorithms could be changed to account for these chains, given supporting data.

Exhibit 13
Conceptual Approach to Fuel Consumption and Emissions Analysis



Source: Van Aerde and Baker, Queen's University, 1995

Despite some shortcomings specifically in the areas of modeling acceleration/deceleration, modal emissions modeling and a bias towards 1992 Oldsmobile model vehicles, INTEGRATION is a major step in the right direction. It emphasizes the importance of micro-scale modeling to better capture the fuel consumption and emissions impacts of ITS implementation. Opportunities to improve the fuel consumption and emissions algorithms of the model will be investigated in conjunction with work being conducted by other researchers.

3.1.2 FHWA's TRAF-NETSIM Traffic Simulation Model

TRAF-NETSIM is a microscopic traffic simulation model that tracks the movements of individual vehicles on a second-by-second basis at single intersections and on freeway segments and ramps. Unlike INTEGRATION, TRAF-NETSIM's operating environment does not cover entire freeways or corridors. However, the range of driving behavior covered by TRAF-NETSIM includes velocities between 0 and 110 feet per second *and* acceleration levels between ± 9 feet/sec^2 (i.e., acceleration levels between roughly ± 7 mph/sec). In this manner, this model is well suited to capture events outside of the FTP, which only extends to accelerations that are between ± 3 mph/sec.

As in the case of INTEGRATION, the modeling capabilities of TRAF-NETSIM have been expanded to include modules for predicting fuel consumption and emissions. Using a user-

specified drive cycle, the current version of TRAF-NETSIM estimates hot-stabilized emissions of CO, HC, and NO_x as a function of a vehicle's travel speed and level of acceleration.
The relationship between emissions, speed, and accelerations inherent in TRAF-NETSIM has been established from data gathered on-road (via vehicle instrumentation) and on a chassis dynamometer. In the early 1980's, the Oak Ridge National Laboratory (ORNL) developed fuel consumption models for TRAF-NETSIM based on testing data covering fifteen light-duty vehicles. Emissions data were also collected on six of the fifteen vehicles, and results were employed to develop lookup tables that relate CO, HC, and NO_x emissions as a function of travel speed and acceleration. More recently, ORNL has revised the relationships to include information collected from tests on eight well-functioning, late-model year vehicles, ranging from a 1988 Chevrolet Corsica to a 1995 Geo Prizm. The testing techniques included:

- steady-speed testing conducted on public roads
- acceleration testing conducted on an airport runway
- emissions and fuel consumption measurements on a chassis dynamometer.

The derived emissions and fuel consumption relationships were incorporated into TRAF-NETSIM and then validated against four different drive cycles: the FTP, ARB02, REP05, and HL07. Results indicate that the relationships imbedded in TRAF-NETSIM map relatively well to estimates developed under each of the referenced drive cycles.

While the current version of TRAF-NETSIM incorporates the revised emissions and fuel consumption relationships developed by ORNL, FHWA plans to upgrade the model in the following ways:

- Expand the traffic simulation capabilities of TRAF-NETSIM by linking it to a macroscopic traffic model — specifically, TRAF-NETFLO. This will allow for larger spatial scales than the single intersections, freeway segments, or freeway ramps that are currently modeled.[11]

- Add modal emissions and fuel consumption lookup tables that represent such specific facilities as freeways, arterials, and freeway ramps, and such specific driving activities as lane changing.

- Further revise the emissions and fuel consumption relationships to better represent the in-use vehicle fleet. For example, ORNL is currently soliciting funds to conduct a second battery of tests on eight malfunctioning vehicles.

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[11] FHWA is in the process of developing CORSIM. This traffic simulation model will expand on the geographic representation of TRAF-NETSIM while retaining TRAF-NETSIM's fuel consumption and emissions components. FHWA is currently testing the relevant algorithms.

These activities will enhance future versions of TRAF-NETSIM. In the short-term, it may be possible to use TRAF-NETSIM's current emissions and fuel consumption relationships to improve the emissions and fuel consumption modules of INTEGRATION. Doing so will ensure that the operating environment (i.e., freeways, corridors, arterial networks) inherent in INTEGRATION is maintained and that a more robust emissions and fuel consumption methodology is developed.

Some important caveats characterize this option, however. First, TRAF-NETSIM does not account for trip-based emissions, since it only estimates emissions under hot-stabilized operating conditions. Second, although the emissions and fuel consumption relationships inherent in TRAF-NETSIM may be more robust than those inherent in INTEGRATION, they do not reflect the in-use vehicle fleet. Finally, incorporating the TRAF-NETSIM emissions and fuel consumption relationships into INTEGRATION only addresses the modal emissions issue, it does not address the need for feedback mechanisms to travel demand models.

3.1.3 UC Berkeley's AIRQ Post-Processor for Linking Transportation Models

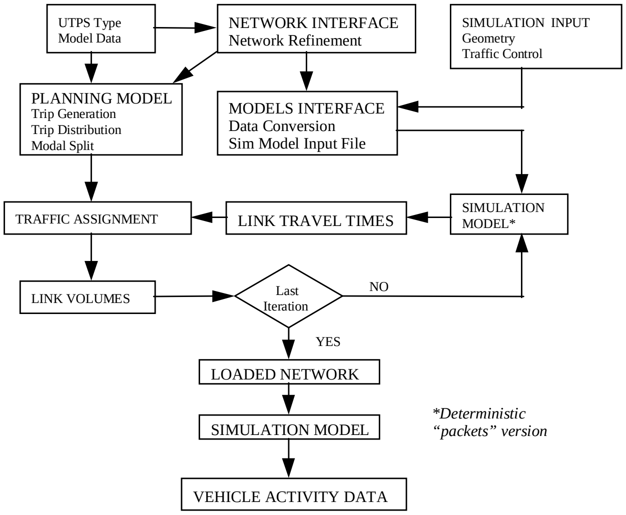
Exhibit 14 demonstrates the process that can be used to link travel demand models (such as UTPS) with traffic simulation models (such as TRAF-NETSIM). Projected traffic volumes from the travel demand model can serve as inputs for the traffic simulation models, which are then executed to produce estimates of the total time spent by vehicles in each driving mode. Travel speeds predicted by the simulation model are then fed back to the traffic assignment algorithm employed by the planning model to refine link volumes until a user-specified convergence criterion is achieved. Given convergence, the simulation models can be executed with the final link volumes to estimate the time spent in each driving mode (including level of acceleration).

While this feedback routine increases the accuracy of the volume estimates, two issues complicate the application of this approach in the field.

- This model formulation requires multiple microscopic simulations of large-scale networks; this may not be feasible to simulate given the computer resources typically employed by practitioners.

- The data required to run the models are not readily available to most MPOs. Specifically, simulation models require detailed network coding at the intersection/approach level, as well as data on lane channeling and usage, traffic control, etc.

Exhibit 14
Linkage of UTPS and Simulation Models



The University of California at Berkeley recently developed a transportation modeling platform that addresses these constraints, and can be employed to develop detailed modal emissions inventories for large urban areas.[12] Using TRAF-NETSIM, INTRAS,[13] and field data, UC Berkeley developed relationships between the time spent in each driving mode (i.e., cruise, acceleration, deceleration, and idle) and basic link characteristics based on simulations of selected surface street networks and freeway sections in the San Francisco Bay Area (which encompasses 1,120 zones). To integrate the simulation models with four-step travel demand models (specifically UTPS), the relationships were incorporated in a post-processor model named AIRQ. AIRQ consists of relationships between link characteristics and the proportion of the total time spent per driving mode. In turn, these relationships are used to calculate vehicle activity from the travel demand model outputs.

To decrease the data and coding requirements inherent in the approach depicted in Exhibit 14, AIRQ incorporates a stratification scheme of individual network links into distinct "link types" that are a function of facility type, design, traffic, and control characteristics. For each "link type," the process centers around two steps.

- Using micro-simulation models, vehicle activity data are generated on small-scale networks for different combinations of link characteristics and demand patterns.

- Simulation outputs produce the set of relationships determined by the following functional relationship:

$$T_{ij} \quad = \quad F(\mathit{link\ type}, v/c)$$

where T_{ij} is the proportion of time spent on a network link i in driving mode j expressed as a function of the link's type and the volume to capacity ratio (v/c) specific to the link.

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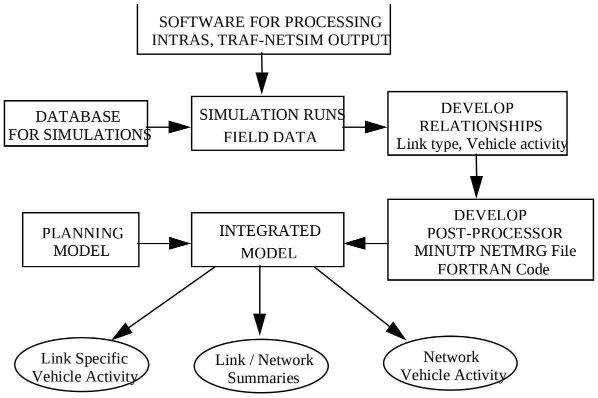
[12] See Skabardonis, Alexander, TRB Paper No. 97-0123, *A Modeling Framework for Estimating Emissions in Large Urban Areas*, January 1997.

[13] INTRAS is a microscopic traffic simulation model that traces the second-by-second activities of vehicles operating along freeways.

In this manner, the VMT, travel time, volume, and v/c for each link type estimated by the travel demand model serves as the input for the post-processor to obtain time spent by mode. Exhibit 15 demonstrates the process employed to develop the AIRQ model.

To validate the model, predicted volumes and speeds were compared with field data over 100 representative links in the MTC San Francisco Bay Area network. Although results were developed for the typical morning peak hour, the model can be applied to other time periods by executing the assignment algorithm of the four-step travel demand model to obtain link volumes and speeds specific to a temporal scenario. Given that results from planning models can be affected by peak spreading, adjustment factors can be applied based on volume profiles and network congestion patterns to modify the volume estimates per time period.

Exhibit 15
Process for Developing the Proposed Model



Source: University of California, Berkeley, January 1997

This approach exemplifies an innovative modeling methodology for linking travel demand models to traffic simulation models. Even though the Expert Panel Session did not discuss AIRQ, this model may be useful for the fuel consumption and emissions modeling effort. At a minimum, results from the model integration routines developed for this effort can be compared to those developed by UC Berkeley.

Although UC Berkeley's modeling methodology addresses the necessary linkages across travel demand and traffic simulation models, it does not detail how the model results can be linked to modal emissions and fuel consumption data to develop a comprehensive methodology for modeling emissions and fuel consumption impacts of ITS. Efforts are currently underway that may provide valuable modal emissions data and model interfaces for such a modeling methodology. These are discussed below.

3.1.4 EPA's MOBILE6 Emissions Factor Model

EPA is in the process of revising and improving MOBILE, its highway vehicle emissions factor model. The current version of the model, MOBILE5a, was released in March 1993, and one interim update to the model has been conducted since then (MOBILE5a_H).[14] Given that four

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[14] MOBILE5a_H incorporated a number of changes intended to improve the ability of modelers to estimate the benefits of various innovative inspection and maintenance (I/M) programs and to improve the accuracy of modeling situations in which such programs are applied to different subsets of the relevant motor vehicle fleet.

years have elapsed since the last comprehensive revision to MOBILE, and that additional test data and analyses have become available since 1993, EPA's Office of Mobile Sources (OMS) is planning significant changes to be incorporated in a new version of the model, MOBILE6.

OMS plans significant changes not only to the underlying emission factor estimates, but also to how emissions factors are modeled. The most pertinent changes relevant to modeling the emissions impacts of ITS are described below.

- *Development of new facility-specific driving cycles*. One area of concern with respect to the accuracy of modeled emission factors has been the methods used to correct emission estimates based on the Federal Test Procedure (FTP), which represents overall urban area driving. EPA is improving the accuracy of emission estimates over the range of travel speeds of interest along specific roadway functional classes. Facility-specific drive cycles have been developed using second-by-second speed data collected from vehicle instrumentation. EPA is in the early stages of conducting vehicle tests to characterize emissions under the representative drive cycles. However, emissions will not be characterized on a second-by-second, or mode-by-mode, basis. Nevertheless, facility-specific drive cycles will reflect events outside of the envelope of the FTP, thereby enhancing emission factor estimates. Likewise, facility-specific drive cycles and emissions estimates will facilitate the integration of emission factor models with traffic simulation models.

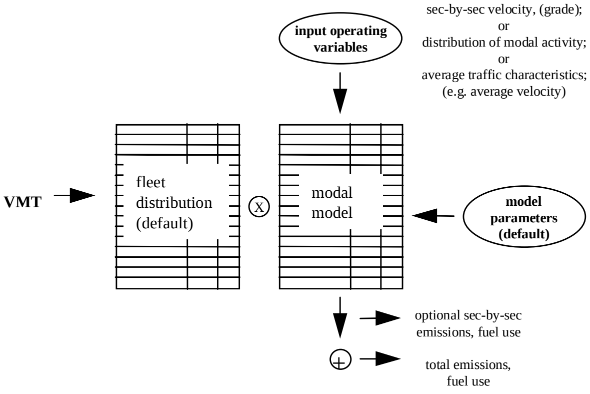
- *Start emissions and separation of start from running emissions*. MOBILE has used operating mode fractions (describing the portion of overall vehicle miles traveled under cold-start, hot-start, or stabilized operating conditions) as an input to provide exhaust emission factors in grams per mile that include start emissions. EPA is proposing to make two major changes in this area: 1) the provision of start emissions (in grams per vehicle per start) and stabilized running exhaust emissions in grams per mile, and 2) the modeling of start emissions as a function of the time that vehicles have been off, or "soak time."

While these changes would strengthen an ITS emissions evaluation process, MOBILE6 will not be released for use until 1999. Until then, facility-specific drive cycles are available and vehicle testing is almost complete.

3.1.5 UC Riverside's Modal Emissions Model

Under the sponsorship of the National Cooperative Highway Research Program (NCHRP), The University of California at Riverside is currently developing a comprehensive modal emissions model involving in-house dynamometer testing of over 300 vehicles.[15] As conceptualized, the model will predict second-by-second tailpipe emissions under a variety of driving conditions for a wide range of light-duty vehicles—vehicles that can be characterized as well-functioning, deteriorating, or mal-functioning. A generalized concept of the model's inputs and outputs is provided in Exhibit 16.

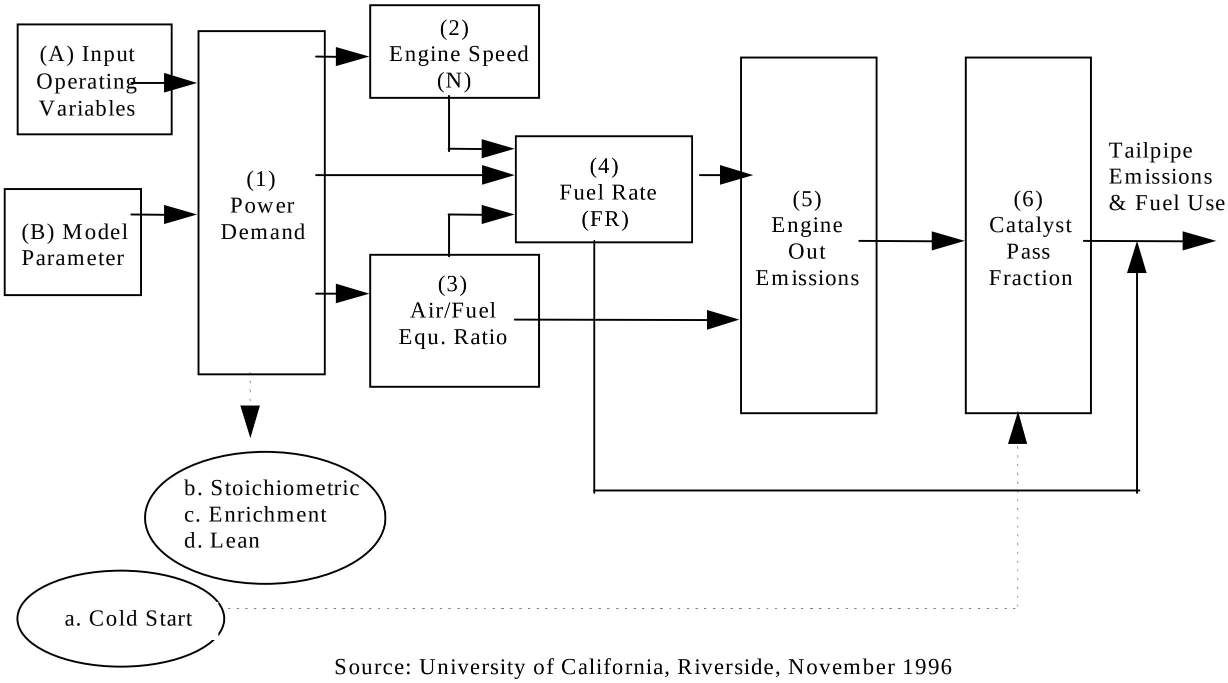
Exhibit 16
UC Riverside Model Input/Output



Source: University of California, Riverside, November 1996

As depicted in Exhibit 17, the
arameterized physical
approach that consists of six
air/fuel ratio, 4) fuel-

Exhibit 17
Modal Emissions Model



Source: University of California, Riverside, November 1996 rate, 5) engine-out emissions, and 6) catalyst pass fraction. The following vehicle operating conditions will be included in the model:

- cold and hot vehicle starts
- normal, stoichiometric operation
- high-power enrichment
- lean-burn operation.

UC Riverside's modal emissions model is being designed so that it can interface with both microsimulation traffic models that generate second-by-second speed and acceleration trajectories along specific links or at a sub-area level, and travel demand models that produce average speed and total vehicle volume data over a regional network. To ensure that the model can be readily integrated with transportation models, both temporal and vehicular aggregations are embedded in the algorithms. Consequently, the model is being built up by measuring second-by-second engine-out and tailpipe emissions of individual vehicles. In addition, 28 different vehicle/technology categories (referred to as *composite vehicles*) have been chosen based on vehicle class (e.g., car or truck), emissions control technology (e.g., no catalyst, 3-way catalyst, etc.), emissions standard levels (based on model year), power-to-weight ratio, and emitter level categories (e.g., normal emitter, high emitter).

Using a bottom-up approach, the basic building block of the model is an individual vehicle operating on a second-by-second basis. The ultimate goal of UC Riverside's research, however, is to develop an emissions model that can predict emissions in several-second modes for each average, composite vehicle category.

As of summer 1998, over 300 vehicles had been tested, analyzed, modeled, and calibrated as part of the NCHRP effort. These vehicles represent a wide variety of emission-level categories, ranging from relatively clean vehicles (such as the 1995 Toyota Tercel) to gross emitters (such as the 1981 Toyota Celica). Results from the vehicle tests contain both engine-out and tailpipe emissions for HC, CO, NO_x, and CO_2 under hot-stabilized vehicle operating conditions. The final model is expected to be completed by the end of 1998.

3.1.6 Georgia Tech's GIS-Based Mobile Emissions Model

Under a cooperative agreement with the Federal Highway Administration and the U.S. Environmental Protection Agency, the Georgia Institute of Technology is currently developing a GIS-based emissions modeling process that predicts modal vehicle operations and generates

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[15] See TRB Paper No. 970706, M. Barth, et. al., *The Development of a Comprehensive Modal Emissions Model: Operating Under Hot-Stabilized Conditions*, January 1997.

mesoscopic estimates of HC, CO, and NOx for a metropolitan area. The methodology allows for facility-level aggregations of microscopic traffic simulation, or disaggregation of traditional macroscopic four-step travel demand forecasting models to develop emission-specific vehicle activity data. Vehicle activity data are joined with fleet characteristics and operating conditions to produce spatial and temporal (hourly) emission estimates. Emissions estimates are developed for road segments and zonal areas and aggregated to grid cells for input into photochemical models. The Georgia Tech model is being developed to be compatible with most of the four-step travel demand models used by transportation planning agencies.

Vehicles are not tracked through the urban road network in the Georgia Tech model. Instead, statistical distributions of vehicle activity by facility type and underlying traffic, roadway, and traffic control conditions are used. This foundation in fundamental traffic engineering principles allows the model to be transportable to any travel demand modeling system used by metropolitan areas. Furthermore, GIS technology is well developed in many transportation planning agencies; this allows modeling features and presentation graphics to be efficiently developed.

Exhibit 18
GIS-based Modal Model Conceptual Design

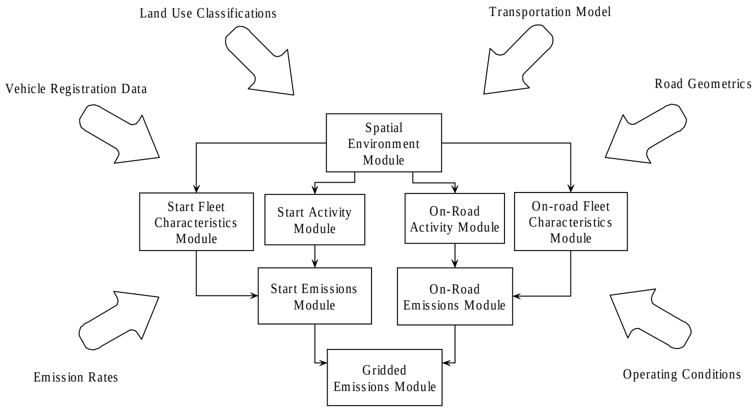


Exhibit 18 presents the conceptual design for the model. The interface between transportation model outputs and the modal emissions module is accomplished via the development of modal activity profiles that are a function of traffic flow, volume to capacity ratios, average travel speeds, roadway grades, and facility configuration. Cold and hot-start emissions are developed as a function of vehicle registration data. Engine starts are forecast and allocated at a ‘start’ zone spatial level, and running emissions (hot-stabilized and enrichment) are forecast and allocated at the road segment or link level.

Emission rates for CO, NOx, and HC are derived as functions of vehicle technology groups and modal variables via the use of a refined tree-based regression analysis of vehicle emission test data from a variety of sources (e.g., the U.S. EPA and the California Air Resources Board). This results in a database of emissions data collected on over 700 vehicles, representing over 4,000 different vehicle-tests. Vehicle technology groups are broken down by pollutant, model year, fuel delivery technology, and high versus normal emitter status.

Exhibit 19 represents a modeled portion of the Atlanta, GA, Metropolitan region from 7:00 to 8:00 AM. The exhibit shows increased levels of HC emissions with increased shading of grid cells. The following processes characterize the specific vehicle activity algorithms embedded in Georgia Tech's modeling framework.

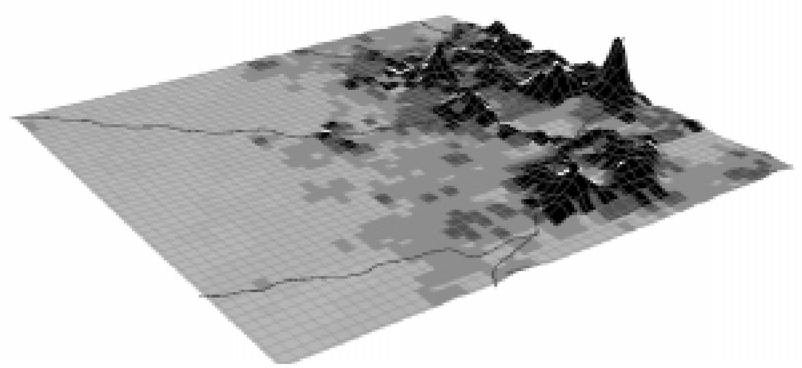
- Trips generated by transportation models are disaggregated by land use and socioeconomic data to the census block level — a 'start' zone.

- Currently, the primary road segments that are modeled are determined by the local MPO's travel demand model (e.g., TRANPLAN). Other links (local roads) are modeled on a zonal basis.

- Every modeled link is assigned a speed (from empirical observation) and acceleration profile that is determined by the modeled activity on the link, the road's classification, and its geometrics.

- Spatially and temporally allocated technology group distributions are developed for each 'start' zone and road segment and aggregated to grid cells.

Exhibit 19
HC Emissions in Modeled Portions of Atlanta



Model validation will be based on two methods: remote sensing for emissions and traffic monitoring for travel. Remote sensing data has been collected at over fifty sites with observations totaling more than 300,000 vehicles. These data provide site-specific measurements of CO and HC, roadway geometry, traffic volumes, and license tag information that can be linked to the vehicle registration data. The model is currently being validated using these data.

The Atlanta Advanced Traffic Management System (ATMS) data, collected as part of the 1996 Olympics, will provide unique opportunities for assessing the air quality impacts (measured during the Olympic period) of major changes in activity patterns.

Georgia Tech's GIS-based model reflects a comprehensive and innovative approach to motor vehicle emissions modeling and may be considered for evaluation of fuel consumption and emissions impacts of ITS implementation in the future. The automobile component of the model was completed in 1997, with current efforts focusing on other parts of the model. Further analyses are needed to determine how the model and/or its supporting data can be integrated into the fuel consumption and emissions evaluation methodology.

3.1.7 Los Alamos National Laboratory's TRANSIMS Model

Georgia Tech's modeling efforts highlight the types of changes in transportation modeling paradigms that are receiving much attention from the transportation community. In the long term, it may be possible to do away with established modeling platforms and move toward large-scale simulation efforts. As evident in ongoing transportation model developments, such efforts are being aimed at fully integrating transportation and emissions models so that the following key issues are addressed:

- representation of individual traveler and freight movements
- representation of environmental and vehicle characteristics
- simulation of continuous traffic, transit, freight, bike, and pedestrian activity-based travel patterns over an extended period of the day, as well as different days of the week, months, and seasons.

TRANSIMS, which is under development at the Los Alamos National Laboratory, with funding from FHWA, the Federal Transit Administration (FTA), and EPA, is the only example of ongoing work to fully deploy a large scale transportation simulation effort that considers each of these issues. When fully developed, it will represent a new modeling paradigm that goes well beyond existing transportation modeling platforms.

TRANSIMS is being designed as a system of linked modules with explicit techniques for feedback and linkages to an emissions module. It is planned that the model will use the emissions data collected by UC Riverside as part of the NCHRP study to develop a modal emissions model.

TRANSIMS also includes modules that mimic travel behavior and patterns on an activity-by-activity basis. In general, the flow among the different modules of TRANSIMS may be summarized as follows.

- Given sufficient demographic data, synthetic populations of households are created at the desired level of detail and distributed to match observed development patterns.

- Household activities, activity priorities, activity locations, activity times, mode, and travel preferences are generated using transportation models.

- Individual travel plans are simulated and the demand for travel is determined and assigned on a second-by-second basis.

- Vehicle data on velocities, accelerations, decelerations, average travel speeds, and average travel times are determined and fed into the emissions module.
- Emissions estimates can be fed into EPA's models to assess ambient concentrations of criteria pollutants at the regional and/or local level.

The Los Alamos National Laboratory is currently developing Interim Operational Capabilities (IOC) for TRANSIMS. For instance, a Network Editor is being developed that will modify transportation system networks to include added detail on intersections. The Network Editor has been tested as part of a recently completed Dallas IOC case study in which traffic simulation enhancements were investigated. However, a timeline for the availability of the Network Editor for use by practitioners has not yet been determined.

Although progress has been made on TRANSIMS, neither products of IOC case studies nor a fully operational model will be ready for the public domain in the near future. A fully operational TRANSIMS will not be available until 2003.

3.1.8 Mitretek's Travel Demand Modeling Efforts

Exhibit 20
Proposed MOEs for Evaluation

Primary MOEs	Travel time by mode (HOV, SOV, Transit) Throughput (person, vehicle) Mode choice, Trips by Mode VMT by mode (HOV, SOV, Transit) PMT by Mode (HOV, SOV, Transit) Deferred Trips Capital Costs O&M Costs
Derived MOEs	Value of Time Savings Delay (recurrent & incident) reduction Mode Shift from SOV Congestion Index Reliability and Variance reduction (Std. Dev. of arrival times, travel times) Mobility Index
Alternate MOEs	Accidents Fatalities Air Emissions LOS by Link Energy Consumed Equity Average vehicle occupancy/Transit load factor Accessibility Travel time/Best information travel time Usefulness of travel information No. of person trips with error in route/ mode choice due to poor information

In an effort to evaluate the benefits, costs and impacts of ITS, and to evaluate ITS investments under a Major Investment Study (MIS) process, Mitretek has developed a methodology that evaluates traditional and ITS strategies. The methodology is specific to the transportation needs of Seattle's North Corridor, extending from the Seattle central business district to SR526. As part of this effort, Mitretek analyzed alternatives consisting of hypothetical ITS and traditional strategies, with the objective of highlighting and testing analysis methods.

Mitretek's methodology is composed of modifications to an existing planning model and its linkage to a simulation model: namely, the Puget Sound Regional Council's approved Regional Travel Modeling Process that was modified based on the EMME/2 travel forecasting platform and INTEGRATION (1.5x). Specifically, a set of measures of effectiveness

(MOEs) were defined that were sensitive to ITS strategies and variability in the system. Exhibit 20 lists the candidate MOEs and the measures that will be used in the evaluation.

Once the MOEs were defined, the travel analysis flow was developed for the study. Exhibit 21 depicts the basic process developed by Mitretek for the study. This basic process includes the following steps:

- regional forecasting to predict regional travel patterns and expected travel conditions
- a sub-area traffic simulation to capture the operational characteristics and the system variation during the period of analysis
- scenario analysis of representative travel days in the AM peak period to capture non-recurrent conditions and effects of congestion due to weather, incidents, construction, special events, etc.
- feedback to ensure that the estimated traffic effects in the sub-area simulation is also reflected in the regional analysis.

The specific enhancements to the PSRC travel forecasting process under this study are listed below.

- Additional facility types, capacities, and speed codes for different ramp types and HOV and express facilities were introduced, as were additional volume delay functions for ramps.

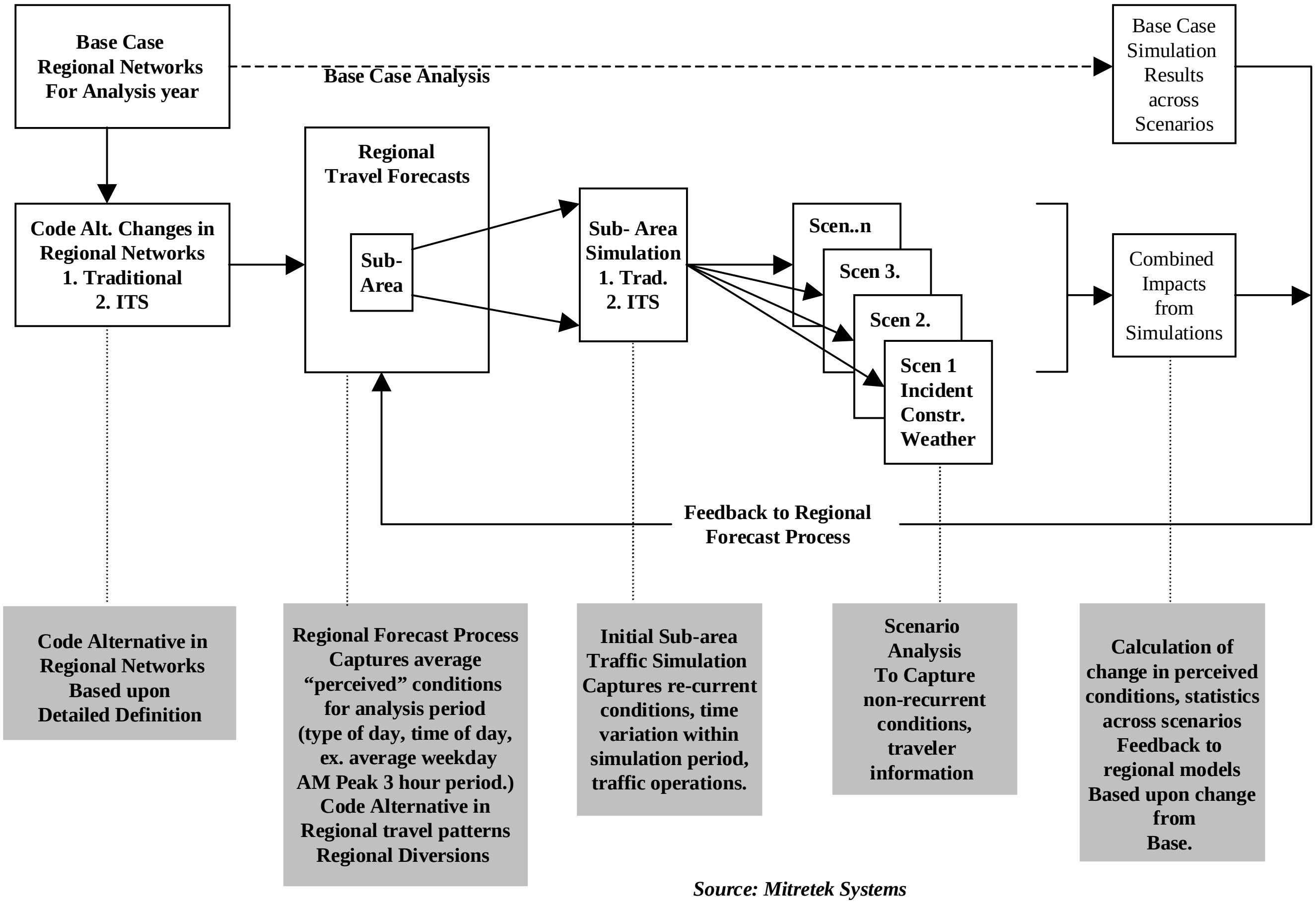
- Additional network detail was included to capture any proposed changes in the sub-area and to ensure consistency of coding requirements of the simulation model and its interface to the regional travel model.

  The additional link types defined for the study networks include the following:

  - ❑ High level of service ramps: a ramp connection with free merge at entry and exit
  - ❑ Low level of service ramps: a ramp connection with control at exit
  - ❑ Ramp meters: link with ramp meter at exit
  - ❑ Local access links: neighborhood diversion for access to expressway where direct ramp does not exist
  - ❑ HOV bypass ramps: ramp/lane for HOV bypass around ramp meter
  - ❑ Freeway HOV diamond lanes: freeway HOV in diamond lane configuration
  - ❑ Freeway barrier-separated HOV: barrier-separated HOV with controlled access/egress
  - ❑ Arterial HOV: HOV lane along arterial
  - ❑ Ferry: representing ferries crossing the Puget Sound.

- Feedback mechanisms were developed between planning and simulation models allowing changes in capacity, delay, and congestion to be captured. Feedback loops between assignment and trip distribution were already part of the PSRC process.

Exhibit 21
Traffic Flow Analysis



Code Alternative in Regional Networks Based upon Detailed Definition

Regional Forecast Process Captures average "perceived" conditions for analysis period (type of day, time of day, ex. average weekday AM Peak 3 hour period.) Code Alternative in Regional travel patterns Regional Diversions

Initial Sub-area Traffic Simulation Captures re-current conditions, time variation within simulation period, traffic operations.

Scenario Analysis To Capture non-recurrent conditions, traveler information

Calculation of change in perceived conditions, statistics across scenarios Feedback to regional models Based upon change from Base.

Source: Mitretek Systems

- The effect of traveler information, incidents, weather and other conditions on mode choice were examined.

Mitretek's enhancements to the regional travel modeling process are a contribution to research efforts that focus on capturing the effects of non-recurrent conditions, especially as they relate to the incorporation of the effects of pre-trip information on route choice, mode choice, and temporal trip distributions. This modeling framework could serve as an analytic platform for regions across the country.

3.1.9 STEP Travel Demand Model

As with any other economic activity that consumes scarce resources, tripmaking involves a cost. Faced with alternative modes of transportation and routes from an origin to a destination, the consumer selects a mode and route on the basis of out-of-pocket financial costs, travel time, comfort, and convenience. In the case of motor vehicle travel, money costs generally include such operating costs as gasoline, parking, vehicle repair, and toll costs, as well as such ownership costs as vehicle depreciation and insurance. Costs associated with the time involved in undertaking a trip are referred to as the time costs of travel. These costs reflect an opportunity cost to the motorist since the time devoted to travel could be used to generate income, participate in consumption activities, or engage in leisure. The perceived comfort and convenience of a given route or mode must also be accounted for in the total cost of tripmaking. These qualitative cost measures differ from one individual to another, and modes and routes are often ranked differently by individual travelers based on comfort and convenience. All of these costs taken together are often referred to as the perceived user cost of travel.

An important element in the derivation of the demand for travel is the effect of carrying capacity (i.e., facility performance) on perceived user costs. As a given highway becomes congested, virtually every component of perceived user cost increases. Money costs increase in proportion to fuel costs and vehicle depreciation (the wear and tear of stop and go driving). Comfort and convenience also decrease. But more importantly, time costs increase dramatically. As congestion worsens on a given facility, travelers respond to these rising costs by switching to alternative modes, routes, or times of travel. In this manner, travel demand on the highway is inversely related to perceived user costs—as costs increase, users demand less travel on the facility. Likewise, as congestion is mitigated via, for example, either ITS deployment or highway capacity expansion, perceived user costs decrease, and travelers demand more travel on the affected facility. These increases in travel stemming from decreases in perceived user costs are called "induced demand."

Given that ITS deployment is expected to mitigate recurrent and non-recurrent congestion, corresponding changes in the demand for travel must be captured to ensure that the evaluation process considers the full impacts of deployment on fuel consumption and emissions. However, the inability to capture the effect of changes in perceived user costs on traveler behavior and travel demand is an important limitation of conventional four-step travel demand models.

In an effort to address the linkages between perceived user cost, traveler behavior, and the demand for travel, DHS has developed STEP, a travel demand modeling package designed for planning applications and policy analysis related to transportation pricing issues. STEP is essentially a logit model based on disaggregate household data. It is composed of an integrated set of travel demand and activity analysis models, supplemented by a variety of impact analysis capabilities. To approximate the effects of changes in network performance on travel demand (or vice versa), STEP incorporates the Bureau of Public Roads (BPR) equation for estimating level of service.[16] In this manner, the calibrated BPR equation can be used to compute a new equilibrium quantity of travel.

STEP's simplified level of service model, however, is intended only to approximate the effect of changes in network performance. It is likely to be inadequate in cases where large network perturbations could occur or where specific route changes are at issue. In those cases, STEP can be used in conjunction with a more detailed network-based travel demand model.

Several additional features of STEP suggest that this modeling package is useful for a fuel consumption and emissions modeling framework, especially as it relates to induced travel demand impact analyses.

- STEP's regional, sub-area, and corridor-level analysis capabilities may fit the scope and scale of the expected travel behavior and system performance impacts associated with ITS deployment.

- STEP's microsimulation formulation permits the modeling package to be used as a survey tabulation technique employing sophisticated data transformations and linkages. For example, vehicle data from travel surveys can be tabulated so that exact usage patterns by model year or vehicle type can be determined.

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[16] This equation uses peak and off-peak travel times and base case demand estimates to calibrate a supply function for appropriate spatial groupings of trips (i.e., trips in broadly defined corridors). The basic form of this equation is as follows:

$$t = a \text{ x } (1 + (V/C)^b)$$

where, t is travel time in minutes per mile, V is the volume in vehicles per hour, C is the capacity in vehicles per hour, and a and b are coefficients fit to each corridor.

- STEP's models are applied using actual or forecast data on household socioeconomic characteristics, the spatial distribution of population and employment (i.e., land use), and transportation system characteristics for the selected analysis year(s).

- STEP can analyze any change in the transportation system that can be represented in terms of the variables in its models and associated with a specific geographic area or grouping of households. For example, a new highway or transit service can be represented by changed travel times and costs for the areas served.

Over the years, the STEP modeling package has been applied in a number of Bay Area studies and has been adapted for use in studies in Los Angeles, Sacramento, Chicago, and the Puget Sound region (Seattle). Currently, STEP is being calibrated for the New York region. Applications can proceed with model re-estimation for a specific region by creating a new set of models for STEP. To date, however, nearly all applications outside the Bay Area have relied on extensive re-calibration of the default models plus a limited amount of re-estimation to match local conditions.

3.2 Summary of Modeling Developments

Exhibit 22 summarizes the research efforts described in this section and their applicability to the development of a fuel consumption and emissions modeling framework. Useful information, methodologies, and data are available from most of the referenced research efforts. For instance, modal emissions algorithms and data are currently available from TRAF-NETSIM and will be available shortly from the UC Riverside work and possibly even from the Georgia Tech work. Likewise, UC Berkeley's interface methodology has been finalized, and the post-processor can be used to interface the chosen traffic simulation model to travel demand models.

However, results from current research efforts do not address the entire spectrum of issues that the emissions and fuel consumption modeling methodology must deal with. For instance, modal emissions data will only be available for hot-stabilized vehicle operating conditions and will not represent the full range of variance inherent in in-use vehicle fleets. As a result, gaps in methodology must be identified and resolved via additional analytic techniques.

3.3 Modeling vs. Measurement

Developments associated with the next generation of MOBILE may facilitate a less resource-intensive evaluation approach that is based on field measurement techniques. This approach would rely on MOBILE's facility-specific emissions factors and on vehicle instrumentation at each site to develop emissions and — via instrumentation — fuel consumption impact estimates for the

Exhibit 22
Summary of Modeling Developments

Model	*Contribution*	*Availability*
INTEGRATION	Fuel consumption and emissions algorithms must be refined.	Currently operational
TRAF-NETSIM	Can be used to enhance the modal fuel consumption and emissions algorithms inherent in INTEGRATION.	Currently operational
AIRQ	Can be used to help interface INTEGRATION with the chosen travel demand models.	Currently operational
MOBILE6	Drive cycles by functional road class and improved trip-based emissions algorithms can be drawn.	Release for use in 1999
Mitretek Systems Integrated Travel Demand/Traffic Simulation Modeling System	By interfacing the regional travel demand model with a traffic simulation model, the effects of pre-trip information on route choice, mode choice, and temporal trip distributions can be evaluated.	Currently operational
UC Riverside’s Modal Emissions Model	By interfacing the “interim” model with the revised (for level of acceleration) traffic simulation component of INTEGRATION, results from this work can be used to estimate the modal emissions impacts of deployment.	To be released in late 1998
Georgia Tech’s GIS-Based Mobile Emissions Model	Emissions component (MEASURE) can be used to fortify the emissions algorithm inherent in INTEGRATION.	Beta versions of emissions component (MEASURE) are being tested. Not available until after EPA peer review process is completed.
STEP	Potential tool for evaluating the effect of changes in level of service on travel demand, particularly induced travel.	Currently operational
TRANSIMS	Cannot be used.	Not available until 2003

without and *with ITS* scenarios. Specifically, a measurement-based approach would involve three basic steps.

- Instrumented vehicles would be operated at each site to assess changes in the operation profiles of vehicles for each functional road class.
- Data collected from vehicle instrumentation would be used to develop functional road class drive cycles for the *without* and *with ITS* scenarios. In this manner, before and after speed/acceleration profiles for each functional road class would be generated.
- These data would then be mapped to MOBILE6 functional road class-specific emissions factors to estimate emissions impacts of ITS deployment.

Various issues would need to be resolved if such a measurement-based approach is to be used. First, as ITS deployment at sites is occurring gradually over time, collecting baseline data requires a clear definition of the *without* and *with ITS* scenarios. Second, fleet representation must be addressed during vehicle instrumentation. At a minimum, at least one vehicle from each vehicle class (as defined by MOBILE) must be instrumented. Data extrapolation techniques would then be needed to capture fleet variability within a class—this is especially needed if fuel consumption estimates are generated directly from instrumentation. Third, changes in drive cycles resulting from non-ITS investments or events will not be captured by this approach. Techniques for isolating ITS-related changes in the speed/acceleration profiles of trips need to be developed. Finally, emissions and fuel consumption impacts estimated by this approach will not isolate impacts attributable to the deployment of specific components, unless instrumentation is conducted before and after the deployment of specific ITS elements. Such an approach may not be practical.

As a result, although a measurement-based approach can help to validate estimates developed via an integrated modeling approach, it may not be robust enough to meet the needs of decision-makers, especially in those regions that will draw on the ITS modeling development process for guidance. Moreover, as ITS investments are mainstreamed into the transportation planning process, a measurement-based approach becomes less feasible.

Appendix: Modeling Data Needs

This appendix discusses individual data elements that will be required to model ITS components under the umbrella of modeling techniques discussed in Section 2 of the report. These data—used as model inputs—include collected data, projections, and outputs from other models. The data needs are discussed for each of the following categories: transportation systems; emissions and fuel consumption; and telecommunications and ITS.

A.1 Transportation System Data

Transportation systems are modeled by means of two techniques:

- travel demand modeling
- traffic simulation, including vehicle maneuvering modeling.

The two modeling techniques have distinct yet complementary data needs. Travel demand models require more regional level data, while traffic simulation models require corridor, link, and individual vehicle level data. Each of these data elements is discussed in more detail in the following subsections.

A.1.1 Travel Demand Models

Travel demand models are used for predicting the change in transportation system usage or travel behavior changes stemming from changes in land use and socioeconomic inputs and changes in the composition of the transportation system (e.g., capacity expansion). Data requirements for these models are classified under the following categories: demand; supply; and system performance.

Data needs relevant to each category are discussed below.

Demand

Typically, travel demand is estimated based on economic data, demographic distribution, and land use data.

- *Economic Data*. For the purpose of evaluating the emissions and fuel consumption impacts of ITS technologies, regional data on the following economic variables must be identified or developed:
    - ☐ income by household

  - ☐ employment by groups such as office, retail, industrial, and other
  - ☐ vehicle ownership by household/dwelling units
  - ☐ number of households/dwelling units, group quarters, and manufactured homes
  - ☐ specific special generator data such as supermarkets, stadiums, historic and tourist sites, clubs, recreation grounds
  - ☐ projected future growth for each of the economic variables.

- *Demographic Data.* As only a certain section of the total population can drive either because of legal restrictions or because of personal ability, demographic data are useful in determining the production factors. The following data variables are to be used for demographic data needs:

  - ☐ population by age, sex, population density
  - ☐ household size, age distribution, number of dependents
  - ☐ future projections for each of the demographic variables.

- *Land Use Data.* Land use information is used for determining the effect of land use planning and zoning on transportation system utilization and performance. The following land use variables are needed for this modeling methodology:

  - ☐ land area under use for residential and employment purposes
  - ☐ concentration of housing and employment land uses
  - ☐ walk access and drive access from residential and non-residential areas to transit stop locations
  - ☐ future land use projections.

Supply

Information on the supply of transportation systems relevant to travel demand models is available at the regional level. Supply data can be divided into the following modal groups: highway, rail transit, bus transit, and carpool.

- *Highway*. The following highway link data are needed to effectively model the entire highway system:

  - ☐ road segment length in miles
  - ☐ number of lanes
  - ☐ posted speed in miles per hour
  - ☐ capacity in number of vehicles per lane per hour
  - ☐ jurisdiction code for regional models

  - ❑ road facility type such as local, collector, minor arterial, major arterial, expressway, and freeway.

- *Non-Rail Transit.* Non-rail transit such as commuter bus, express bus, feeder bus, and paratransit services have the following data requirements:

  - ❑ round trip travel time
  - ❑ bus speed and average stop time
  - ❑ time to enter and exit from a park-and-ride lot
  - ❑ bus stop location
  - ❑ peak and off-peak headway or service frequency.

- *Rail Transit.* Data need to be collected or estimated for the following variables related to rail transit system supply:

  - ❑ round trip run time in minutes
  - ❑ stop locations and stop access methods through walk and drive
  - ❑ station-to-station fare matrix in current year dollars
  - ❑ park-and-ride lot locations and access
  - ❑ peak period and off-peak period headway (service frequency in trips per hour)
  - ❑ single-track versus double-track service
  - ❑ direction of service, especially important for commuter rail service.

System Performance

Transportation system performance is measured through regional and more microscopic utilization measures. Data needs associated with these two broad categories of measures are presented below.

- *Regional Measures.* Data need to be collected on the following regional measures to check the performance of travel demand models in predicting regional behavior:

  - ❑ production/attraction counts at zonal level
  - ❑ vehicle miles of travel (VMT) by road facility class
  - ❑ vehicle hours of travel (VHT) by road facility class
  - ❑ regional mode split at the county level or some other jurisdiction level
  - ❑ percent of links with volume to capacity ratio greater than 1.0 by road facility class
  - ❑ origin-destination vehicle and person trips at the county level or some other jurisdiction level

  - ☐ stated preference surveys and revealed preference surveys for transit and HOV lane usage under ITS scenarios
  - ☐ average regional trip length by mode of travel
  - ☐ fare box recovery.

- *Microscopic Measures*. The following data are needed to evaluate the performance of travel demand models in predicting local corridor or transit line level travel patterns:

  - ☐ screenline traffic counts in vehicles per hour
  - ☐ link level travel times in minutes by mode of travel
  - ☐ link level travel speeds in miles per hour
  - ☐ percent of total link traffic made up of trucks and buses
  - ☐ link level volume to capacity ratios
  - ☐ transit ridership by time of day, also passenger miles of travel
  - ☐ maximum load point (the segment of the transit route that has the greatest number of passengers on-board) and maximum load (the maximum number of passengers on-board at any point during a typical transit vehicle run)
  - ☐ individual line farebox recovery
  - ☐ volume to capacity ratio during peak and off-peak periods on roadway facilities where buses operate.

A.1.2 Traffic Simulation Models

Traffic simulation models use link level data and produce microscopic measures of effectiveness while simulating the movements of individual vehicles. Specific vehicle movements such as turning movements, acceleration/deceleration rates, lane changing behavior, yellow-signal reaction, aggressiveness/defensiveness in driving, passing, gap acceptance, and even accidents can be modeled using traffic simulation models. Link level measures of effectiveness (MOE’s) such as volume, density, level of service, stop delay, moving delay, volume to capacity ratio, queue backup, number of signal cycles needed for clearance, emissions, and fuel consumption are also produced. Some simulation models have animation programs tied to their mathematical models. This helps in the visualization of the traffic flow along the network.

Data requirements for traffic simulation models are classified under three categories: demand, supply, and performance.

Demand

Traffic data comprise the demand side of a traffic simulation model. Most traffic models require that the traffic data be converted to a relatively small time period such as fifteen minutes or less.

- *Traffic Data.* Traffic models use the following traffic data in conjunction with other data to simulate traffic in a network:
    - ❑ link entry volume by lane and by time of day (peak hour, peak period, all-day)
    - ❑ link travel time
    - ❑ pedestrian traffic crossing roads
    - ❑ percent trucks, buses, and heavy vehicles
    - ❑ turning volume data at intersections and interchanges
    - ❑ carpool and vanpool trips by time of day
    - ❑ forecasts for all the above for a future model
    - ❑ emergency response vehicle time
    - ❑ time needed to clear an incident, and the associated back up queue.

Supply

The system supply data needs of traffic simulation models include link geometry, operation of signals and traffic signs, and the following highway operating conditions.

- *Link Data.* Data in this category includes:
    - ❑ link length in miles including turn lane lengths
    - ❑ number of lanes including turn lanes
    - ❑ lane width in feet
    - ❑ posted speed on links in miles per hour
    - ❑ capacity of links in vehicles per lane per hour
    - ❑ lane adds and/or drops for freeway links
    - ❑ length of acceleration/deceleration lanes
    - ❑ connections between adjoining links
    - ❑ grade and radius of curvature
    - ❑ direction of traffic per lane, especially useful for reversible lanes in urban areas.

- *Signal and Sign Data.* The following data must be collected:
    - ❑ type of signals on roads
    - ❑ inter-signal spacing and progression on arterials
    - ❑ signal phasing and turning movements
    - ❑ upstream distance of freeway exit signs from the exits
    - ❑ mean start up delay at each signal
    - ❑ distance of VMS from nearest downstream ramp or signalized intersection

  - ☐ bus preemption and emergency vehicle preemption (yes/no).

- *Highway Operating Conditions Data.* This includes information on wet/dry pavement and concrete, asphalt or unpaved surfaces.

System Performance

Data on traffic systems performance are needed to check the accuracy of the output from traffic simulation models. Performance of traffic simulation models is typically judged on the basis of the following variables:

- traffic volume at specific link locations through the use of radar detectors, loop detectors, and any other means
- traffic classification data at specific link locations
- number of signal cycles required for clearing an intersection
- percent of vehicles exiting or entering at a freeway ramp

A.2 Emissions and Fuel Consumption Related Data

Some of the input data required for estimating motor vehicle emissions and fuel consumption may be available from the region where ITS deployment is being considered. For instance, some regions compile information describing the motor vehicle fleet, and have used these data to execute MOBILE and generate regional emission inventories specific to highway vehicles. Such fleet characterization data include: registration distributions by vehicle class, fuel type, and vintage; VMT data by functional road class and time-of-day; ambient conditions data, such as temperature by season, time-of-day, etc.; and trip data, including number of trips by purpose, cold-versus hot-start fractions, etc. While some of these data can be readily employed by the methodologies described in Section 3, more refined data will be needed to accurately model the fuel consumption and emissions impacts of ITS deployment.

As discussed in other sections of this report, modal emissions models require a different set of data that characterize vehicle operations and emissions on a second-by-second basis. These data are being collected through dynamometer tests and will eventually be compiled to reflect the range of operating conditions (e.g., cold starts, hot-stabilized, etc.) and the range of fleet characteristics (e.g., engine families, malfunctioning versus well functioning, etc.). Furthermore, drive cycles are being developed that are more representative of true vehicle operations. Data for the development of these drive cycles are being collected via vehicle instrumentation. Together, modal emissions factors being developed with the help of dynamometer tests and drive cycles being developed via vehicle instrumentation will be the central components of modal emissions and fuel consumption models.

Emissions and fuel consumption data will need to be collected under the *without ITS* base case and under the *with ITS* case. It is suggested that data be obtained directly from individual vehicles so that emissions and fuel consumption estimates can be directly correlated to model inputs such as vehicle age, engine type and size, and speed-time profile.

The remainder of this subsection focuses on the more rudimentary types of supporting data that are needed for the emissions and fuel consumption evaluation. The more rudimentary data on emissions and fuel consumption can be divided into three categories: input, meteorological, and output.

Input

Input to an emissions and fuel consumption model includes the number of vehicles and their mechanical and operating characteristics. Data on the following variables typically are required for these models:

- number of vehicles (i.e., link volume)
- vehicle mix, such as percentage trucks, buses, other heavy vehicles, and light vehicles
- vehicle age including information on engine size, presence of catalytic converters
- vehicle speed-time (acceleration/deceleration) profiles
- regional vehicle miles of travel (VMT)
- regional vehicle hours of travel (VHT)
- average trip length by purpose.

Meteorological

The meteorological conditions prevailing during the time-period being modeled include the important environmental conditions of humidity, temperature, and existing air quality.

Output

Output from emissions and fuel consumption models include emissions and the fuel consumption rates. The following data variables comprise the output side of emissions and fuel consumption data:

- total vehicle emissions by pollutant (VOC, NOx, PM)
- individual vehicle emissions by speed and acceleration modes
- vehicle emissions and fuel consumption by road facility type and signal spacing
- savings/reduction in emissions and fuel consumption due to placement of individual ITS component.

A.3 Intelligent Transportation Systems Data

Section 3.5 describes the need for data collection plans that stress the importance of developing a comprehensive inventory of ITS deployment initiatives being consider by a region. Data characterizing ITS initiatives must cover the spatial and temporal dimensions of the systems, especially as they relate to network location (e.g., VMS location, freeway coverage of CCTVs and loop detectors, etc.) and temporal operation (e.g., ramp metering). In general, test plans developed by a region for ITS deployment must provide adequate specificity to support modeling and field measurement efforts undertaken for the purpose of evaluations. This subsection exemplifies the types of data that may be needed, especially for traveler information systems.

ITS-related data can be classified into three categories: utilization, user acceptance, and results. The data are essentially a measure of the level of usage of information being dispensed by various means; the level of acceptance or a perceived reliability indicator for users; and such results as permanent or dynamic changes in travel behavior. Each ITS component’s performance can be judged with the help of such data.

A sample scenario of ITS related data collection efforts will clarify the importance of the three parts mentioned above. Let us assume a scenario in which a traveler is going from Seattle to a fictitious Phoenix suburb called Abcdef. Abcdef is connected to Phoenix by rail and a bus transfer. The traveler plans the trip to ensure that travel time to the airport and the waiting time therein are minimized. For this pre-trip planning stage, the traveler may use the Internet, automated telephone service, or an information kiosk. As soon as the traveler uses such a service, the utilization counter goes up by one. The traveler interacts with the systems and gets some specific information. The traveler may or may not use this information depending upon the level of confidence in the information or depending upon other personal reasons. To find out if the traveler used such information, a survey might be conducted. This survey will provide data on the user acceptance/information reliability part of data on ITS components.

Let us further assume that the traveler has decided to use the information provided by the system to make a travel decision. This decision may be to totally avoid transit, based upon a possibility of missing a transfer connection between the train and bus to Abcdef. On the other hand, the decision might be to use the trip schedule provided by the system. In any event, a result has been achieved. The result can be a permanent one, implying that every time the traveler goes to the airport, the same mode/route are adopted. On the other hand, the result may be trip specific. Once again, a user survey will bring out the permanency of the result. Permanent results can be classified as static changes in travel behavior whereas temporary results may be classified as dynamic changes in travel behavior.

The scenario presented above can be applied to a daily commute trip to work, or to an occasional trip to the supermarket, or to an even less recurrent trip to the beach. In any case, the data needs are the same and are as follows:

- *Utilization.* Every ITS component has its own user interface device or method. VMS systems interface through a remote VMS screen, kiosks have the ability to be interactive through touch screens, in-vehicle information may be through audio/video displays. Since every system has its specific interface medium, the data collection medium is also the same. Most of the data on these may be collected at source. Some of the data such as that on non-interactive systems will be derived from surveys and interviews. Data needs, however, can be generalized into the following variables:

    - ❑ number of occasions on which the system was accessed by users in a typical time period
    - ❑ in case of interactive systems, the number of inquiries made of the system during an average interaction period
    - ❑ the types of inquiries: pre-trip planning, in-vehicle route choice, in-vehicle trip planning, incident response or emergency vehicle response inquiry
    - ❑ purpose of inquiry: trip planning or reactive to a situation
    - ❑ all the above information by time of day.

- *User Acceptance.* User acceptance is important to understand the “real” utilization of the system. The following data will bring out the real utilization of ITS systems:

    - ❑ number of times the information from ITS was used for: pre-trip planning, in-vehicle trip planning, route diversion, mode of travel change, destination of travel change in the past day, week, month. This information needs to be asked in conjunction with the number of times the traveler interfaced with ITS technologies

    - ❑ the reliability of information in terms of incident detection and response, transit management and trip planning, freeway management systems

    - ❑ the travel time savings *perceived* due to signal progression and traffic signal control on a commonly used arterial

  - the travel time savings *perceived* on a freeway due to freeway management systems

  - number of repeat uses of the same system.

- *Results*. Any results in dynamic or permanent changes in travel behavior are included in the following data variables:

  - permanent changes in travel behavior such as the decision to make a trip, destination choice, mode choice, and route choice
  - changes observed in average speeds and travel times on road links and transit lines
  - dynamic changes in travel behavior.

The ITS-related information collected and organized into the groups mentioned above is useful in determining any changes in travel behavior due to the impact of ITS components only. Information on travel behavior changes feeds into the travel demand modeling stage of the models presented in Section 3 of this report, thus affecting the emissions and fuel consumption estimates.

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