Final Report

Run-Off-Road Collision Avoidance Countermeasures Using IVHS Countermeasures

TASK 3-Volume 1

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US Department
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Intelligent Transportation Systems

Impact Assessment Framework:

Final Report

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Executive Summary

Introduction

One of the most compelling reasons for investment in Intelligent Transportation System (ITS) services is to realize a reduction in traffic congestion. Volume on America's highway network is expected to double by the year 2020 from 1.9 trillion vehicle miles traveled to about 3.8 trillion miles. A recent National Cooperative Highway Research Program study concluded that because of congestion, over 1.2 billion hours of traffic delay were being experienced annually in 37 of the largest metropolitan areas in the United States. The total cost in lost economic productivity due to all traffic congestion has been estimated at roughly $100 billion annually.

While there is broad consensus that ITS can improve traffic flow and reduce congestion, there are very few analytical tools available to support this conclusion. To address this limitation, in 1992 the Federal Highway Administration ITS Joint Program Office (JPO) requested the Volpe National Transportation Systems Center to create an analytical tool (or framework) that could be used to predict ITS impacts and to identify potential benefits of implementing Advanced Traffic Management System (ATMS) user services. ATMS was a logical starting point because it provides the foundation upon which other types of ITS services will evolve.

An ATMS implementation will usually employ several different adaptive traffic control strategies to attain congestion mitigation and incident management. These strategies typically include synchronized freeway ramp metering, dynamic arterial signal coordination, high occupancy vehicle ramp bypasses, rapid incident response and integrated traffic management.

Background

There are roughly five types of models widely used today by transportation practitioners. These models address regional planning, traffic engineering, emissions, fuel consumption and safety related concerns. Up to the time of this study the "state-of-the-art" in transportation planning and traffic simulation was to perform planning and simulation exercises in isolation. Most short and long-range planning activities, performed by Metropolitan Planning Organizations (MPOs), are aimed at modeling travel demand to forecast traffic congestion within a regional transportation network. On the other hand, transportation engineers typically use traffic simulation models to derive site specific improvement plans for addressing very localized traffic issues. All of these model types have proven their value and are successfully being used today by many professionals within the transportation field.

Approach

The framework developed by the Volpe National Transportation Systems Center represents an innovative design which incorporates the strengths of widely used planning and simulation models into an integrated modeling methodology. The resulting framework improves the sensitivity and capability of currently available transportation models to assess impacts and identify potential benefits of implementing different combinations of ATMS technology.

The framework integrates a regional planning model with freeway and arterial simulation models, and employs emissions, fuel consumption and safety models in a unique way to predict operational traffic characteristics and to estimate noxious emissions, fuel consumption and determine safety implications. The framework design represents a step forward from previous analytical tools because it allows transfer of data between models automatically and introduces elements of dynamic assignment to produce reliable estimates of congestion, travel time and speed. Additionally, the framework uses estimates of traffic operating characteristics for smaller, more discrete time intervals and allows dynamic representation of interaction between these time intervals.

Through integration of planning and simulation models the advantages of both have been* retained and can be applied more effectively to assess ATMS impacts. By complementing the limitations of a planning model with the strengths of simulation models, the advantages of route and mode choice can be provided coupled with more accurate predictions of link speed and travel time for a given volume of traffic. This combination provides sufficient sensitivity to reliably predict Measures of Effectiveness (MOE) variables impacted by ATMS technology that planning or simulation models alone cannot achieve. Analytical determination of ATMS user impacts within this study are based solely upon MOE data,

User Services Modeled

The framework was designed to evaluate the impact of several ITS technologies, commonly associated with ATMS user services, upon a transportation network. By selecting framework input control parameters, various combinations of these technologies can be simulated and the resulting data can be evaluated against a baseline set of conditions for determining beneficial impact. Services modeled by the framework concentrate on four key ATMS traffic management strategies as defined below:

1) Ramp metering - is designed to control traffic volume on a freeway by limiting the rate at which vehicles are allowed to enter the freeway via metered ramps. The goal of ramp metering is to optimize traffic throughput and speed on the freeway and to break up platoons of entering vehicles.

2) Signal coordination - signal timing controls vehicle movements on urban roadways. By coordinating signals between adjacent intersections, parallel roadways, or throughout an entire network, delay is reduced because the signal system responds to traffic conditions and demand when it occurs.

3) Integrated traffic management systems - coordinates freeway ramp metering systems with signal timing systems, on adjacent arterial streets, so that queues from a freeway ramp do not extend onto the arterial which can disrupt arterial flow.

4) HOV lanes and ramp meter HOV bypass lanes - high occupancy vehicle (HOV) lanes are lanes that restrict traffic to multi-occupant vehicles. Ramp meter HOV bypass lanes enable HOV vehicles to bypass the existence of a queue at a ramp meter and therefore, provides direct access to the freeway for high occupancy vehicles.

Design

The framework consists of various transportation models linked together by interface software that facilitates transfer of data between the various components. The high level structure developed for the analytical framework is represented in Figure 1. This data flow diagram illustrates the interaction of major framework components with some of the important data elements passed between the models. The diagram reveals that a data feedback path exists between the planning and simulation components which provides the mechanism for dynamic traffic assignment. With a data feedback mechanism the framework can produce more accurate estimates of speed and volume compared against traditional modeling techniques.

Planning and simulation analysis is executed as an iterative process. Estimates of mode split and assigned traffic volumes are produced by the planning model and serve as input to the simulation models, which produce revised estimates of link speed for the freeway and signalized arterials. The revised speeds are then feed back into the planning model and the process is repeated until travel speeds and volumes converge to a predetermined threshold.

Performance variables generated by the framework are normally referred to as MOEs. Many of these MOEs are sensitive to the effect of varying some aspect of the network characteristics and, therefore, can be used to evaluate the impact of implementing ATMS user services. The responsive MOEs are considered important to the framework because they reflect changes in traffic dynamics that are induced by ITS technologies. In the case of the framework, the transportation facility behaviors are varied through implementing different traffic management strategies that are activated by framework input parameters. The magnitude of change upon individual MOEs will vary depending on the specific ATMS service being considered and these MOEs can be compared against baseline network performance to determine the relative magnitude and direction of impact.

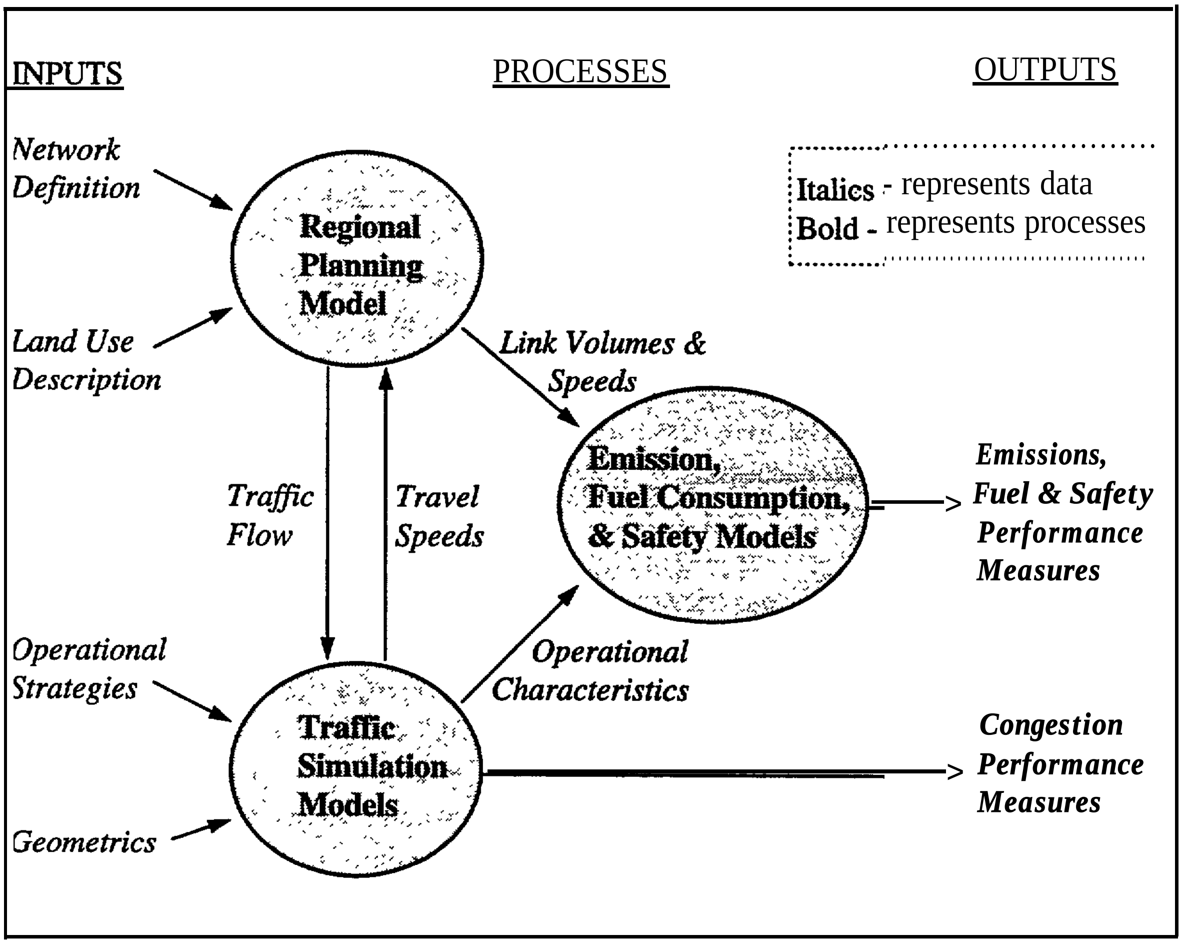

Figure 1: ITS Modeling Framework High Level Data Flow Diagram

For this study the operational MOEs that are used to quantify network characteristics are: vehicle miles traveled (VMT), traffic volume (VOL), average vehicle speed (SPD), vehicle hours of delay (VHD) and fuel consumption (FUEL). Emission MOEs are expressed in units of kilograms and predict carbon monoxide (CO), hydrocarbons (HC) and nitrogen oxide (NOx) pollutants. The last MOE category deals with safety issues and predicts personal injury levels, property damage only (PDO), and total accidents. All safety MOEs are expressed in units of incidents per million miles traveled.

Area Studied

The physical location selected as the demonstration corridor for this project targeted the I880 Bay Area corridor located in Alameda County, California which extends from San Leandro through Fremont, to just north of the town of Milpitas. The study corridor consists mainly of I880 and an adjacent strip of transportation facilities that parallels the I880 freeway. I880 is the major north/south freeway serving the east Bay Area extending from US 101 in San Jose to Interstate 80 in Oakland. This corridor includes a major parallel arterial that intersects the freeway about midpoint in the study area. The corridor is composed of three region types that include rural, residential and business district areas. These area classifications are used to support analysis of MOE impact upon different community types. The I880 freeway consists of rural and residential areas while the parallel arterial is located primarily in business districts and residential areas.

The availability of baseline data was an important consideration in choosing the demonstration area, since it was essential to enable comparisons among ATMS scenarios. One of the main reasons for selecting the I880 corridor was the extensive amount of baseline data that was available through the efforts of previous research programs and studies. The I880 database included information relating to freeway mainline volumes, ramp volumes, speed and delay data, vehicle occupancy, arterial volumes, arterial speed and delay data, arterial geometrics, intersection turning movement volumes, and accident/incident data.

All of the data mentioned above was used to determine and characterize the baseline operating conditions of the study area. With improvements proposed for the corridor, including the implementation of HOV lanes and ramp metering, a comparison of “before” and “after” ATMS operating conditions is possible.

Scenarios Considered

The impacts of selected ATMS user services upon the demonstration corridor for operational performance, total emissions and safety factors were simulated across a set of six alternative ATMS scenarios. Performance of the corridor under each scenario was compared to that obtained for a baseline (existing network) configuration. The actual scenarios considered during the framework simulation are described below. (All scenarios included HOV lanes.)

Scenario 1 - Fixed time signal coordination based on morning peak volume. This scenario represents the baseline configuration to which other scenarios are compared.

Scenario 2 - Demand-based arterial signal coordination over a 3 hour morning period from 7:00 am to 10:00 am.

Scenario 3 - Fixed time metered freeway ramps, based on morning peak volume, combined with fixed time signal coordination on the parallel arterial.

Scenario 4 - Synchronized freeway ramp metering, optimizing free flow, combined with fixed time signal coordination on the parallel arterial.

Scenario 5 - Synchronized freeway ramp metering combined with demand-based signal coordination on the parallel arterial.

Scenario 6 - Fixed time metered freeway ramps, based on morning peak volume, combined with arterial demand-based signal coordination.

Results

Analysis conducted during this study indicates that operational performance of the demonstration corridor is boosted in terms of a general increase in speed and reduction in total delay due to ATMS user services. Maximum benefits are achieved with the simultaneous implementation of signal coordination on arterial streets accompanied with metering on freeway ramps. Demonstration corridor results obtained during extensive scenario testing are summarized in Figures 2 & 3 for the parallel arterial and I880 freeway, respectively. MOE impacts obtained on the parallel arterial vary widely for each scenario tested. Different configurations of ATMS user services generate MOE results with characteristically unique profiles. The MOE data curves obtained on the parallel arterial are illustrated in Figure 2. It is interesting to note that, unlike the freeway, the combination of ramp metering and signal coordination produced significant variations in parallel arterial performance depending upon the exact nature of the ATMS service (fixed or dynamic). For example, fixed signal coordination in conjunction with fixed ramp

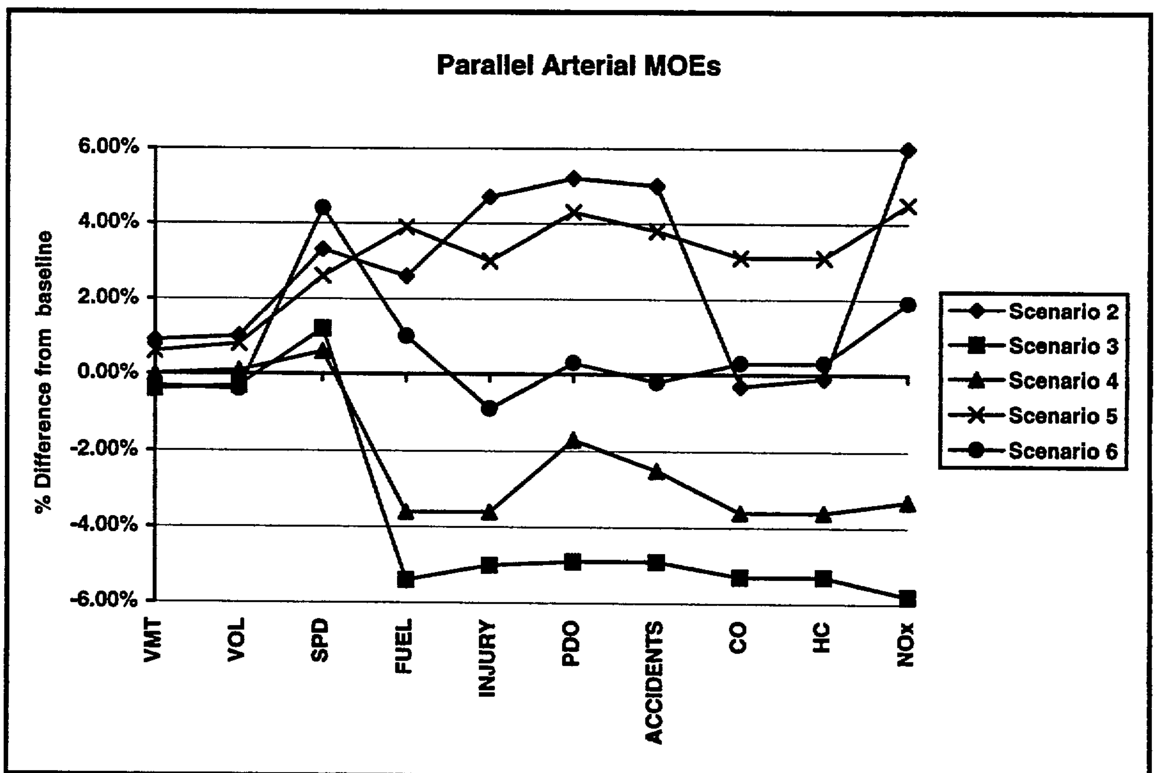

Figure 2: Parallel Arterial Measures of Effectiveness

metering produced faster arterial speeds, a reduction in vehicle hours of delay and was accompanied with the best improvement in safety, emissions and fuel consumption MOEs. This trend is also observed, to a lesser degree, for fixed signals combined with dynamic ramp metering services. The single largest improvement in parallel arterial speed was created through the use of dynamic signals and fixed ramps. The remaining scenario, using a combination of dynamic signals and dynamic ramps, produced results with increased average speed but resulted in elevated levels of fuel consumption, emissions and vehicle incidents.

An examination of freeway data in Figure 3 indicates that most of the scenarios tested influence freeway operation in a consistent manner. Only scenario #2 (arterial dynamic signals) produced results that were significantly different in character from other scenarios evaluated due to the absence of any form of ramp metering. This scenario was designed to directly influence the parallel arterials only. The framework data strongly indicate that a ramp metering strategy will have a profound impact upon freeway operation. Some of the benefits obtained on the freeway through ramp metering are a significant reduction in vehicle hours of delay without encountering any increase in congestion. Average speed is seen to increase while emissions of CO and HC both

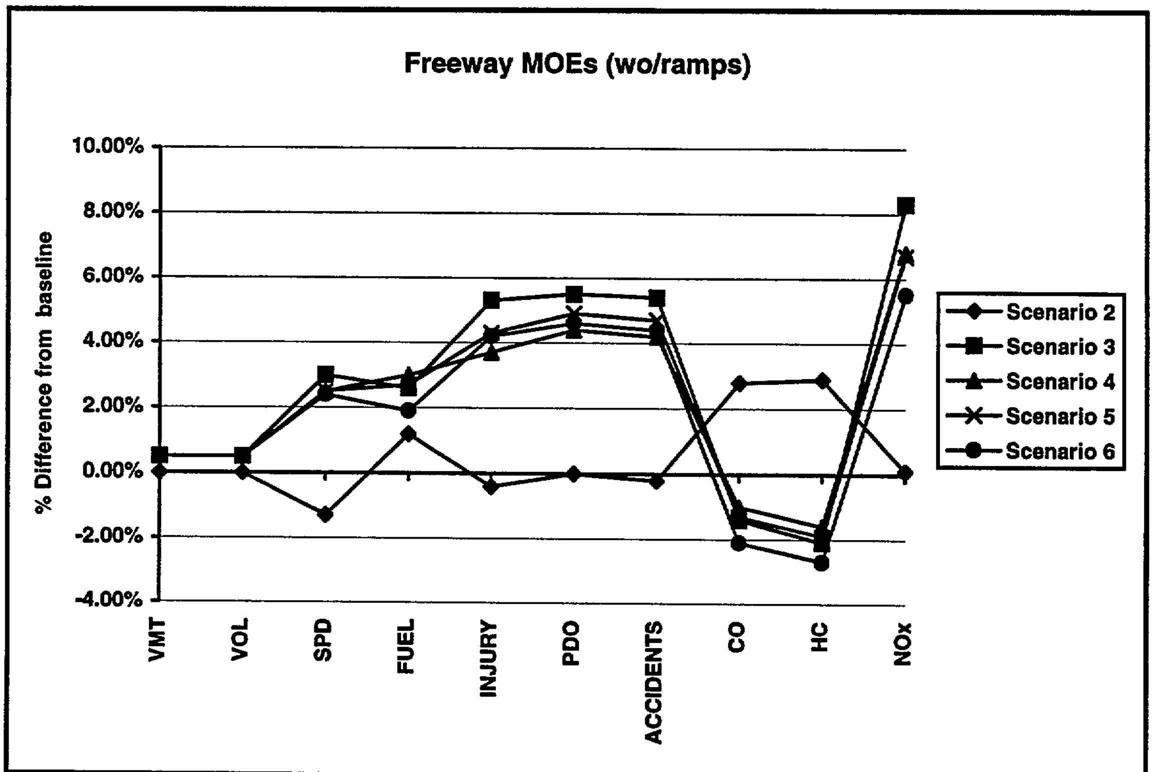

Figure 3: Freeway Measures of Effectiveness

decrease. A signal coordination strategy implemented on the parallel arterial, without freeway ramp metering, appears to slightly degrade freeway speed and VHD while having only a limited effect upon other freeway MOEs.

The evaluation of framework results clearly suggests that several MOEs should be collectively considered when determining network impact resulting from ATMS user services. The overall effect of these technologies appears to be a compromise between many interdependent measures of effectiveness. For example, an improvement in speed and congestion will tend to have associated with them an increase in NOx emissions, fuel consumption and vehicle incident rates.

Conclusion

The research and model development activities performed at the Volpe Center, as described in this report, have clearly demonstrated the technical feasibility of joining popular planning models with traffic simulation tools. This approach was successfully used to create refined values of traffic speed and volume that were used as input to several impact models for the purpose of determining ATMS related implications. As a direct result of this project, Volpe has demonstrated the value of using established and proven models for understanding new traffic problems posed by lTS applications. During the project a network-wide safety impact model was linked, along with popular emissions models, to the improved traffic simulation data to demonstrate the feasibility of using a modeling framework to estimate system-wide impacts beyond traditional traffic flow measures.

This study has demonstrated that the framework is a useful analytical tool in evaluating the impacts related to ITS adaptive control strategies applied to a corridor with integrated freeways and signalized arterials. System-wide impact assessment analysis can be performed to selectively target specific MOE improvements for particular geographic areas where deployment can be most beneficial. This approach leverages the dependent nature of MOEs and allows a transportation practitioner to select individual ATMS services for obtaining optimal network-wide results. Finally, the specific framework results, from implementing any of the strategies described within, will vary with local network geometry and other region-specific conditions.

Finally, the team at the Volpe Center would like to thank all those involved in this project. The project’s sponsors at the Joint Program Office, Gary Euler, Burton Stephens, Ronald Giguere and Mel Cheslow, the contractors who participated in the implementation of the prototype, and a peer review panel composed of academic researchers and planners from various Metropolitan Planning Organizations, all made valuable contributions to the final outcome.

Table of Contents

List of Tables

List of Figures

1. Background

The Intelligent Vehicle Highway Systems (IVIS) Act[1] of 1991 provided the impetus for an accelerated multi-year research and testing program to evaluate application of Intelligent Transportation System (ITS) technology for solving metropolitan transportation problems. This Act authorizes an investment of $659 million, over six years, to identify techniques for reducing traffic congestion and improving highway safety while having a positive impact on environmental air quality. Methods typically considered for ITS involve the application of sensors, communication technology, and adaptive traffic control systems to effect individual travel choices or to dynamically adjust roadway conditions according to actual demand. It is estimated that approximately $6 billion will be required over the next twenty years to support research, development and testing to ensure a successful National ITS Program.

There are between 60-70 different highly interdisciplinary ITS technologies that are broadly classified into five types of user services. They are normally referred to as Advanced Traffic Management Systems (ATMS), Advanced Traveler Information Systems (ATIS), Advanced Public Transportation Systems (APTS), Commercial Vehicle Operations (CVO), and Advanced Vehicle Control Systems (AVCS). ATMS traffic management normally incorporates areawide surveillance and detection systems that operate in real-time to detect various changes in traffic flow. Adaptive responses to these changes can take the form of coordinated arterial signals, dynamic freeway ramp metering, demand management and providing accurate transportation information (e.g. variable message signs, advisory radio, etc.). This report concentrates on user services associated with ATMS.

The current National ITS Program is simultaneously focusing on five key components critical to the success of this program. These activities include 1) developing a system architecture, 2) establishing ITS technology standards, 3) conducting ITS operational field tests, 4) dealing with legal, public and institutional issues, and 5) development and testing of ITS evaluation methodologies. Organizations such as the Mitre Corporation, the Department of Energy National Laboratories and the Volpe National Transportation Systems Center are actively engaged in ITS research and analysis. The Volpe National Transportation Systems Center has focused their work within the fifth component dealing with research on various ITS modeling methodologies.

The rational for performing ITS research is based upon estimates of projected improvements in traffic safety, reduction of environmental pollutants, enhanced mobility, reduced fuel consumption, and the improved convenience and comfort offered to drivers

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1 The IVHS Act of 1991 is part of the Interrnodal Surface Transportation Efficiency Act of 1991.

through implementation of ITS. A common research view is that ITS technology may have considerable potential for addressing many of our nations transportation problems.

While there is broad consensus that ITS can improve traffic flow and reduce congestion, to date there has been no analytical basis to support this optimism. In 1992, the Federal Highway Administration ITS Joint Program Office requested the Volpe National Transportation Systems Center to create an analytical tool that could be used to predict various ITS impacts and to identify potential benefits of implementing ATMS user services. ATMS was a logical starting point because it provides the foundation upon which other types of ITS services will evolve. The Volpe Center teamed with a contractor, JHK & Associates, in an effort to assess the best use of existing models to evaluate the public impacts of ITS. The result of this effort is a framework composed of linking files to facilitate the exchange of data between regional planning and traffic simulation models. Initial results are promising and are discussed in detail, within section 13 of this report, for several combinations of ATMS user services.

2. ITS Predicted Benefits

One of the most compelling reasons to invest in ITS services is to realize a reduction in traffic congestion. Volume on America's highway network is expected to double from 1.9 trillion vehicle miles traveled to about 3.8 trillion miles in the year 2020[2]. A recent National Cooperative Highway Research Program (NCHRP) study[3] concluded that over 1.2 billion hours of traffic delay were being experienced annually in the 37 largest metropolitan areas in the United States. The total cost of all traffic congestion has been estimated at $100 billion annually in lost economic productivity. Urban travel is increasing at a rate of 4% per year[4]. Traditional techniques involving investment in construction of new transportation facilities are expected to accommodate less than 25% of this additional demand. Heavy investment in construction of new transportation facilities is not seen as a viable option due to limited availability of urban space and fiscal constraints. Only through more efficient use of existing finite transportation networks and facilities can significant new improvements be achieved. Some estimates of potential ITS impact indicate that a reduction in traffic congestion of as much as 20% can be obtained in ITS-equipped municipalities[5].

Approximately 60 percent of all urban freeway congestion is non-recurring, the result of incidents such as accidents, disabled vehicles, and spilled load?. Incident occurrences by time of day and day of the week are generally proportional to traffic volumes. Some studies indicate that most incidents occur during the weekday commute hours, while accident severity increases during the off-peak periods and weekends, presumably due to the higher speeds that can be achieved during non-commuting peak hours. Incident management is thus a key component of ITS strategies to improve traffic flow.

Another important benefit of ITS is in the area of collision avoidance for improved traffic safety. Roughly l0-30 million vehicles' are involved in traffic accidents each year and more than 40,000 persons are killed and another five million injured yearly in these accidents'. The annual economic loss from traffic accidents amounts to 2% of the US gross national product. This translates into a national cost of $600 per registered vehicle

2 A. Hobeika, H. Sherali, W. O'Neill, "Optimal Diversion Strategies for a Modified Urban Network", Virginia Polytechnical Institute, July 1989, page 2.

3 National Cooperative Highway Research Program Report 340, December 1991, page 3.

4 Department of Transportation, "Surface Transportation Research and Development Plan", Report to Congress, Volume I & II, July 1993, page 11.

5 IVHS America, "Strategic Plan for IVHS", April 24, 1992, page I-5.

6 Jack L. Kay, "Introduction to IVHS", presentation materials used at ITE sponsored workshop in Washington, D.C., August 9, 1992.

7 VNTSC, "Report to Congress on IVHS", March 1990, page 40.

8 Department of Transportation, "IVHS Strategic Plan, Report to Congress", Dec 18,1992, page 3.

annually or $.05 for each vehicle mile traveled. If traffic vehicle miles traveled increases at the present rate by the year 2020 it is projected that over 100,000 fatalities will occur each year. Some estimates[9] indicate that properly equipped ITS highway facilities may reduce the number of traffic collisions by 8%. That translates into 3,200 saved lives and over 400,000 injuries avoided entirely each year at current traffic levels. If fully realized, this improvement could represent an overall benefit of $6 billion annually (based upon conservative total traffic accident costs of roughly $75 billion per year). Additionally, the fatality rate associated with these accidents may be reduced, from the current level of 1.9 deaths per 100 million miles traveled, by minimizing the contribution of driver error implicit with these accidents. Such error is a major contributor to traffic accidents.

Adaptive traffic control systems, such as dynamic signal coordination and dynamic ramp metering, constitute a significant portion of ATMS user services. Implementation of these technologies reveals that maximum benefits are tightly coupled to the volume of traffic flow. The largest benefits are achieved where links are short, flows are high and significant flow variation occurs during the peak periods. Traffic simulations produced by TRANSYT-7F, for networks consisting of 50-100 nodes, indicate an annual benefit from congestion reduction on the order of $1 to $1.3 million[10]. Considering the hundreds of network facilities located throughout the US that can benefit from this technology suggests that a significant benefit can be derived from this single ITS technology alone. Implementation of adaptive traffic control systems into urban areas are the simplest to achieve since adaptive control is a proven technology and represents one of the least complex forms of ATMS user services.

Capacity management techniques such as ramp metering have already demonstrated that significant benefits are possible using ATMS user services. For example, ramp metering was found to reduce peak period congestion by up to 60% on various Chicago expressways while reducing accidents by up to 18%. Another application of ramp metering, on Houston's Gulf Freeway, improved travel times by 25% and significantly impacted safety by reducing accidents by a factor of two (50% reduction). In Seattle, ramp metering reduced travel time by 48% with fewer resulting traffic accidents while supporting an overall increase in traffic volume. The Minneapolis/St. Paul[11] freeway experienced a 35% rise in speed and an accident decline of 27% after implementation of ATMS services. On Long Island, ATMS services reduced travel time by 20%, fuel consumption dropped by 7%, hydrocarbon emissions fell 13% and carbon monoxide

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9 Congressional Research Service, "IVHS: Challenges, Constraints and Federal Programs", Feb. 18, 1992, page 17.

10 NCHRP, "Assessment of Advanced Technologies for Relieving Urban Traffic Congestion", Report 340, Dec. 1991, page 73-74.

11 Mobility 2000, "IVHS Summary" (reprint), Executive Summary for National Leadership Conference, April 1990, page 6.

emissions decreased by 17%. Therefore, ATMS services can be effectively used to reduce congestion by improving traffic flow while reducing accidents and emissions.

Traffic information broadcasting can be used to divert traffic onto arterials to avoid an accident scene. Investigations have shown that Incident Management can provide maximum benefits in situations where diversion of traffic is sufficient to prevent demand from exceeding capacity. Diversion needs to be small (roughly 10%) and timely. Benefits will decrease as information delay increases. The maximum benefit comes from managing incidents that effect only one lane which, if left unattended, can reduce link capacity by over 18%. This type of incident represents the most common occurrence of an accident and is the easiest to address by using a diversion strategy. A study by NCHRP concluded that up to $65 million[12] could be saved annually, for the Seattle metropolitan area, with the deployment of effective incident management. It is projected that a total of $2.4 billion could be saved yearly by providing incident management services to 37 of the largest cities within the United States.

In addition to congestion, the most often discussed benefit of ITS is its contribution to reducing traffic emissions. An EPA report states that 43% of total nitrogen oxide, 3 1% of hydrocarbons, and 66% of carbon monoxide emissions are caused by transportation sources[13]. Today 50% of the nation lives in areas that exceed the smog standard and one third live in areas exceeding the carbon monoxide standard. A reduction of traffic congestion will, therefore, improve air quality while reducing fuel consumption in many urban and rural areas. The need for fewer emissions has been accelerated by passage of the Federal Clean Air Act Amendments (CAAA) of 1990. The framework provides a tool that can be used to evaluate and quantify the magnitude of improvement in noxious emissions, safety and fuel consumption that is possible using ITS technologies.

ITS represents a major modernization of the transportation industry infrastructure and over the next twenty years could have a societal impact on the scale of the Interstate Highway System. The Department of Transportation (DOT) strategic vision for future transportation systems includes automated highways that improve the safety, efficiency and convenience of the highway system, while simultaneously extracting greater productivity out of the available infrastructure. Benefits will be collectively achieved for rural and urban drivers, younger and older drivers, public transportation riders and commercial vehicle operators.

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12 National Cooperative Highway Research Program Report 340, December 1991, page 65.

13 IVHS America, "Strategic Plan for IVHS", April 24, 1992, page II-12.

2.1 Advanced Traffic Management Systems Defined

An Advanced Traffic Management System (ATMS) will employ several adaptive traffic control strategies to attain congestion mitigation and incident management. These strategies include synchronized freeway ramp metering, dynamic arterial signal coordination, high occupancy vehicle ramp bypasses, rapid incident response and integrated traffic management. Congestion management techniques are implemented to manage both recurring and non-recurring congestion. Recurring congestion typically occurs during the peak hours and is the result of excess demand on the facility. Non-recurring congestion is the result of incidents which obstruct the flow of traffic, reducing network capacity as a result.

ATMS is heavily reliant on the real-time collection and processing of traffic data. Data collection techniques will frequently include the use of freeway surveillance and loop detection devices. The data collection system will detect actual traffic conditions on the transportation facility and relay this information to a control center. In order to effectively collect and process real-time information, from a variety of sources, a central clearinghouse needs to be established or adapted for this purpose. Typically, a Traffic Management Center, or TMC, will serve this clearinghouse function. (Traffic Information Center (TIC) or Traffic Operations Center (TOC) are used interchangeably with TMC.)

A TMC will typically collect information regarding traffic within its jurisdiction, verify the events requiring a response (i.e. incidents), devise an operational strategy to respond to these events, and implement the control strategy (often in conjunction with a human operator). Frequently, the TMC will use adaptive traffic systems to respond to information being received. For instance, loop detectors sending information to the TMC indicating congestion at a particular location may trigger or modify the traffic signalization in that area to be revised or freeway ramp metering to be started. As ATMS strategies become more advanced, these responses will become more integrated and automated.

Information coming into a TMC is typically collected, analyzed and summarized using a data fusion process. The TMC will normally receive estimates of congestion from several sources for a specific roadway segment. The data fusion process ranks the credibility of each data source, factoring in the age of the estimate, and then determines which estimates are most likely to be correct. The TMC formulates a response and coordinates action taken, to resolve roadway problems, by informing units that need to be activated (i.e. police, tow trucks, field devices, etc.). When a TMC is adapted to disseminate real-time information to travelers, a TMC response will usually include some media element that provides information to the public via commercial radio, television or other “value added” traffic information providers. In addition, some TMCs have designated phone lines for motorists to use to report incidents or to receive traffic reports. Calls from motorist with cellular phones have proven to be very helpful.

The primary characteristics of an Advanced Traffic Management System are summarized below:

a) ATMS collects real-time traffic data using technologies that will enhance the capability of the traffic network.

b) ATMS technologies are used to detect, identify and respond to changes in traffic flow. ATMS is also used to predict where congestion might occur, and to implement strategies to prevent congestion on a real-time basis.

c) ATMS includes area-wide surveillance and detection, which is crucial to providing optimal system strategies. Surveillance and detection play an integral role in ATMS by detecting incidents quickly and enabling implementation of an incident management strategy.

d) ATMS integrates the management of various road facilities, including both freeways and arterials. Management of facilities includes:

    Transportation information

    Demand management

    Freeway ramp metering

    Arterial signal control

e) ATMS requires collaborative action from many different transportation management agencies to develop and implement strategies to improve traffic flow in multi-jurisdictional regions.

f) ATMS includes rapid response incident management strategies to detect, verify and respond quickly to incidents.

There are numerous examples of comprehensive operational traffic management systems for freeways as represented above. Mobility 2000, the forerunner to IVHS America, estimated that approximately 1,000 centerline miles of freeway are covered by some form of ATMS and that an additional 10,000 freeway miles warrant such a system.

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3. Current State of Transportation Modeling Practice

There are roughly five types of models widely used today by transportation practitioners. These models address regional planning, traffic engineering, emissions, fuel consumption and safety related concerns. Transportation planning models are normally used to make long-term forecasts of congestion within a regional transportation network and traditionally predict parameters such as vehicle volume, speed and vehicle miles of travel (VMT). Traffic engineering models on the other hand are used to simulate traffic conditions on existing or proposed facilities and these type of models estimate speed and vehicular flow rates. The third model type deals with estimation of polluting emissions and these models are specifically designed for this purpose. Emission models require VMT, fleet composition, vehicular speed and ambient temperature as key input variables. Fuel consumption models represent the forth model type and measure consumption of fuel given a particular set of operating parameters and volume of traffic. The last model type is used to predict safety factors and these models operate based upon historical accident data. In some cases safety models will also incorporate transportation facility geometry. Accurate safety predictions are based upon and directly related to the key measures of effectiveness (MOE) that are predicted by planning or traffic models.

Planning models usually excel at mode selection, route choice and representing traffic volume within a network. Traffic simulation models on the other hand excel at estimating link travel times (speeds) and network operational characteristics.

To effectively use these tools, a regional transportation network is constructed to represent the transportation facilities for a region. Traffic networks are comprised of two elements called nodes and links. Nodes represent points in space while links represent lines connecting nodes. Any particular network can be represented as a database comprised of numerous nodes and links. Each node is equivalent to an intersection, interchange, zone centroid, geometric road change, elevation change or the presence of a transportation facility. A link is defined as a segment between two nodes and each link is assigned attributes defining its characteristics such as length, free-flow speed, capacity and road type. Normally, urban area traffic analysis will consider existing highways and include only the major streets in the traffic network.

3.1 Planning Models

The dynamics of predicting transportation trends through planning models traditionally involves the analysis of land use, travel demand, socioeconomic/demographic characteristics, traffic distribution and travel behavior. These are the central elements that planning models operate upon to generate long term traffic predictions. Usually, planning models deal with very large and complex transportation systems and are macroscopic in their approach. A regional planning model is almost always used in a wide geographical region that is multi-jurisdictional in nature.

A conventional transportation planning process will describe urban travel demand using a four step process involving trip generation, trip distribution, mode split (selection) and traffic assignment. The four step process evolved as a logical sequence of analyzing and processing key control variables and operating upon the interrelationships between economic activity, trip generation, and demand choices. The four step process has been established as a standard transportation methodology and is widely used for forecasting urban travel demand and establishing various performance measures at the link level (e.g. volume, v/c ratio, etc.). Planning models calculate inter-zonal traffic flow, estimate spatial traffic distribution, consider alternate modes of travel and assign trips to specific traffic routes.

The four steps involved in this planning process[14] are described below:

a) Trip Generation - is a function that will predict the total number of trips generated by each zone and the number of trips that will terminate in each zone. Trip generation predicts travel demand as a function of land use patterns and associated activities. It frequently will employ population and land use forecasts as a basis to estimate generation of trips from a zone and trips attracted to a zone. Trip generation basically employs cross-classification or regression techniques and will operate upon census data. A cross-classification technique predicts trips based upon family size and number of autos owned. The individual household level trip information is then aggregated to determine total trips (trip-ends) at the zone level. The regression approach predicts zone trips based upon number of households, work related trips, auto ownership and the number of workers who reside within a zone. Regression models can frequently include other independent variables to fine tune the results.

b) Trip Distribution - allocates the "trip-ends" for each zone to other zones using zone attraction data. Trip distribution is typically determined using a gravity model in which the origin (O) to destination(D) trips for each zone are determined as a function of several attractiveness measures. A major attractiveness measure is the impedance factor that represents travel time and travel costs corresponding to a particular O-D zone pair. A calibration adjustment factor (K) is also used to balance the aggregate O-D trips to the total travel information generated during the trip generation step (a) above.

c) Mode Split - selects alternate modes of travel for each O-D trip. This selection reflects the availability of alternate forms of private and public transportation

14 Edward K. Morlok, "Introduction to Transportation Engineering and Planning", McGraw Hill, 1978.

within a transportation network and usually involves choices dealing with single-use auto, multi-use auto, bus and rail (train). The mode split function is typically structured using a "Logit" choice probability model which includes and compares service measures such as travel time, travel cost, vehicle availability, access to transit service and socioeconomic variables for each travel mode.

d) Traffic Assignment - the process by which trips are allocated onto the traffic network while being optimized for some measure of travel (such as travel time) between each pair of originating and destination zones. There are several methods by which traffic assignment is performed: all-or-nothing, iterative (capacity constraint), incremental, stochastic and equilibrium are among the most popular assignment methods. In the context of this study, a user equilibrium assignment approach is used to determine route choice for vehicle trips on the traffic network. The basis for user equilibrium assignment was derived from Wardrop's criteria, which states that "traffic will distribute itself in a network so that travel costs on all routes used between two points are equal to or less than the costs associated with other unused routes".

A planning process will normally repeat or iterate on the assignment step described above until link volume convergence is obtained between iterations. Usually, the process starts by selecting the initial minimum time travel route (using free-flow link times) for all trips contained in the O-D trip table. The total number of trips for each link are then summed and this number represents the individual link volumes. After this step a Bureau of Public Roads (BPR) capacity-restraint function is used to consider the effect that traffic volume has upon travel time (more congestion implies longer travel times and slower speeds). This revised travel time based on link volume is usually higher than the initial free flow time. The revised travel times are then used to recalculate the new minimum travel route for all trips in the O-D table. This operation will redistribute link volumes based upon the new minimum travel times. The assignment step will continue to iterate, distributing link volumes using the latest estimates of dampened link travel time, to calculate the minimum trip paths. The trip assignment process will terminate when link volumes converge to an acceptable threshold value or reach an equilibrium point.

3.2 Traffic Models

Traffic simulation models are mathematical methods of approximating real-life traffic situations. Traffic models are used to assist in planning, design and operation of transportation facilities. From a theoretical viewpoint, there are two types of traffic simulation models: macroscopic and microscopic models. (Recently, mesoscopic models have been developed which attempt to capture the best features of both model types.)

- Macroscopic models are based on deterministic relationships developed through research on highway capacity and traffic flow. The simulation process for a macroscopic model takes place on a road section-by-section basis rather than tracking individual vehicles. Macroscopic models require considerably less demanding computer resources than microscopic models. They do not, however, have the ability to analyze improvements and designs in as much detail as microscopic models.

- Microscopic models simulate the movement of individual vehicles on a road. Typically, vehicles enter a transportation network using a statistical distribution of arrivals and are tracked through the network on a second-by-second basis. Computer time and storage requirements for microscopic models are large, usually limiting the network size and amount of time that can be reasonably simulated.

Traffic engineers usually employ traffic simulation models to design or test any number of different proposed traffic facility modifications to determine their impact on a specific traffic network. These models are also used to optimize urban resources to improve the movement of people and goods without impacting community values. Traffic models are used when a strictly empirical approach is not practical or appealing since a simulation is often less costly, more efficient and requires no change to existing facilities. Simulation models have a more detailed focus since they consider the effects of network changes to a much lower level than planning models. Many of these models simulate operation of every vehicle in the transportation network and use small time step increments over the analysis period for all links contained within the traffic network. Traffic models require considerably more time to execute than planning models because of the low level of detail used to describe operation of the network.

When a traffic system is represented by a simulation model the effects of different traffic management strategies upon the traffic system's operational performance can be determined. This performance can be expressed in terms of Measures of Effectiveness (MOE) which include parameters such as average vehicle speed, vehicle miles traveled (VMT), vehicle hours of delay (VHD), etc. In addition, MOEs can provide valuable insight into the responsiveness of traffic flow to the applied strategy thereby providing a basis for optimizing the proposed strategy.

Historically, simulation models were developed to model traffic in distinct operating environments such as freeways, corridors (including a freeway and major arterials), surface street grid networks, and rural highways. Typically, these transportation sub-networks have distinct operational characteristics that are reflected in the simulation model. However, as traffic congestion has increased, both in time and in space, the assumption that each sub-network operates independently has become invalid. Many simulation models are being enhanced to address and model this emerging traffic inter-dependency. Operating environments for traffic simulation models are summarized in

Table 3-l which describes the ability of each model to simulate the four distinct operating environments defined as freeway, corridor, arterials or rural highway configurations.

Table 3-1: Operating Environments For Various Traffic Simulation Models

Model	Freeway	Corridor	Arterial Network	Rural Hwy
1. CORFLO	X	X	X	
1A. FREFLO	X			
1B. NETFLO1		X	X	
1C. NETFLO2		X	X	
2. FREQ*	X	X		
3. INTEGRATION	X	X	X	
4. FRESIM	X			
5. TRANSYT7F**			X	
6. NETSIM			X	
7. SATURN	P	P	X	
8. CONTRAM	P	P	X	
9. ROADSIM				X

X: Existing capability
P: Partially existing capability

* FREQ, a macroscopic model that simulates corridor traffic operations including one freeway and one parallel arterial.

** TRANSYT-7F a macroscopic model that simulates a given, non-dynamic traffic flow in a signalized surface street network and optimizes signal timing parameters.

3.3 Emission Models

Emission models created for highway vehicles attempt to quantify the primary emissions of gasoline powered engines. The emissions from an engine consist of chemical compounds that have a direct and damaging effect upon the environment. Three types of emissions have been the subject of extensive attention in emission modeling; carbon monoxide (CO), hydrocarbons (HC) and oxides of nitrogen (NOx). Carbon monoxide has significant pollution potential if concentrations are allowed to develop in localized "hot spot" areas such as intersections and highway ramps. HC and NOx are compounds that combine with other chemicals in the presence of sunlight to form ozone and other damaging oxidants.

Basic emissions are very much a function of vehicle drive cycle, average speed and vehicle load. The drive cycle represents the pattern of vehicle acceleration, deceleration, cruising and engine idling. Average speed is an important variable related to emissions. CO, HC and NOx each have different emission profiles relative to average vehicle speed. Vehicle load appears to be important in determining emissions but is generally not modeled in the industry today.

Most emission models use three primary measures of speed, vehicle miles traveled and basic emission rates to calculate total pollutants. The emission rate is very sensitive to average vehicle speed. Link emissions are determined by multiplying link volume by length and a particular emission rate given the vehicle's average speed. MOBILE and EMFAC are two popular models used to calculate total emissions based on vehicle class and these models predict emissions for cold start, hot start and hot stabilized operating modes. In practice most emissions modeling has revolved around the Environmental Protection Agency (EPA) MOBILE model series. However, an alternate model called EMFAC and a set of practices have been developed and used by the state of California. Both schemes for predicting emissions are in use today.

3.4 Fuel Consumption Models

Fuel usage models measure the amount of fuel consumed by petroleum powered internal combustion engines. These models determine fuel consumption using a set of attributes defining the basic engine design, emission controls, fuel types and driving conditions.

Fuel consumption has been traditionally regarded as a function of average travel speed, vehicle miles traveled (VMT), or a combination of the two. There are several software packages that estimate fuel consumption in this way. However, considerable research has indicated that fuel consumption models based only on VMT and/or average speed may not be specific enough to produce accurate estimates of fuel consumption. Research has shown fuel consumption to be affected by several factors not typically included in fuel models. Currently, new models are being developed to account for these factors, which include:

- The operating characteristics of a vehicle, which are defined by rates of acceleration and deceleration, and the characteristics of the engine during periods of idle an cruising. (The pattern of operating characteristics for a vehicle over a specific distance or time period is referred to as the vehicle profile.)
- Vehicle class; and
- Road geometry, including gradient and curvature.

The most significant factor in contributing to fuel consumption is the operating characteristics of the vehicle. Considerable research work has demonstrated the correlation between fuel consumption and acceleration and deceleration. Many models are being developed to include fuel consumption rates based on both speed and operating characteristics to account for the difference in fuel consumption between cruising at a steady speed versus accelerating for a distance and achieving an average speed equal to the cruise speed.

3.5 Safety Models

Traditionally, safety models have measured safety in terms of the number of accidents per million miles traveled. These models incorporate accident information into a database and determine safety predictions using a range of accident rates based upon different factors. The factors used in accident prediction models usually include VMT and speed since the accident rate increases proportionally to these two parameters. Accident prediction models are calibrated for an area using site-specific historical accident data.

Recent work in the safety field has revealed that safety is not only a function of VMT, speed or the design of the infrastructure but is dependent on several factors occurring simultaneously. Some of these conditions relate to road-user factors (vehicle driver), and some are related to non-road-user factors (engineering and environmental). It is therefore, quite difficult to identify the "cause" of an accident since it is frequently a combination of these factors.

Road-user factors describe the driver of a vehicle and include age, gender, driving style, seatbelt usage, use of alcohol, and the vehicle mass. There is an inverse relationship between the mass of a vehicle and the risk to persons involved in an accident. The less mass a vehicle has results in more risk to the driver of the vehicle and reduced risk to other road users. Conversely, the more mass a vehicle has, less risk is incurred to the driver of the vehicle and more risk is shifted to other road users.

Non-road-user factors include area type (rural vs. urban), functional class of the road, time of day, road configuration, weather, and presence of traffic signals or signs. Accidents will decrease when there is a reduction in miles traveled, weave sections less than 1000 feet in length, lessening the severity of road curvature or grade, and elimination of short merging lanes.

Environmental factors related to safety include characteristics such as temperature, surface condition, visibility and wind. Accident statistics reveal that accident rates decline during poor weather conditions, suggesting that inclement weather is a deterrent to travel and encourages drivers to reduce speed, which improves safety. However, there may also be other relationships between safety and mobility: an increase in the rate of acceleration will enable a driver to reach cruise speed faster, reducing the time required to merge with the freeway, which increases safety. This may also increase overtaking opportunities, which may cause safety to be jeopardized.

4. The ITS Framework

Currently, the "state-of-the-art" in transportation planning and traffic simulation is to perform planning and simulation exercises in isolation. Most of the short and long-range planning exercises are aimed at modeling travel demand to identify existing or future bottlenecks within the transportation system. On the other hand, transportation practitioners typically use traffic simulation models to derive site specific improvement plans for addressing very localized traffic issues. Both of these model types have proven their value and are successfully being used by many professionals within the transportation field.

The methodology developed by the Volpe National Transportation Systems Center incorporates the strengths of widely used planning and simulation models into an integrated modeling framework. This framework provides a set of file linkages that enables data sharing among the integrated models. The approach improves the sensitivity and capability of currently available transportation models to assess impacts and potential benefits of implementing different combinations of ITS technology. The framework integrates a regional planning model with freeway and arterial simulation models in a new way to estimate noxious emissions, fuel consumption and determine safety benefits. It principally focuses on impacts related to the availability of ATMS user services. The design is innovative because it allows transfer of data between models automatically and introduces elements of dynamic assignment to produce reliable estimates of travel time and speed. These variables are among the key Measures of Effectiveness (MOE) and are major contributors to predicting benefits associated with ATMS user services.

By effectively incorporating planning and simulation models into the framework, the advantages of both have been retained and can be applied more effectively to assess ATMS benefits. By complimenting the limitations of a planning model with the strengths of simulation models, the advantages of route and mode choice can be provided coupled with accurate predictions of link speed and travel time for a given volume of traffic. This combination provides sufficient sensitivity to reliably predict MOE variables impacted by ATMS technology that planning or simulation models alone cannot achieve. Analytical determination of ATMS user benefits is based solely upon MOE data. The MOE variables used to assess impact are vehicle miles traveled (VMT), link volume, vehicle travel speed, vehicle hours of delay (VHD), kilograms of pollutants emitted, gallons of fuel consumed, and the number of accidents encountered.

The framework has been designed to evaluate the impacts of five ITS technologies commonly associated with ATMS user services. By selecting framework input control parameters various combinations of the technologies listed below can be evaluated for determining impact:

a) Ramp metering - controls freeway traffic volume by limiting access at freeway entrance ramps (typically accomplished with signals).

b) Signal coordination - controls vehicle movement and delay by coordinating traffic signals between adjacent intersections based upon actual traffic conditions or using a fixed time scheme (synchronization may occur at a sub-network level).

c) Integrated traffic management - coordinates ramp metering and signal timing for arterials adjacent to a freeway to prevent ramp queues from extending onto arterials.

d) HOV lanes - these lanes restrict access to multi-occupant vehicles.

e) Ramp metered HOV bypass lanes - enable multi-occupant vehicles to avoid any traffic queue that may exist at the freeway ramp.

5. Framework Architecture

A primary goal of the ITS Benefits Assessment Framework project was to develop an analytical tool that improved the sensitivity and capability of currently available transportation software to assess impacts and potential benefits of implementing ITS user services, principally ATMS user services. The analytical tool that was developed represents an integrated framework that links a regional planning model with freeway and arterial simulation models, and incorporates emissions, fuel consumption and safety models to determine impacts. The framework was developed with a desire to determine impacts upon vehicle travel time, roadway congestion, polluting emissions, fuel consumption and safety factors with the implementation of several ATMS traffic management strategies. The resulting framework is considered innovative because it allows the automatic transfer of data between various models, introduces elements of dynamic assignment and produces more accurate estimates of travel time and travel speed, than current models can produce, to assess impact of ATMS user services.

The discussion contained in the following sections describes the modeling framework requirements, architecture, design approach, existing models selected and data flow interfaces developed to achieve ATMS impact assessment.

5.1 Framework Requirements, Considerations and Design Criteria

Requirements developed for the framework were based on the need to produce a tool that is sensitive to the influence of ATMS user services, incorporates the best available technology, reflects proven methodologies, provides reliable MOE information, and could be completed within project time constraints. Modeling tools considered for the framework included regional transportation planning models, freeway simulation models, and integrated dynamic route assignment models. When implemented alone, none of these three analysis techniques were suitable to assess impacts of ITS technology because they did not match the design criteria or lacked sufficient sensitivity to the variables affected by ATMS services.

Several design approaches were studied in an attempt to meet the stated framework requirements. The primary alternatives considered included the use of a conventional planning model only, simulation models only, or combinations thereof, linked planning and simulation models, or an integrated dynamic route assignment model. During the framework analysis phase a preferred design approach emerged that made use of a combination of existing analysis tools.

A major functional element of a fully integrated model framework is the capability for providing dynamic assignment, both in time and in space. For example, in such a system a queue that develops on a specific network link during a particular time interval could affect traffic operations in upstream links during the same time interval or during neighboring time intervals. Dynamic assignment models appear to be sensitive to the variables affected by ATMS user services and are also capable of producing regional forecasts and estimates of mode split. Several integrated dynamic assignment models exist or are currently under development, however, to be included into the framework these models must be mature, widely available, fully documented and operate in a 386 PC environment.

Evaluation of ITS benefits within any particular urban area requires analytical capabilities presently found in planning models. The modeling framework requires integration of mode choice and major route selection functionality that traditionally has been solved by the overall structure and orientation of a planning model. Representation of transportation system characteristics in planning models, and the performance that results from traffic flow operating in the highway network, is useful for planning purposes but is far too coarse to detect any congestion, mobility, emissions, fuel consumption and safety benefits that ITS technologies are likely to produce. Most importantly, planning models are ill-equipped to represent the travel time differences that result from application of alternative ATMS strategies.

Historically, simulation models were developed to model traffic in distinct transportation sub-networks such as freeways, freeway corridors, surface street grid networks and rural highways. These transportation sub-networks have distinct operational characteristics, which are reflected in simulation modeling. Simulation models are superior to planning models in the evaluation of operational characteristics and in the estimation of link travel times for sub-networks. Accurate estimation of congestion, mobility, emissions, fuel consumption and safety impacts from the changes introduced by ATMS technologies requires the detailed representation of capacity and flow provided by simulation models. For example, consideration of ramp metering benefits necessitates the use of a freeway simulation model while assessment of benefits from traffic signal coordination requires use of an arterial network simulation model. While simulation models are clearly superior in evaluation of operational characteristics, they are not designed to predict regional mode shift or route choice and, therefore, are not capable of estimating all of the impacts of implementing ATMS technologies.

Based on the strengths of planning and simulation models described above, the analytical tool design selected for this project was created by merging planning and simulation models to enhance the capabilities of each and to improve precision in forecasting. Integration of the distinct functions provided by planning and simulation models could be accomplished through transfer of data between the two modeling systems or by fully combining all functions into a single, internally consistent software package. The former approach was selected for the prototype framework given the limited schedule time available for framework development. This modeling structure has the sensitivity to capture subtle impacts of implementing ATMS user services and the capability to evaluate mode choice and forecast traffic flow in a network. The framework, for instance, uses estimates of traffic operating characteristics for smaller, more discrete time intervals and allows more dynamic representation of interaction between these time intervals. The design makes considerable progress in addressing individual deficiencies of existing models for assessing ATMS user services. Several enhancements were also made to the various models comprising the framework making the new tool more sensitive to the impacts of ATMS technologies than its individual model components.

A key element of the framework is its ability to forecast travel demand. The planning model is used in two ways within the model framework. The first is to perform a standard travel forecasting process, and the second is to provide the iterative assignment process with simulation components of the framework. The model framework is designed to work with any planning model that follows the standard four-step modeling process and is capable of reading and writing ASCII files containing capacity, volume and speed data as part of a dynamic process. The framework is compatible with most regional planning software packages, including SYSTEM II (JHK Associates), MINUTP (COMSIS Corp.), TRANPLAN (DKS Associates), and EMME/2 (INRO Consultants, Inc.). All software enhancements and interfaces developed for this project were written external to the planning model and are sufficiently generic to be transferable to other transportation planning software packages. Likewise, the emissions and fuel consumption components provide the structure within which different emission and fuel consumption estimation models and rate models may be applied. In keeping with this philosophy a different set of accident rates can also be incorporated into the safety model.

5.2 Components of The Model Framework

The high level structure for the analytical framework is represented in Figure 5-1. This data flow diagram illustrates the interaction of major framework components with some of the important data elements passed between the models. The diagram reveals that a data feedback path exists between the planning and simulation components and through this path the mechanism for dynamic traffic assignment is provided. With the data feedback improvement the framework can produce more accurate estimates of speed and volume.

The framework is comprised of a set of transportation models linked together by interface software which facilitates the transfer of data between the various components. Planning and simulation analysis is executed as an iterative process. Estimates of mode split and assigned traffic volumes are produced by the planning model and serve as input to the simulation models which produce revised estimates of link speed for the freeway and signalized arterials. The revised speeds are then fed back into the planning model and the process is repeated until travel speeds and volumes converge.

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As stated previously, the SYSTEM II planning model includes support for the traditional four steps of the travel demand forecasting process. The framework, however, only incorporates mode split and assignment steps which represent the last two operations of the four step process. Mode split is applied in the framework to measure any differences in transportation mode resulting from implementation of ATMS user services. The assignment step is necessary to assess shifts in volume resulting from changes in travel time and speed that result from the implementation of specific ATMS services. The initial two steps, of the four step planning process (trip generation and trip distribution), were not incorporated into the model framework because none of the ITS technologies being evaluated is assumed to have a significant effect on the number of trips produced or on the distribution of trips from zone to zone. Instead, ATMS user services are more likely to affect trip assignment by impacting the level of congestion on network facilities or by informing travelers of the level of congestion on specific facilities.

The SYSTEM II regional planning component of the prototype framework is responsible for accomplishing the following major functions:

a) Predict the mode split between transit trips including single-occupant automobile and multi-occupant automobile trips.

b) Distribute total auto person trips by vehicle occupancy level for each trip purpose.

c) Convert person trip tables into vehicle trip tables by applying vehicle occupancy rates.

d) Create AM peak, PM peak and off-peak period trip tables from the daily trip tables.

e) Select travel paths through the roadway network based upon a minimum travel impedance (defined as a function of time, distance and cost) between zones for all auto modes in the AM peak period.

f) Assign trips onto the network by modifying individual link volumes that were selected for each vehicle trip.

5.2.2 Simulation Models

The freeway simulation component of the model framework is accomplished using FREQ, a macroscopic model that simulates traffic operations in a freeway corridor. The function of FREQ in the model framework is to provide refined estimates of operational characteristics on freeway facilities within the study area. FREQ operates on the basis of speed/volume and demand/capacity relationships and was considered to be the most appropriate freeway simulation model.

The arterial simulation component of the model framework is provided by TRANSYT-7F, a macroscopic simulation model that is used to provide refined estimates of operational characteristics on signalized arterial surface streets within the study area corridor. TRANSYT-7F simulates traffic flow in small time increments and is capable of simulating non-dynamic traffic flow in a signalized network. This model is often used for optimizing signal timing and evaluating the effectiveness of new signal timing plans in reducing stops, delays and fuel consumption on arterial streets.

Macroscopic simulation models were selected for the prototype model framework instead of microscopic models for the following reasons:

a) The framework design requirements specified a system to be operable on at least a 386 personal computer. It is unlikely that a framework composed of planning and microscopic simulation models could efficiently analyze a moderate-sized network in a 386 or 486 environment and therefore, a Pentium processor configuration is recommended.

b) Optimization of network flows is currently not available in microscopic models.

c) Existing microscopic models are tedious and cumbersome to use. At present, the level of analytical effort associated with microscopic simulation applications is not practical for analysis of freeways and corridors. Most microscopic simulation applications concentrate on small segments (sub-networks) of a transportation network.

d) Data requirements for configuring microscopic models are very intensive and require significantly more data collection effort than macroscopic models. Coding this data for microscopic models is considerably more tedious as well.

e) While macroscopic models such as FREQ and TRANSYT-7F have been used in multiple applications, most existing microscopic models are only in the late development stages and are still undergoing testing and debugging.

f) Calibration of microscopic models involves several parameters that can be adjusted to reach a desired calibration result. These parameters may include variables such as driver behavioral characteristics (passive, aggressive), vehicle kinematic properties (speed, acceleration), and vehicle status (queued, free-flowing). Because very little information is known about the true distribution of these variables in the driver/vehicle population, the microscopic model calibration process could be a significant source of error.

5.2.3 Emissions and Fuel Consumption Models

To estimate the impacts of ATMS user services on vehicular emissions two different emission rate models were selected. The first emission model integrated into the framework is called MOBILE 5a and was developed by the Environmental Protection Agency (EPA). The MOBILE 5a model is used to predict emissions in every state within the US except California. The second emission model, referred to as EMFAC7F, is a model developed by the California Air Resources Board and used primarily in California. Both MOBILE 5a and EMFAC7F estimate hot and cold start emissions and hot stabilized exhaust emissions for carbon monoxide (CO), hydrocarbons (HC), and oxides of nitrogen (NOx). Link-specific estimates of total emissions are derived using an emission rate for each vehicle type and are dependent on link volume and speed produced by the planning and simulation models. The magnitude of pollutants predicted by EMFAC7F are generally lower in value than those predicted by MOBILE 5a given the same input link variables (e.g. speed, volume, vehicle type). Specific differences between MOBILE 5a and EMFAC7F emission rates, and the functions of the programs used to estimate emissions, are described in more detail in section 9.6.1.

Fuel consumption impacts were estimated using the same procedures and methodology used to estimate emission impacts. The emission/fuel consumption impact estimation model EMIS provides the structure within which both emission rates and fuel consumption rates may be applied to link-based data produced by the model framework. Fuel consumption is estimated as the product of the fuel consumption rate at the assigned speed for each link, given the link volume and link length. A particular fuel consumption rate model used for this evaluation was developed by the Caltrans Office of the Transportation Laboratory in cooperation with the U.S. Department of Transportation and the Federal Highway Administration[15].

Fuel consumption rates are a function of average operating speed and are stratified into two vehicle types (light duty vehicles and heavy duty vehicles). The Caltrans rate model provides a set of future year fuel consumption growth factors, which are necessary for future year analysis. Adjustment factors used for the baseline year analysis (1990) were developed in 1991 for Caltrans as part of a study to modify the emissions, fuel consumption and growth factors used by the FREQ simulation model[16]. The adjustment factors used for the 1995 analysis are based on energy forecasts and projections developed in 1993 by the Energy Information Administration, U.S. Department of Energy, Office of Integrated Analysis and Forecasting[17].

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15 Talaga, Dan, Joe Palen, Mas M. Hatano, and Earl C. Shirley. "Energy and Transportation Systems". Report prepared for Office of Transportation Laboratory, California Department of Transportation. FHWA Report No. FHWA/CA/TL-83108. Sacramento, California: State of California Department of Transportation, Division of Engineering Services, Office of Transportation Laboratory, July 1983.

16 Ostrom, Barbara K., Lannon Leiman and Adolf D. May. "FREQIO Modifications: Emissions Factors, Gasoline Consumption, and Growth Factors". Working Paper UCB-ITS-WP-91-2. Berkeley, California: Institute of Transportation Studies, University of California at Berkeley, June 1991.

17 Talaga, Dan, Joe Palen, Mas M. Hatano, and Earl C. Shirley. "Energy and Transportation Systems". Report prepared for Office of Transportation Laboratory, California Department of Transportation.

5.2.4 Safety Model

Implementation of ATMS user services will impact the number and type of accidents occurring in a transportation network. Accidents can be impacted by redistributing vehicle miles traveled (VMT) to different facility types with different levels of congestion, by affecting the number of vehicle stop and start cycles, or smoothing traffic flow which reduces speed variability. ATMS user services that smooth traffic flow and reduce congestion, such as ramp metering, incident management systems and signal coordination systems, may reduce speed variability and the number of vehicle stops. Several factors, including facility type, geometric design and degree of congestion, may contribute to the number and severity of accidents in a network. When congestion on a facility increases, traffic turbulence and speed variability typically increase, which in turn may cause the number of accidents on a facility to increase. As the degree of congestion increases, however, average speeds typically decrease, which reduces accident severity.

Accident rates are also affected when VMT is redistributed to different facility types. This may occur when ATMS user services provide travelers with information about congestion, causing them to divert to a different facility with less congestion. Accident rates vary significantly depending on facility type. The safety impact of drivers diverting from a congested freeway to a less congested arterial, for example, will not only be affected by the difference in congestion level on the two facilities but also by the fact that the accident rate for an arterial is typically higher than that for a freeway.

Sullivan studied several freeway sections with recurrent peak period congestion in the San Francisco Bay Area to develop models that directly relate accidents rates to mainline freeway commute peak period congestion[18]. The levels of congestion in Sullivan's models represent recurrent queuing characteristics of the commute peak period and not non-recurrent incident conditions. Sullivan concluded, "The number of accidents increases with traffic flow and an increasing number of ramps per mile and decreases with the presence of auxiliary lanes and the percentage of the peak period during which no queuing is present." His models also consistently indicate that the average accident rate during the presence of recurrent queuing ranges from two to three times the average accident rate when there is no queuing. Extensive statistical tests have failed to identify any other factors, such as number of ramps, percentage of truck traffic, time of day or the presence of auxiliary lanes, as contributing to the difference in accident rates.

FHWA Report No. FHWA/CA/TL-83/O8 Sacramento, California: State of California Department of Transportation, Division of Engineering Services, Office of Transportation Laboratory, July 1983.

18 Sullivan, Edward C., "Estimating Accident Benefits of Reduced Freeway Congestion", Journal of Transportation Engineering 116(2), 167- 180, March/April 1990.

A new safety model was developed for the framework and it incorporates safety factors that were determined using **historical** accident data available for the study corridor. The safety model estimates accidents using the key factors of:

- Facility type: Freeway and arterial
- V/C ratio range: 0.0 to 0.7, 0.7 to 0.9, 0.9 to 1.0, and greater than 1.0
- Accident type: Total accidents, casualty accidents (fatal and injury accidents were grouped together because the accident database contained so few fatal accidents), and property damage only (PDO) accidents.

To assess the safety impacts of ATMS user services, a three-hour peak period was modeled using the framework. The accident rate determined by facility type, accident type and v/c ratio range is multiplied by the corresponding estimate of VMT (based on data included in the output from the model framework) to predict the number of accidents. The safety impact of each user service is measured in terms of the difference in accidents resulting from shifts of VMT between facility types and between v/c ratio ranges.

5.3 Measures Of Effectiveness

Performance variables generated by the framework are normally referred to as Measures of Effectiveness (MOE). Many of these MOEs are sensitive to the effect of varying some aspect of the network characteristics and therefore, can be used to evaluate the impact of implementing ATMS user services. These responsive MOEs are considered important to the framework because they reflect changes in traffic dynamics that are induced by ITS technologies. In the case of the prototype framework the transportation facility dynamics are varied through implementing different traffic management strategies that are provided within the framework. The magnitude of change upon individual MOEs will vary depending on the specific ATMS service being considered. Table 5-l below identifies many of the MOEs that are generated by the framework and can be used to evaluate the impact of implementing ATMS traffic management user services.

Table 5-1: Framework Measures of Effectiveness

Impact Area	Measures of Effectiveness
Congestion (operational measures)	Vehicle miles traveled (VMT) for freeway and parallel arterial Vehicle volume (VOL) for freeway and parallel arterial links Average vehicle speed (SPD) for freeway and parallel arterial Vehicle hours traveled (VHT) for freeway and parallel arterial Vehicle hours of delay (VHD) for freeway and parallel arterial
Emissions	Pollutants (CO, HC and NOx) emitted in kilograms/hour by time of day, vehicle type and functional class.
Fuel Consumption	Gallons of fuel consumed per hour by time of day, vehicle type and functional class.
Safety	The total number of accidents, incidents resulting in casualty, and accidents reflecting property damage only (PDO).

6. User Services Modeled by Framework

Planning and simulation models, incorporated into the framework, were adapted in several distinct ways to estimate the impact of implementing specific ATMS user services. The various adaptations of theses models are discussed in considerable detail in the innovations section of this report. Services modeled by the framework concentrate on evaluating the key ATMS traffic management strategies as defined below:

1) Ramp metering - Ramp metering is designed to control traffic volume on a freeway by limiting the rate at which vehicles are allowed to enter the freeway via metered ramps. The goal of ramp metering is to optimize traffic throughput and speed on the freeway and to break up platoons of entering vehicles.

2) Signal coordination - Signal timing controls vehicle movements on urban roadways. By coordinating signals between adjacent intersections, parallel roadways, or throughout an entire network, delay is reduced because the signal system responds to traffic conditions and demand when it occurs.

3) Integrated traffic management systems - Integrated traffic management systems coordinate freeway ramp metering systems with signal timing systems on adjacent arterial streets so that queues from the freeway ramp do not extend onto the arterial which can disrupt arterial flow.

4) Incident management systems - Incident management systems include several technologies that detect and/or respond to traffic incidents and congestion which provide motorists with information regarding current incidents or congestion. Detection systems are typically comprised of a combination of loop detectors and closed circuit television. Changeable message signs and highway advisory radio (HAR) are systems that inform motorists of incidents and suggest possible diversion routes.

5) HOV lanes and ramp meter HOV bypass lanes - High occupancy vehicle (HOV) lanes are lanes that restrict traffic to multi-occupant vehicles. HOV lane restrictions can vary widely by location. HOV lanes may be exclusive bus lanes, exclusive bus/taxi lanes, exclusive bus/carpool lanes (with varying vehicle occupancy restrictions), or exclusive bus/taxi/carpool lanes. Ramp meter HOV bypass lanes enable HOV vehicles to bypass the existence of a queue at a ramp meter and therefore, provides direct access to the freeway for high occupancy vehicles.

6.1 Ramp Metering

The primary purpose of implementing ramp metering is to control traffic volume on the freeway by limiting the rate at which vehicles can enter via ramps. The goal of ramp control is to optimize freeway traffic throughput and speed and to break up queues of entering vehicles. Ramp metering is a strategy for managing recurring congestion and has been effective where congestion occurs near freeway on-ramps or merge points. While ramp metering increases the capacity of a facility slightly, it may impact safety by reducing the occurrence of rear-end accidents, increase average speed by up to 30 percent in heavily congested areas, and improve overall efficiency as measured by vehicle miles of travel (VMT) per hour. While motorists on the ramps will experience increased delay waiting for freeway access, it is anticipated that the benefit of increased freeway travel speed outweighs the detriment created by the additional delay on ramps. The locations selected for ramp metering are based on accident patterns, bottleneck queue locations, and forecasted changes in travel. Traffic simulation is generally used to assist in this type of analysis. Ramp metering reduces accidents, especially in the vicinity of ramps, by reducing the number of speed changes experienced by drivers (stop and go conditions) and through smoothing the traffic flow at freeway merge points.

6.2 Traffic Signal Coordination

Vehicle movements on intersecting urban roadways are normally controlled by traffic signals that are adjusted to improve traffic flow by varying the signal timing length. When used in this fashion traffic signals between adjacent intersections and parallel roadways can be coordinated to improve network traffic flow as part of an overall traffic management strategy.

Isolated intersection control systems reduce delay by responding to traffic conditions with a change in signal timing. These systems may operate in fixed time or as semi-dynamic or fully dynamic signals. Fixed time coordination refers to groups of signals that are timed in relation to one other based on the estimated travel times on links connecting them. Dynamic signal coordination systems use loop detection capabilities to adapt to changes in traffic patterns and respond to traffic demands by implementing appropriate signal settings. These adaptive traffic control systems receive information from on-street detectors at critical intersections and use the traffic data to select the most appropriate signal timing from a pre-determined library of signal plans.

6.3 Integrated Traffic Management

Traffic control strategies are more effective when implemented in groups such as using ramp metering in conjunction with signal coordination. If implemented independently ramp metering rates and arterial signal timing sequences can impact one another. For example, when freeway on-ramp queues extend onto surface streets they adversely affect operation of signalized intersections. Therefore, integration of freeway ramp metering systems and network traffic signal control is perceived as beneficial to achieving the full potential of ATMS capability.

6.4 Incident Management

Incident management includes many technologies used to detect and then effectively respond to traffic incidents and/or congestion. These technologies or services may be as simple as providing a phone number for motorists to call, using cellular phones, when they see incidents or may include incident detection or video imaging systems. Incident detection systems are typically comprised of a combination of active loop detection and closed circuit television technology.

Because incidents are more likely to occur during peak periods, incident detection and response systems may significantly improve congestion levels at these times. Incident management is the coordinated pre-planned use of human and mechanical resources to restore full capacity to a facility as soon as possible after an incident occurs, and to efficiently manage traffic during an incident[19]. Automatic incident detection systems typically consist of a small computer or distributed microprocessor system that monitors signals from vehicle detectors, typically standard induction loops, spaced along the highway. The loop detectors are usually spaced every l/2 mile in congested areas and every l/3 mile in less congested areas. The induction loops typically provide measurements of volume, lane occupancy and speed at each surveillance point. Lane occupancy is the percentage of time the detection zone is occupied by a vehicle and is a parameter that summarizes the basic aspects of the traffic stream. Special algorithms detect incidents by looking for particular disturbances in traffic flow patterns, such as the presence of stationary or slow-moving vehicles over individual induction loop sensors (measured as spot speed variation). Differences in traffic flow characteristics between upstream and downstream detector stations (paired comparisons) are often used as the basis for identifying incidents.

Closed circuit television (CCTV) is used primarily in incident management to provide visual verification of congested conditions in critical areas. CCTV provides direct information regarding the type of incident which enables the immediate dispatch of appropriate response equipment. Current practice is to use CCTV for continuous coverage in high incident areas, with spacing at approximately one mile or closer, depending on geometric conditions. Video imaging detection systems (VIDS) consist of a standard video camera, a microprocessor and image processing software. Video images are analyzed using the software to estimate traffic flow characteristics, including volume, occupancy, speed and classification of vehicles.

Several traffic management systems have been designed and installed to respond to traffic incidents. For example in Virginia, loop detectors embedded in the road provide traffic

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19 Dennis C. Judycki and James R. Robinson, "Managing Traffic During Nonrecurring Congestion", ITE Journal 62(3), March 1992, pages 21-26.

information to a central computer at a Traffic Operations Center (TOC)[20]. The TOC computer compares current volumes to known capacities of the road and regulates ramp meters depending on conditions. Incidents are detected using paired comparisons. Closed circuit TV cameras enable TOC staff to view incident scenes to confirm their existence and to identify the nature of the incident. The Illinois Department of Transportation operates a freeway traffic management program in the Chicago area. The Chicago program includes freeway traffic surveillance and real-time traffic control that is centrally-supervised and operates using loop detectors, ramp controls, highway advisory radio, and variable message signs. Updated motorist information concerning route choice is provided on changeable message signs and highway advisory radio.

Because a large number of traffic accidents occur during bad weather, some traffic designers believe that ATMS devices such as variable message signs, speed signs, ramp metering and diversion should take weather into consideration. With such a system drivers receive warning messages via a control center about present and predicted travel conditions and assessments of when risks are deemed excessive. This information enables drivers to know when to reduce speed and keep larger headways between vehicles to maintain safe driving conditions in poor weather.

6.5 High Occupancy Vehicle (HOV) Lanes and HOV bypass lanes

Highway lanes that are dedicated for use by only multiple occupant vehicles are considered HOV lanes. HOV lanes can exist in many forms such as exclusive bus lanes, exclusive taxi lanes, bus and car-pool lanes, or as bus, taxi and car-pool lanes combined. In whatever form, all HOV lanes provide for the smooth flow of vehicles through circumventing freeway segments that are operating near v/c ratios of 0.9 and higher. The logic behind instituting HOV lanes is that single occupancy drivers will observe the contrast in high multi-occupancy vehicle speed while they are mired in heavy freeway congestion. This congestion difference eventually induces motorists to abandon their single-occupancy vehicle for a bus or car-pool. It is not desirable therefore, for an HOV lane to be operating at or near capacity since the inducement to use it decrease as the HOV lane v/c ratio increases.

Existence of HOV lanes on a freeway are not without impact to the single occupancy vehicle lanes. Generally, a lane is usually removed from an existing highway to create HOV service and this modification will reduce the traffic capacity of the remaining freeway lanes. The new HOV lane is delineated from other traffic by the use of either traffic cones or permanent barriers that will pose a lateral obstruction (narrowing) to

20 Joan Morris and Stacy Marber, "Virginia's Traffic Management System", ITE Journal 62(7), July 1992, pages 13-15.

traffic flow in adjacent lanes. This restriction in traffic mobility may impact safety. Lastly, the movement of vehicles entering and leaving a HOV lane can become very disruptive to other traffic on the freeway at HOV access and departure points.

Another volume control strategy that also provides an incentive to use HOV vehicles is signal preemption for buses and other HOV vehicles. Signal preemption reduces the delay for travelers in HOV vehicles by minimizing the time they wait at traffic signals. When signal preemption is implemented at metered ramps the resulting ramp bypass can provide a real incentive for ridesharing using busses or car-pools. Ramp bypasses enable HOV passenger vehicles to avoid waiting for freeway access at a metered ramp.

7. Framework Innovations

The ITS framework links a regional planning model, a freeway simulation model, an arterial network simulation model, and multiple impact models to estimate congestion, mobility, emissions, fuel consumption and safety impacts of alternative IVHS strategies. This particular design was considered to be a pragmatic approach for developing a workable framework to assess ITS benefits.

Several adaptations were made however, to the framework models to improve their appropriateness and utility for analyzing ATMS traffic management user services. The framework, for example, incorporates estimates of traffic operating characteristics for smaller, more discrete time intervals and allows for dynamic interaction between these time intervals. The framework modifications include a provision for control linkages between models, improved travel estimates and the establishment of data transfer compatibility among framework models.

The full scope of framework innovations are presented and discussed throughout the following sections.

7.1 Existing Model Deficiencies

Previous sections of this report established the background concerning relevant ITS technologies and introduced some of the models available to quantify potential benefits of ATMS user services. In this section of the report, deficiencies of these existing models are described, and suggestions for enhancing the existing models, for inclusion into the framework, will be presented.

A review of the variables affected by ITS technologies, reflected against existing modeling capabilities, reveals a number of significant deficiencies in current modeling systems. ITS technologies are likely to produce benefits by subtly changing characteristics of the transportation system or by indirectly changing the way travelers interact with the transportation system. The intricacy of these influences when combined with the methods of estimating mobility, congestion, emissions, fuel consumption and safety impacts using available models prove to be insufficiently sensitive due to generalizations and approximations made within each model. Three specific areas have been identified as significant deficiencies;

1) Dynamic representation of demand

2) Representation of time-varying capacity

3) Representation of volume-dependent capacity

7.1.1 Dynamic Representation of Demand

Most regional planning models produce daily forecasts of travel with some stratification by major time period; usually AM peak period, PM peak period and off-peak period. The smallest time increment for which forecasts are produced is generally one hour. Simulation models are generally designed for representation of smaller time periods, usually fifteen minutes, and require input on travel patterns for these smaller time increments. Regional planning models are also generally deficient in their dynamic representation across time periods and how performance in one time period might impact travel in subsequent time periods. The nature of ITS technologies and their influence on travel behavior requires explicit representation of small discrete time intervals and dynamic interaction between these time intervals.

7.1.2 Representation of Time-Varying Capacity

The introduction of surveillance and control ITS technologies provides an opportunity for optimizing traffic flow patterns through central control of facility capacities. This is achieved through arterial signal timing, freeway ramp metering, reversible lanes, and other traffic management devices. These capabilities allow for dynamic changes in capacity on a continuous basis to respond to the performance of the network or to respond to the occurrence of accidents or incidents on the transportation system. Planning and simulation models generally exhibit static representation of capacities over a period of time. The evaluation of ITS benefits requires a modeling systems that allows for variation in capacity within time periods as well as across time periods.

7.1.3 Representation of Volume Dependent Capacity

Most often, the time-varying nature of capacity resulting from ITS technologies occurs because of changes that are made in response to observed volumes. In such cases, the capacity is not only time-varying, but also volume-dependent. As an example, the metering rate for a freeway ramp may be changed one or more times within a specific time period to respond to observed levels of flow or congestion on the freeway. In this case, the capacity of the ramp link is dependent upon the volume of one or more links on the freeway. At present, neither planning models nor simulation models alone can represent this volume-dependent capacity, where the capacity of a link is a function of the volume on some other link in the system.

7.2 Model Enhancements Required for Framework

Given the model deficiencies cited above, several enhancements have been identified for the prototype framework modeling components. These improvements deal with;

- Time of travel
- Travel impedance (time and cost) estimation

- Mode choice
- Route assignment

For each of these areas, specific improvements made to enhance framework operation are described in the following sections.

7.2.1 Time of Travel

To be sensitive to the impacts resulting from ITS technologies current planning model methodologies must be enhanced to provide a technique for allocating total daily travel to small, discrete time periods. This time allocation has been performed in the past, but in a static fashion that does not allow for dynamic shifts of travel between the discrete time intervals. The methodology must reflect peak spreading[21] that occurs as impedance in one time period increases relative to other time periods, and travelers choose to shift to another time period to avoid the higher impedance. The methodology must accommodate queue carryover when a bottleneck location, or other capacity constraint, delays travel on a link from one time-slice into the next. The algorithm for time-slicing needs to be dynamic, representing the interrelationship between different time-slices. While this need has generally been incorporated into simulation models, it has not been a characteristic of planning models. Planning models have generally treated travel in different time periods as totally independent of each other.

7.2.2 Travel Impedance (Time and Cost) Estimation

Significant enhancements are required in the way planning and simulation models estimate travel times and delay as a function of volume flow. Enhancements were made in travel time and delay estimation capabilities in the planning model by increasing the detail of the network and by introducing generalized simulation modules into the path building and travel time estimation algorithms. A generalized simulation module provides an estimate of the incremental travel time that results because of a specific geometric or operation characteristic that cannot be reflected in the normal travel time estimation process. The incremental time is estimated as a function of the flow on the link or the flow on some other specified link in the system. (An example might be a traffic signal on an arterial link.) The incremental delay added to an approach link would be estimated as a function of the volume on the approach link, the volume on the cross street, and the number of turning movements at the node where the signal is located.

7.2.3 Mode Choice

A number of ATMS services are specifically oriented towards encouraging the use of carpooling, vanpooling or public transportation by giving priority to these types of

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21 N. Rosenberg & V. Alexiadis, "Peaking Spreading Methodology for Intelligent Transportation Modeling", VNTSC Report.

vehicles on the roadway system (e.g. ramp meter bypass, HOV lanes, and signal preemption). This situation is particularly true for estimation of carpooling and vanpooling. Most regional planning models have reasonable capability for predicting the split between automobile and transit for home-based work trips, but the allocation of the share of work trips by automobile to occupancy levels is generally inadequate, as are the models to predict mode choice for home-based non-work trips and non-home-based trips. Models for predicting the vehicle occupancy for trips other than home-based work trips in a manner that is sensitive to travel time differences are virtually nonexistent. For mode choice and vehicle occupancy impacts of ITS technologies to be modeled, significant enhancement of the planning model was required.

7.2.4 Route Assignment

Extensive development was needed on the method used for vehicle route assignment. User equilibrium route choice was achieved through an iterative application of the simulation models and the assignment function. Since the effects of ATMS user services are reflected in the speeds produced by the simulation models these speeds form a critical link between the route assignment function and the traffic simulation.

7.3 Planning Model Adaptations

Several enhancements were made to the planning model to increase the sensitivity of the framework to subtle changes in operating characteristics. As stated before a wide range of planning models can be used within the framework but the selected planning model must be adapted to produce and read ASCII interface data files to support the iterative dynamic forecasting process. This ASCII interface ensures that a reliable and consistent data exchange is achieved between the planning model and simulation models. The remainder of this section describes adaptations that were made to the planning model before its inclusion into the framework.

1. The traffic network representing the study area highway corridor was defined to a sufficient level of detail to insure that a consistent representation existed between the planning and simulation models. There is a requirement for a direct correspondence between ramps, freeway mainline, and arterial links included in the planning and simulation traffic networks. In addition, high occupancy vehicle (HOV) lanes were represented as separate parallel facilities and were assigned a special facility class code.

2. High occupancy vehicle demand was estimated for all trip types. Accurate forecasting of HOV trips requires consideration of all reasons for taking trips and then validating the planning model HOV estimates against auto occupancy field counts obtained at selected study area locations (screenlines).

3. The planning model required an analysis period adaptation to predict individual hourly trip assignments for each hour within the analysis period. Excess link demand for these hourly assignments were then temporally distributed to adjacent analysis hours through the use of a peak-spreading algorithm developed specifically for the framework.

4. Network link capacities, speeds and volume-delay equations were modified to insure consistency with operational curves and parameters employed in the simulation models.

7.3.1 Highway Network Representation

The highway traffic network used for the study area corridor was created to a sufficient level of detail to allow a consistent representation to exist between planning model forecast functions and estimates of link operation produced by the simulation model. The interface between these models could not function properly without establishing link level correspondence among all links used by the planning and simulation models. The following actions were taken to insure link consistency:

a) All ramps, parallel arterials, and frontage roads were included in the freeway corridor network.

b) An equivalence file was created which equates link segments in the planning model with the corresponding link segments, including ramps and mainline segments, in the FREQ freeway simulation model. Another equivalence file equates planning model arterial links with TRANSYT-7F arterial links.

c) HOV lanes and metered ramp HOV bypass lanes were coded as separate parallel facilities with a special facility class code. All HOV lane access points were coded as separate links connecting the HOV lanes to the mixed-flow lanes.

d) Local street attribute data (lanes, free-flow speeds, capacities, and length) for ramps, arterials, and frontage roads were verified for the study area, because link lengths must be accurate to the nearest hundredth of a mile. Data used in the planning model for freeway, arterial, and local streets must be consistent with network data operated on by simulation models.

7.3.2 HOV Demand Modeling Capabilities

In the determination of travel demand, there are frequently considerable discrepancies between HOV model estimates and observed roadway counts of multi-occupant vehicles. This discrepancy stems from the fact that most planning model estimates represent only work trip modal allocations. To realistically assess the impact of ATMS user services, on HOV facilities, a new HOV procedure for non-work trips was developed. This model enables total HOV demand to be estimated for all relevant trip purposes and vehicle types. In addition, the new planning model HOV estimates were then validated against actual auto occupancy counts at selected screenline field locations within the study area.

The new planning model procedure splits non-work auto trips into drive-alone trips and HOV trips to provide improved estimates of non-work HOV volume. The procedure was applied to Home-Based Shopping/Other (HBSO) trips, Home-Based Social/Recreation (HBSR) trips, and Non-Home-Based (NHB) trips that represent the three major non-work trip types. The procedure was not applied to the other two non-work trip types (Home-Based University and Home-Based School) because those trips have no significant effect on HOV trip volume estimates.

Auto person trips were converted to auto vehicle trips using an average vehicle occupancy rate. This rate will vary by trip type and is defined to be always greater than or equal to one. The split between drive-alone trips and HOV trips is based on the assumption that the total number of person trips and vehicle trips would remain constant. Given the total number of person trips and vehicle trips, and assuming an average car-pool occupancy of 2.45 persons/vehicle, the following two equations were developed and solved to determine the number of drive-alone and HOV vehicle trips for the three primary non-work purposes identified above:

(1) ***Total auto person trips = Drive-alone person trips + HOV person trips***

(2) ***Total auto vehicle trips = Drive-alone vehicle trips + HOV vehicle trips***

where:

Drive-alone vehicle trips = Drive-alone person trips

HOV vehicle trips = HOV person trips / 2.45 people

7.3.3 Analysis Period Adaptations

Several adaptations were made to refine the time period used for analysis in the planning model. These modifications include an adjustment in the planning model to predict hourly traffic assignments for each of the three hours within the analysis period and the addition of a peak-spreading capability to distribute excess hourly demand. The peak spreading model was specifically developed for the framework to identify congestion-dependent travel and redistribute excess link demand to adjacent hours within the analysis period.

Another reason peak spreading capability was added to the framework is to improve the accuracy of the planning model output. Estimates of volumes produced by planning models sometimes significantly exceed the capacity of the transportation network because planning models produce estimates of the willingness to travel rather than estimates of travel that is feasible under prevailing conditions. Volume-to-capacity (v/c) ratios greater than 1.00 are not uncommon in planning model forecasts. Using a peak spreading function, to distribute excess traffic among the peak period hours, can significantly improve the accuracy of traffic volume and speed forecasts.

Typically, simulation models will focus on a 15 minute analysis period, rather than an hourly period, to account for all congestion occurring during the peak analysis period. For this reason, a new interface module was created to enable integration of the planning and simulation models. This interface converts the planning model hourly traffic volume assignments into four separate 15 minute intervals for processing as required by the simulation models.

7.3.4 Adaptations to Speed-Flow Curves

The speed-flow curves used in the assignment step of the planning model process were replaced with more accurate curves reflecting the lower speeds encountered during heavily congested conditions. Speed-flow curves used in traffic assignment are typically flatter than curves derived from actual speed-flow observations. As a result, speeds predicted by planning models are usually higher than actual speeds, especially at v/c ratios that are near or over 1.0.

The new speed-flow curves, used for traffic assignment, more closely match relationships found in the traffic models FREQ and TRANSYT-7F used for freeways and parallel arterial simulation respectively. The planning model, using the new speed-flow curves, was re-validated and found to produce link speed estimates that were significantly closer to link speeds predicted using simulation models only.

7.4 Traffic Simulation Model Adaptations

A few minor improvements were made to enhance the interface capabilities of the freeway and arterial traffic simulation models. Three particular adaptations were undertaken as part of the framework project;

1. Adapted the simulation models to accept external generated trip tables. For example, in a standalone environment FREQ synthesizes O/D trip tables based on freeway and ramp volumes that are inputs to the model. The freeway and arterial simulation software was modified to be capable of reading externally generated trip tables for single occupant and HOV vehicles.

2. Modified the interface of the FREQ simulation model to accept input directly from a regional network planning model. Normally, FREQ requires binary input for all directly transferred data. Adapting the FREQ model to accept ASCII formatted data greatly enhanced its interface capability.

3. Enhanced FREQ and TRANSYT-7F to create travel time output files for use by the regional planning model. While FREQ and TRANSYT-7F produce data necessary for the planning model travel times, minor modifications to the output data format extended simulation model linkage and transfer capabilities.

7.4.1 Freeway Traffic Simulation

A fully calibrated FREQ model of the study corridor was incorporated into the model framework for freeway simulation. Several adaptations were made to the FREQ Priority Lane (PL) and the FREQ Priority Entry (PE) simulation modules which are used for freeway HOV lane and metered ramp analysis respectively.

a) The FREQ input interface was modified to provide the capability to access 15-minute ramp volumes and occupancy data directly from the ASCII interface file. This ASCII file is created by the PRESIM utility which is discussed in section 9.4.1.1.

b) Modifications were made to FREQ so that initial 15 minute ramp volumes are replaced with new ramp volumes from the ASCII interface file.

c) During the planning/simulation iterative process, adaptations were made to FREQ so that initial vehicle occupancies are replaced with new occupancies read from an ASCII file produced by the PRESIM utility. A set of vehicle occupancies for each freeway origin is required.

d) As part of the iterative process, FREQ was modified to calculate speeds (including ramp delays), for priority and non-priority vehicles, and FREQ writes this speed data to an ASCII file for each 15 minute time interval.

e) The model framework was also enhanced to overcome FREQ's insensitivity to modal shift. The current FREQ model treats HOV lanes separately from ramp metering functional analysis. FREQ requires enabling either FREQPL for priority lane analysis or FREQPE for ramp metering investigations. Users desiring to simultaneously analyze both features must run both FREQ models. For accurate estimation of the interaction between ramp metering and HOV lanes, a linkage between FREQPL and FREQPE was automated as part of the framework interface software.

7.4.2 Arterial Traffic Simulation

TRANSYT-7F requires a variety of geometric, phasing, timing and progression parameters not provided by planning models. Therefore, the base TRANSYT-7F networks were coded to create data input files without volumes before starting the travel speed convergence iteration process. Timing and phasing parameters must be provided with enough flexibility to allow for sizable variations in traffic volume for different turning movements. An overly-constrained timing plan could prevent the flexibility needed to model real time traffic control strategies with the overall framework. Traffic volumes are updated automatically by one of the software modules from the modeling framework.

Prior to executing the iterations between TRANSYT-7F and the planning model, to achieve travel speed convergence, the pattern of peak period volume distribution must be established. This peak distribution information is used to divide peak period turning movement volumes from the planning model into separate 15-minute period volumes. Also, a link-node association file was created to associate the planning model links and nodes to TRANSYT-7F network links and nodes. Other parameters required by the arterial modeling process includes the type of signal coordination control, and a group of turning movement link number codes to match TRANSYT-7F turning movement directions with those from the planning model.

7.5 Emission and Fuel Model Adaptations

Emission rates are determined, for each vehicle type, using the MOBILE 5a and EMFAC7F emission models. These models were not altered for inclusion in the framework. The emission rates produced by MOBILE 5a and EMFAC7F are used as input to the EMISSION and EMIS programs for calculation of trip based and running exhaust emissions respectively.

EMIS is a new program developed specifically for the framework to estimate running emissions and fuel consumption. The ability to support facility specific emission rates and fuel consumption rates was incorporated into the EMIS program during its development. The EMIS program automates the process of using different emission and fuel consumption rates that may vary by facility type, number of lanes and flow type for freeway links. The prototype framework, at this time, only supports facility specific rates for light duty gasoline automobiles (LDGA).

7.6 Safety Model Adaptations

A unique feature of the new safety model, developed for the framework, incorporates an estimate of the congestion conditions under which each accident occurred and is appended to each accident record. With this information it was possible to develop accident rates by level of congestion. A v/c ratio was assigned to each accident record based on the hour in which the accident occurred. (Hourly v/c ratios were derived from the framework.) From the v/c information a composite accident rate was determined for both the freeway and parallel arterial.

A detailed discussion concerning the formulation of safety model accident rates is included in section 9.7.

8. Corridor Study Area

The I-880 corridor in Alameda County, California, was selected as the demonstration corridor and is depicted in Figure 8-l which identifies the location of the corridor and its relationship to the San Francisco Bay Area. I-880 is the major north/south route serving the east Bay Area extending from US 101 in San Jose to I-80 in Oakland, a distance of approximately 50 miles. The majority of the freeway is located in urbanized areas that include both residential and commercial land uses. Industrial land uses are prominent in the southern portion of the corridor. Although I-880 serves as a major truck route in the Bay Area, it draws a large share of daily commuter traffic as well.

The study corridor extends from north of the SR 238 interchange to south of the SR 262 interchange. This section of I-880 is an ideal location for the assessment of ITS benefits for the following reasons:

a) The demonstration corridor is approximately 37 miles long. A shorter corridor would not be desirable for evaluation of spatial and modal shifts in travel.

b) This portion of the corridor is heavily traveled in both directions during peak periods.

c) Design and construction is currently underway to implement HOV lanes, ramp metering, metered ramp HOV bypass lanes, traffic surveillance and control, changeable message signs, highway advisory radio and freeway service patrol throughout this portion of I-880.

d) This section of I-880 offers continuous alternative arterial routes located within one mile of either side of the freeway.

The I-880 freeway, in the vicinity of SR 238 and SR 92, during 1990 was found to maintain an average daily traffic volume of approximately 211,550 vehicles. The 1990 calibrated corridor, both northbound and southbound, includes a basic three lane section (operating as mixed flow lanes) with an additional auxiliary lane north of the SR 238 interchange. The corridor, at the end of 1994, was projected to be comprised of three continuous mixed flow lanes, one continuous HOV lane and one auxiliary lane. This configuration is the same for both the northbound and southbound directions. In the study area corridor, I-880 has approximately two interchanges per linear mile and four freeway-to-freeway interchanges including the SR 238 interchange, the SR 92 interchange, the SR 84 interchange, and the SR 262 interchange.

The Smart Corridor, the SR 91 Corridor from Orange County, California to Riverside, California, and the I-880 corridor were the only corridors considered for which both transportation planning and simulation models were available. The I-880 corridor was selected over the Smart Corridor because all data required to establish a baseline (or "before") analysis of the I-880 corridor had already been collected. In contrast, the data necessary for a baseline analysis of the Smart Corridor was not available. Similarly, the interface between the planning and simulation models for the SR 91 corridor was not as robust as that for the I-880 corridor.

The existence of baseline data was a very important consideration since it is critical for assessment of ATMS benefits. One of the main reasons for selecting the I-880 corridor was the extensive amount of baseline data that was already assembled by JHK & Associates for the I880 corridor. The I880 database included information relating to freeway mainline volumes, freeway ramp volumes, freeway truck volumes, freeway speed and delay data, freeway ramp geometrics, freeway vehicle occupancy, arterial volumes, arterial speed and delay data, arterial geometrics, intersection turning movement volumes, and freeway accident and incident data.

All of the data mentioned above was used to characterize and determine the baseline operating conditions of the study area. With the improvements proposed for the corridor, including the implementation of HOV lanes and ramp metering, a comparison of "before" and "after" ATMS operating conditions was possible.

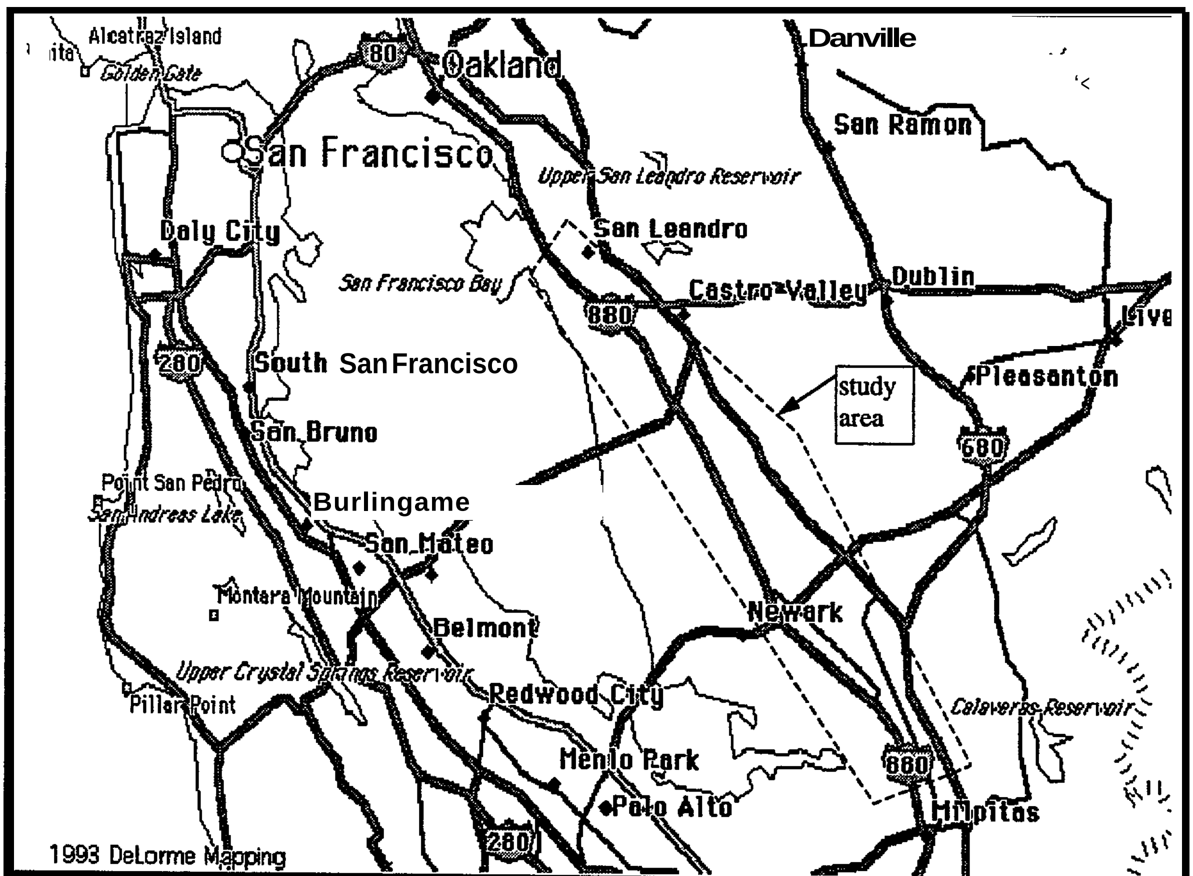

Figure 8-l : I880 Study Area Corridor

8.1 Other Study Area Candidates

The framework project schedule did not allow considerable time **to** be spent for data collection, model development, calibration and validation. For this reason, only corridors for which current, validated transportation planning and simulation (freeway and arterial) models had been developed were considered for the study corridor. Several corridors were examined based on the project team's knowledge, prior work experience, or the implementation of ITS user services. Based upon this information several corridors were considered as candidates:

- INFORM corridor on Long Island, New York
- Five corridors in the U.S. studied by JHK as part of the Analysis of Complex Congested Corridors project
- I-95 Corridor in Dade County, Florida
- SR 91 from Orange County, California to Riverside, California
- Smart Corridor in Los Angeles
- I-880 Corridor in Alameda County, California

Transportation planning, freeway simulation and arterial simulation models developed for each of the candidate corridors were identified. The ideal corridor is one for which a current, validated, operational transportation planning model, freeway simulation model and arterial simulation model was available. The availability of validated models for each corridor, and the sensitivity of those models to the variables affected by ATMS user services, was used as the primary selection criteria. Sensitivity to the variables affected by ATMS user services is necessary for model validation using available baseline data. Each alternative corridor considered for the study area is discussed in more detail below.

8.1.1 INFORM Corridor in Long Island, New York

INFORM information FOR Motorists) is a corridor traffic management system designed to obtain better utilization of existing highway facilities in a 40 mile (64.4 km) long highway corridor on Long Island, New York. The system includes integrated electronic traffic monitoring, variable message signing, ramp metering and related strategies to optimize traffic flow through a heavily congested corridor. The evaluation of INFORM was conducted by JHK & Associates in 1991 using extensive field data, surveys, and data collected through the system. The variables evaluated included vehicle miles of travel, vehicle hours of travel, speed, occupancy, ramp delays, equipment failures, motorist perceptions and other congestion-related measures for the AM and PM peak periods. No transportation planning or simulation models were developed for the corridor as part of the INFORM evaluation.

8.1.2 Congested Corridors

The Complex Congested Corridors project was completed by JHK & Associates in 1992. The purpose of the study was to apply three freeway simulation models and procedures in the 1985 Highway Capacity Manual to real-world situations. Models were applied concurrently in five case study sites located at Seattle, Washington; Minneapolis, Minnesota; Milwaukee, Wisconsin; Columbus, Ohio; and New York City, New York. The strengths and weaknesses of each model were identified and possible model enhancements were suggested. The project included the development of freeway simulation modeling guidelines. The project did not, however, include any modeling of the five sites using either transportation planning models or arterial simulation models.

8.1.3 I-95 Corridor in Dade County, Florida

The I-95 corridor in Dade County, Florida has been modeled using both freeway simulation and transportation planning models. A FREQ model of a 25 mile long corridor of I-95 in Dade County was operational and available. Similarly, the Dade County Metropolitan Planning Association maintains a transportation planning model called the Florida Standard Urban Transportation Modeling System (FSUTMS). FSUTMS, however, is a daily model and provides average daily traffic (ADT) values only. The framework design requires that models integrated into the framework should be compatible with one another in time intervals much smaller than 24 hour increments.

8.1.4 Smart Corridor in Los Angeles, California

The Smart Corridor is a 13 mile long corridor comprising a section of the Santa Monica Freeway (Interstate 10) between the San Diego Freeway (Interstate 405) and the Harbor Freeway (Interstate 110). The area is referred to as the Smart Corridor because an integrated freeway and surface street traffic management system is currently being implemented there. The corridor encompasses an integrated network of parallel arterial streets. ITS strategies are being implemented in the Smart Corridor to manage heavy freeway traffic volumes, typically exceeding 325,000 vehicles per day.

A TRANPLAN transportation planning model of the Smart Corridor was available. The corridor has also been modeled using FREQ for freeway simulation. In the FREQ model, all five arterials parallel to the Santa Monica Freeway were aggregated into one mega-arterial to study the effects of diversion. However, an arterial simulation model of the Smart Corridor was not available.

9. Framework Design

The primary objective of the framework design was to effectively integrate transportation demand modeling tools (planning models), simulation analysis tools and impact models to strengthen current modeling capabilities for evaluating alternative ITS strategies. An additional objective of the framework was to develop an automated linkage between planning, simulation, and impact models to achieve an easy to use analysis tool. To accomplish these objectives, all interfaces between the models were automated to the maximum extent possible.

Section 9 presents the overall framework design and provides a detailed description of control logic and flow of data throughout the framework. During the discussion of control and data flow, all interfaces used to link the framework models together are defined. A detailed summary concerning the development of emissions, fuel consumption, and safety impact models is also provided in section 9.6.

9.1 Framework control and data flow

Within the framework all planning and simulation analysis is accomplished in a cyclical execution fashion. First the travel demand model is run to produce mode choice and to assign traffic volumes. These results are then used in freeway and signalized network simulation, which outputs revised levels of service measures (i.e. speed and volume) for freeways and signalized arterials in the study corridor. If the revised level of service measures deviate significantly from those determined in the travel demand model, traffic reassignment through the travel demand model will be required, followed by another round of traffic simulation, until convergence of service measures is achieved.

The framework project development team created interface software to provide automated conversion and transfer of data between a regional planning model, a freeway simulation model, and a signalized network simulation model. This software creates and accepts ASCII tiles in a variable format that can be defined by the user. With this capability the interface software provides significant data exchange flexibility and can be employed as a universal linkage tool.

Data that is converted and transferred from the planning model to the simulation models will include network link descriptors for each 15-minute time slice (such as link length, number of lanes, and trip tables by mode of occupancy level). Data passed from the simulation models to the planning model includes link speed, travel time, and vehicle operating mode information which is used to update the loaded network travel times. The planning model relies upon updated travel times for subsequent path building, travel time estimates, and route assignment operations to improve the overall prediction of travel characteristics.

Individual components of the framework design are illustrated in Figure 9-l. The upper portion of Figure 9-l only identifies the dynamic travel demand modeling process that is used in the planning model component of the framework. The center area of Figure 9-l represents the iterative planning/simulation process that produces refined estimates of network operational measures. The lower portion of Figure 9- 1 represents the operations performed to determine impacts for emissions, fuel consumption and safety measures. All framework functions are accomplished through a series of precisely controlled data exchange and execution steps. A discussion of these steps and the flow of data through the modeling framework is included below:

Step 1: The planning model estimates mode split using the MSPLIT program.

Step 2: The planning model then assigns trips to the network using the ASSIGN module. The assignment module produces estimates of link volume and average travel speed for each of the analysis hours in the peak period.

Step 3: Planning model assigned volumes, capacities and turning movements are then converted to an ASCIl file format using the DATAEDIT utility and TURNDUMP program.

Step 4: The Peak-Spreading module PEAKSPRD reads the ASCII file containing link volume data produced by the planning model assignment, and temporally distributes any excess volume demand between the three analysis hours for freeway links with velocity/capacity (v/c) ratios greater than 1.1 and for arterial links with v/c ratios greater than 1.05. The peak-spreading function enables congestion-dependent travel to be distributed within the analysis period. For instance, an increase in traffic congestion (due to historical, recurrent or incident related reasons) may prompt commuters to change their departure times. This operation only occurs on the first and last iteration of the framework.

Step 5: The PRESIM program converts the one-hour freeway link volumes produced by the planning model into discrete 15-minute link volumes.

Step 6: A portion of the PRESIM program then calculates all street speeds. This module reads the 15-minute link volumes, determined in the previous step, and calculates revised travel speeds for all segments in the planning model network. The PRESIM program then calculates one-hour volume-weighted average travel speeds for each hour in the peak period for all links in the network and loads one-hour speeds to a file for latter processing by POSTSIM.

Step 7: The FREQ Simulation element of the framework reads the 15-minute volumes for both freeway and ramp segments calculated in PRESIM, computes revised 15-minute travel speeds for these segments, and loads the revised 15minute

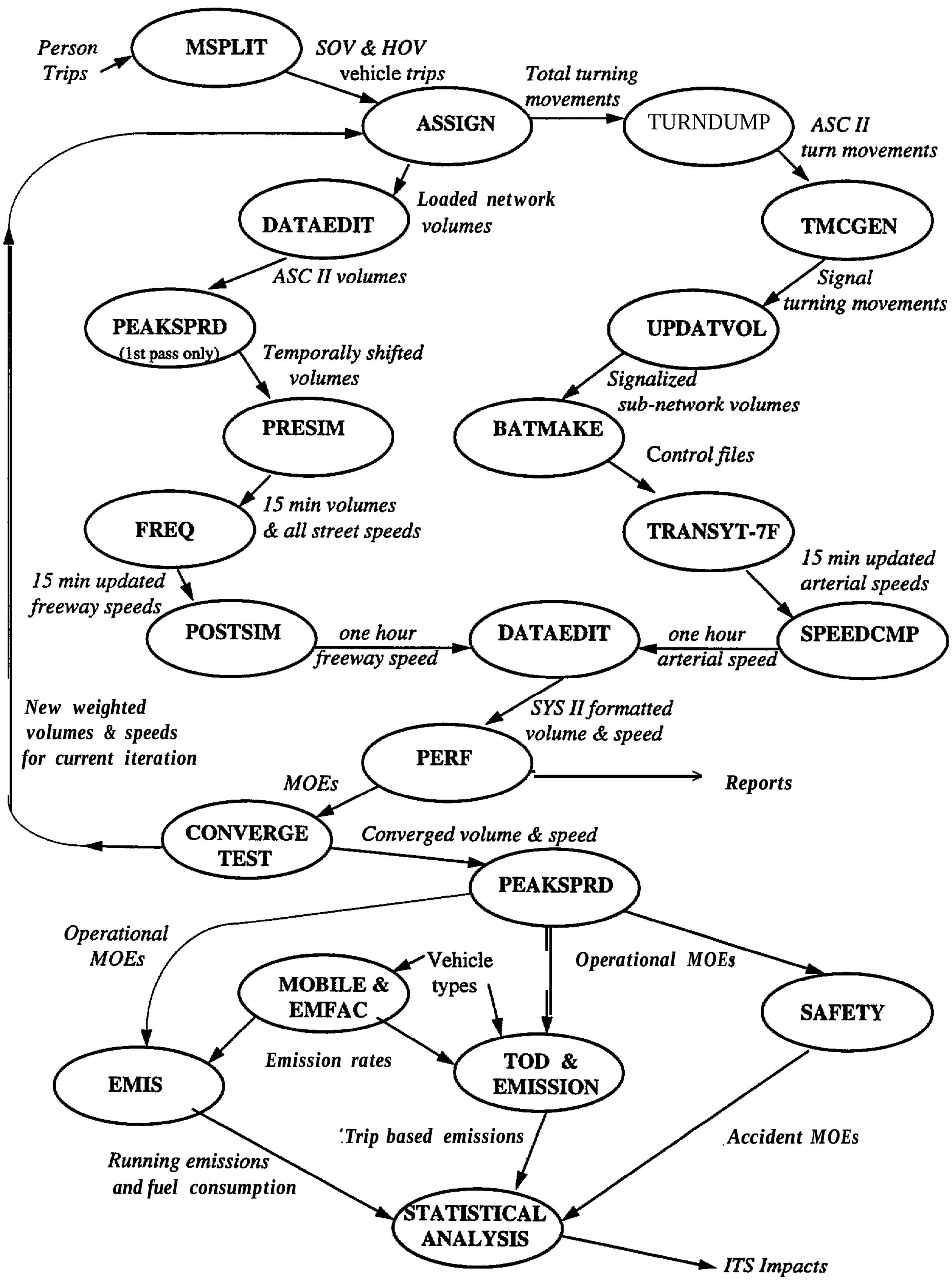

Figure 9-l : ITS Modeling Framework Low Level Data Flow Diagram

travel speeds into a file for POSTSIM processing. The revised speeds for freeway and ramp segments calculated by FREQ supersede the travel speeds for the same link segments calculated in the PRESIM module for street speeds in Step 6 above.

Step 8: POSTSIM is a post-simulation program that converts the 15-minute average travel speeds produced for freeway and ramp segments calculated in FREQ into one-hour "volume-weighted speeds" for the analysis hour. POSTSIM then loads ASCII-formatted one-hour volume-weighted average travel speeds for the freeway, ramps, and street segments into the planning model for the re-assignment function.

Step 9: The Arterial Simulation element of the framework computes link-travel speeds for signalized arterials in the network. The Arterial Simulation element consists of the following operations:

- The TMCGEN module converts ASCII turning movement volume files from the planning model (step 3) into individual turning movement files for each traffic signal network in the study area. During the course of the conversion, turning movement volumes from the planning model are factored to represent shorter time intervals using "peaking factors".
- The UPDATVOL pre-processor copies traffic volumes from the turning movement volume files created by TMCGEN to the appropriate TRANSYT-7F input files. The volume update process is repeated for every time interval and for every TRANSYT-7F network in the study area.
- The BATMAKE utility creates the batch file which controls execution of TRANSYT-7F during the simulation and optimization process.
- TRANSYT-7F performs the traffic simulation and optimization analysis for the signalized arterial sub-networks in the study area.
- The SPEEDCMP post-processor reads TRANSYT-7F output files, computes approach link travel speeds and delays, summarizes this data for multiple time intervals, and loads the ASCII-formatted speed data into the assignment program of the planning model. The arterial travel speeds calculated in this step supersede the arterial travel speeds determined from the PRESIM street module that were loaded to the planning model in Step 8.

Step 10: During this step the framework checks whether the revised travel speeds and volumes, produced in Steps 6 through 9, converge within each hour of the analysis period. If the revised travel speeds and volumes do not converge they are loaded into the planning model for reassignment (ASSIGN), and Steps 5 through 9 are then repeated. This process continues until travel speed and volume converge is achieved within each hour over the analysis period.

Step 11: After travel speeds and volumes have converged the Peak-Spreading function is reapplied to temporally redistribute peak period demand across the three hours in the analysis period.

Step 12: Revised link data including volumes, speeds and v/c ratios are used as input to the emissions, fuel consumption and safety modules.

- The EMISSION program is used to estimate trip-based emissions by tabulating daily vehicle emissions by area type, functional class, screenline or other parameters.
- The EMIS program is used to estimate running exhaust emission and fuel consumption impacts for all hours in the analysis period.
- The SAFETY program is used to estimate accidents by facility type, v/c range, and accident type.

Step 13: A statistical analysis is performed on selected links for important MOEs in the revised loaded network and from this analysis all changes occurring to the MOEs can be determined that are attributed to a particular ATMS strategy.

The overall framework is based on two sub-levels of temporal detail. First, an overall time span for the simulation is selected based on the known length of congested traffic conditions in the study area. Next, the planning model traffic assignments are prepared for shorter time periods, usually every hour in the overall time span. Then, simulation time intervals are selected based on some uniform division of the time periods; usually 15 minutes. Therefore, a model which covers a three hour time span would include three one-hour traffic assignment time periods. From these three time periods, a total of twelve 15-minute time intervals would be simulated using the traffic simulation models.

The software modules in the framework are designed to accommodate up to 24 simulation time intervals of any duration. If desired, the framework could be set up to model six hours of traffic assignments and 24 different 15minute periods of traffic simulation, or four hours of traffic assignments with 24 separate lo-minute periods of simulation, or any other combination that does not exceed 24 simulation time intervals. The 24 time interval restriction is required to be consistent with the inherent 24 time interval restriction contained in the FREQ freeway corridor simulation program.

9.2 Planning Function

The model framework is designed to work with any demand forecast planning model that follows the standard four step modeling process and is capable of reading and writing

ASCII files containing capacity, volume and speed data as part of a dynamic process. The trip generation, trip distribution, and mode split portions of the planning model are executed only once and are, therefore, considered the static portion of the framework. Trip assignment is considered to be the dynamic component of the framework and is accomplished through the ASSIGN program. The assignment function (ASSIGN) used by the framework is discussed in more detail within section 9.5 dealing with framework convergence.

The planning model mode choice function (MSPLIT program) separates the person trip table into several trip tables based on alternative transportation modes (typically automobile and transit). After determining the split between auto person trips and transit person trips, the mode split function determines auto trips for each of the four trip purposes modeled in this application. These trip purposes are defined as; home-based work (HBW), home-based shopping/other (HBSO), home-based social/recreation (HBSR), and non-home-based (NHB) trips. The framework concentrates on the mode choice for auto occupancy and does not evaluate a transit choice. The framework assumes that the trip table generated by the planning demand model represents auto person trips that are grouped by trip purpose.

After determining the split between auto person trips and transit person trips, the assignment function operates on the auto trips grouped by the four trip purposes. Several permutations are made to the auto person trip tables before the auto trips are assigned to the network as single occupancy (SOV) or multi-occupancy vehicles (i.e. drive alone, two occupants, three occupants, etc.). Typically, vehicle trips are assigned to a highway network, where path choice is affected by various use restrictions involving HOV lanes.

The assignment function distributes trips onto the network for each of the analysis hours using an equilibrium assignment algorithm. The equilibrium assignment initially produces a minimum path assignment in which trips from origin zone to destination zone are assigned to the shortest path between zone pairs. The assignment module then calculates congested travel times based upon minimum path v/c ratios, performs a new minimum path assignment using the congested travel times, and then calculates the proportion of the new and previous assignments that will optimize system performance. This operation is repeated within the assignment module until time paths between zones reach an equilibrium. SOV and HOV volumes are stored separately. During the assignment function all turn movement data files are also produced.

The conversion element of the planning model involves two steps. The first (DATAEDIT) converts the assigned link volumes from the planning model to an ASCII format for input to the simulation and peak spreading programs. The second (TURNDUMP) converts turning movement volume assignments to ASCII for input to the arterial simulation program.

In summary, several operations are performed by the mode split, assignment and conversion functions of the planning model and are defined as follows;

a) Work Mode Split

- Assign the AM peak hour auto trip table to the AM peak highway network to produce congested speeds for the AM peak hour.
- Estimate the AM peak hour travel times and costs for the home-based work (HBW) mode split model.
- Estimate the mode split (drive alone, 2-person and 3-person carpools) for the HBW trips based on congested travel times and costs for the HOV and SOV travel options.

b) Non-Work Mode Split

- Factor home-based shopping/other (HBSO) trips and produce HOV and drive alone trip tables.
- Factor home-based social/recreational (HBSR) trips and produce HOV and drive alone trip tables.
- Factor non-home-based (NHB) trips and produce HOV and drive alone trip tables.
- Report district-to-district trips to check that no trips are lost.

c) Vehicle Occupancy

- Factor HOV trips to produce vehicle trip tables by purpose.
- Convert drive alone trips to vehicle trips for compatibility.
- Report district-to-district trips to check that no trips are lost.

d) AM Peaking

- Convert daily trips by mode (auto, drive alone, HOV) to AM peak hour trip tables by purpose (home-based work, non-work).
- Combine AM trip tables by purpose and add external trip table.
- Report AM peak hour (Hour 2) trip table by district.
- Create AM peak hour trip tables (Hour 1 and Hour 3) from Hour 2 table.
- Create off-peak and PM peak hour trip tables.
- Assign off-peak and PM peak hour trips to the highway network.
- Combine AM, off-peak and PM peak hour volumes into average daily traffic volumes.

e) Trip Assignment

- Assign the Hour 2 AM peak hour trip table to the highway network.

- Compute the weighted average total volumes and store (drive alone and carpool) link volumes into a separate volume run number. Transfer link speed to this same run number.
- Assign the Hour 1 and Hour 3 AM peak hour trip tables to the highway network.
- Transfer drive alone and carpool link volumes and speeds into separate volume run numbers.

f) Conversion

- Convert AM peak hour volumes (Hour 1,2, and 3) to ASCII.
- Convert AM peak hour turning movements (Hour 1,2, and 3) to ASCII.
- Compute the weighted average turn movement volumes.

Planning model assigned volumes, capacities and turning movements are converted into an ASCII file format using the DATAEDIT utility and TURNDUMP program which are invoked by the DUMPLINKBAT and DUMPTURN.BAT batch files respectively as shown in Tables 9-l and 9-2. The dynamic portion (ASSIGN) of the planning model is executed during each iteration of the framework. The reassignment function is controlled using the REASSIGNa.BAT batch file (where a = 1,2,3 . . . 8) and is documented and discussed in detail within section 9.5.

Table 9-l: DUMPLINK Batch File

DUMPLINK.BAT BATCH FILE COMMANDS	DESCRIPTION
dataedit dumphr1 dataedit dumphr2 dataedit dumphr3	Creates ASCII file of network link volumes and capacities for the traffic simulation models.

Table 9-2: DUMPTURN Batch File

DUMPTURN.BAT BATCH FILE COMMANDS	DESCRIPTION
turndump turn1.dat turn1.asc 2 turndump turn2.dat turn2.asc 2 turndump turn3.dat turn3.asc 2	Creates an ASCII file of turning movements for arterial street simulation.

9.3 Peak Spreading

This part of the framework is used to distribute excess traffic demand occurring during the peak period to adjacent hours within the analysis period. A peak spreading program (PEAKSPRD.EXE) reads the ASCII files containing link volumes, produced by the planning model assignment function for the three analysis hours, and distributes excess demand among the three analysis hours for freeway links with v/c ratios greater than 1.1 and for arterial links with v/c ratios greater than 1.05.

There are several reasons why a peak-spreading model is a necessary component of this framework. The peak traffic period is typically longer than one hour, and in major urban centers the peak period is typically longer than two hours. To account for all congestion occurring during the peak period, a peak period model consisting of three one-hour intervals was developed for the framework.

Another reason for the peak spreading function is to improve the accuracy of the planning model output. Estimates of traffic volume produced by planning models sometimes significantly exceed the capacity of the transportation network because the models produce estimates of the willingness to travel rather than estimates of travel that is feasible under prevailing conditions. Volume-to-capacity (v/c) ratios greater than 1 .OO are not uncommon in planning model forecasts.

Finally, the peak spreading module enables estimation of congestion-dependent travel distribution within the peak period. An increase in traffic congestion (due to historical, recurrent or incident related reasons), for instance, may prompt commuters to change their departure times.

Implementation of the peak-spreading methodology was accomplished by addressing the following three major requirements;

1. Thresholds were established to differentiate traffic congestion that can be diverted spatially and traffic congestion that can be diverted in time. The v/c ratio was used as a measure of congestion and different v/c congestion thresholds were established for each facility type. V/c threshold limits of 1.10 and 1.05 were used for freeways and arterials, respectively. Congestion exceeding the threshold will be diverted in time only, while congestion with v/c ratios greater than 1.00 but less than the threshold will be diverted in space only. The thresholds represent average v/c ratios observed during the peak hour and are based on relevant research[22].

22 Loudon, William R., Earl R. Ruiter and Mark L. Schlappi. "Predicting Peak-Spreading Under Congested Conditions." Transportation Research Record 1203,1988.

2. A mechanism to measure and proportionally distribute excess demand between three hours in the peak period was established. To determine excess link demand for each hour, the PEAKSPRD program computes vehicle hours of travel (VHT), vehicle miles of travel (VMT), and vehicle hours of delay (VHD). The sum of VHD provides a measure of excess demand that may be diverted temporally. For each analysis hour, the ratio of VHD over total VHT (also normalized by VMT of the peak hour) provides a normalized measure of excess congestion.

3. The user has the option to:

   a) Select the peak spreading interface or not, and if selected to,

   b) Use a proportional Peak-Spreading algorithm that distributes excess demand proportionally over the three analysis hours; or

   c) Use a similar methodology that proportionally distributes excess demand only between the first two hours of the three-hour peak period. This is called a 'historical" or "AM" peak-spreading option because it assumes that travelers have a fixed arrival time and a flexible departure time; or

   d) Use a methodology that proportionally distributes excess demand only among the last two hours of the three-hour peak period. This is called an "incident" or "PM" peak-spreading option because it assumes that travelers have the flexibility to divert in time only during the last two hours of the peak period.

Information describing the time-of-day distribution of trips, for each of the analysis hours during the peak period, is provided by the user as peak factor input to the PEAKSPRD module. Time-of-day information is typically available from Metropolitan Planning Organizations. The time-of-day distribution is expressed in terms of percentage of total daily trips and total daily travel that occurs within each of the analysis hours. Total daily travel and total daily trips within the peak period is assumed to remain constant.

The following steps describe operations performed by the peak spreading process.

- The hourly traffic volumes, for the three analysis hours, are accessed from the planning model and provided as input to the PEAKSPRD program. The LINKa.ASC file contains the planning model output link volume data for pre-peak, peak, and post-peak analysis hours, respectively (where a = 1,2 or 3).
- Peak factors are acquired by the PEAKSPRD program in a file called PEAKFAC.ASC. This file contains the peak factors that are used to distribute the excess demand. These factors are developed using time-of-day distribution data.

  For example a typical set of peak factors are;

90	- Factor for pre-peak hour (90 percent of peak hour)
100	- Factor for peak hour
80	- Factor for post-peak hour (80 percent of peak hour)

- Selection of one of three types of peak spreading is specified through a choice variable.

Variable Value	Peak Spreading Type
1	FLEX (Proportional)
2	AM (Historical)
3	PM (Incident)

FLEX - Distributes excess demand proportionally over the three analysis hours.

AM - Distributes excess demand only between the first two hours of the three-hour peak period. This is called "Historical" or "AM" peak spreading because it assumes that travelers have a fixed arrival time and a flexible departure time.

PM - Distributes excess demand only between the last two hours of the three-hour peak period. This is called an "Incident" or "PM" peak spreading because it assumes that travelers have the flexibility to divert in time only during the last two hours of the peak period.

- A convergence factor is specified for the peak spreading function.
- The PEAKSPRD program then modifies the PEAKFAC.ASC file with the newly determined peak factors.

Convergence within the peak spreading module is checked by recording the rate of change between peak factors created by recursive invocations of peak spreading. When the change in peak factors becomes less than a certain user-specified percentage, the peak-spreading function will stop and hourly link volumes most recently determined are loaded into the PRESIM program.

When the change in peak factors is more than the user-specified percentage, PEAKSPRD informs the user about the modified factors in PEAKFAC.ASC A change in peak factors suggests the temporal distribution of trips over the peak period. Therefore, the user should adjust the three hourly trip tables using corresponding factors from PEAKFAC.ASC, and re-assign the adjusted trip tables on the network using the planning model software.

The PEAKSPRD program reads a value between 1 and 10 percent, and uses this value as a criteria to modify the input peak factors. If the volumes meet the convergence criteria, the program modifies PEAKFAC.ASC with the new factors.

The PEAKSPRD program is executed by invoking the batch file PEAK.BAT shown in Table 9-3.

Table 9-3: Peak Spread Batch File

PEAK.BAT BATCH FILE COMMAND	DESCRIPTION
PEAKSPRD LINK1 .ASC LINK2.ASC LINK3.ASC PEAKFAC.ASC 12	Launches the peak spreading function.

9.4 Traffic Simulation

Some of the modifications required to the traffic simulation models were introduced and discussed in section 7. A more in-depth review of these modifications are discussed throughout the remainder of this section.

9.4.1 Freeway simulation

The freeway simulation component of the model framework is accomplished using FREQ, a macroscopic simulation model that simulates traffic operations on the freeway within the study corridor. The specific function of FREQ, in the modeling framework, is to provide the operational characteristics of ATMS user services on the freeway. In the context of the framework, FREQl 1 (latest version of FREQ) is used to simulate freeway mainline segments and freeway ramps. FREQl 1 is best suited to freeway corridor evaluations, with emphasis on evaluating traffic management and traffic control alternatives such as incident management, ramp metering, mainline HOV lanes, and HOV bypass lanes at metered ramps.

Two interface programs, referred to as PRESIM and POSTSIM, were developed to integrate FREQl 1 within the model framework to accomplish the freeway simulation process. The PRESIM program is used to convert and transfer peak spread planning model assigned volumes to FREQl 1 input file(s), and to calculate enhanced travel speeds for all non-simulated street links in the study area. The POSTSIM program is used to convert and transfer FREQl 1 and street speeds into a format compatible with the planning model for execution of the reassignment function.

The following steps describe the entire freeway simulation process.

- PRESIM accesses the assigned network volumes from the peak spreading planning model function through the interface file LINKa.ASC (for each hour of the analysis time period where a=l, 2 or 3).
- The PRESIM program reads the user specified inputs for time-slice distribution factors via the FACTORS.DAT file.
- PRESIM converts each hourly volume into 4 fifteen-minute volumes as input to FREQl 1 to support the simulation process. This conversion is performed by using equivalence files (EQUV*.PRE), created by the user, that equate network links in the planning model with the corresponding links found in the FREQl 1 model.
- PRESIM will then load volume data and other information into the FREQl 1 model files to enable the freeway simulation analysis.
- PRESIM refines the speeds for the non-FREQl 1 links (streets) using default BPR speed-flow equations and 15-minute distribution factors and then loads these revised speeds into POSTSIM.
- FREQl 1 performs the freeway simulation analysis (by strategy and by direction) and loads the resulting 15-minute interval simulated freeway and ramp speeds into POSTSIM using the equivalence files.
- POSTSIM then computes a weighted average for each analysis hour using the 15-minute speeds and loads the modified speeds into the link attribute files HOURa.OUT (where a=l, 2 or 3) for processing by the DATAEDlT ASCII conversion utility.

Within FREQl 1 two freeway modules exist. FREQPL is used for priority (HOV) lane investigations or for mixed-flow lane investigations. FREQPE is used for priority entry (ramp metering) investigations and for metered ramp HOV bypass lane investigations. Within FREQ the PL and PE versions cannot be run simultaneously but can work together using an interface that was developed to automate the PL/PE linkage. Four batch files were developed to perform the four distinct types of FREQ scenarios that are supported by the framework. These scenario selections are dependent upon user input specified at the time of invoking the framework. The actual sequence of PL/PE execution depends on HOV lane selection and on the type of ramp metering available in the study area (fixed-time or demand responsive). Table 9-4 describes alternative FREQ scenarios, interface data files, and controlling batch files.

Table 9-4: Supported FREQ Scenarios

FREQ Scenario	FREQ Files	FREQ Batch File
1) Scenarios that investigate only arterial traffic signal coordination (fixed-time and demand-responsive) were run with the same version of FREQl 1PL. This version reflects four mixed flow lanes and one HOV lane on the freeway. No ramp metering is investigated in these two scenarios.	FREQl 1PL (speeds and delays for mixed-flow and HOV lanes)	PLINTRFC.BAT
2) One of the analysis scenarios combines fixed-time ramp metering with fixed-time signal coordination on the parallel arterial. Fixed-time ramp metering was based on metering rates developed for the peak 15 minute period of the three hour analysis period. These metering rates were set for the entire analysis time period by fixing the upper and lower limits of ramp metering rates for each ramp in FREQl 1PE.	FREQllPL (speeds and delays for the HOV lane) FREQllPE (speeds and delays for the mixed-flow lanes & fixed metering ramps)	ClINTRFC.BAT
3) Other analysis scenarios combine demand-responsive, coordinated ramp metering with fixed-time and demand-responsive signal coordination on the parallel arterial. Ramp metering for these scenarios was simulated by using the ramp metering optimization program in FREQl 1PE. This program maximizes vehicle miles of travel in the freeway by adjusting ramp metering rates at each on-ramp during each time-slice, so that vehicle throughput is maximized at bottlenecks.	FREQllPL (speeds and delays for the HOV lane) FREQllPE (speeds and delays for the mixed-flow lanes & dynamic metering ramps)	C2INTRFC.BAT
4) Scenarios that investigate only ramp metering (but no HOV lanes) are run with FREQllPE only.	FREQllPE (speeds and delays for mixed-flow lanes)	PEINTR.FC.BAT

A detailed description of framework operation using batch files, contained in Table 9-4, can be found in Appendix C of this report. Using a batch file technique of program control enables separate software applications to be chained or piped together thus allowing data created by one program to be shared with other programs. This technique is used extensively to obtain the control cohesion required by the framework to integrate planning, simulation and impact transportation models. An example of this approach is found in Table 9-5 which lists specific DOS commands used in the C2INTRFC.BAT file. The table also provides a description of each command line. Commands for other scenario batch files are included in this report and can be found in Appendix C. (Refer to PLINTRFC.BAT, PElNTRFC.BAT, and ClINTRPC.BAT.)

Table 9-5: Freeway Simulation Batch File

C2INTRFC.BAT BATCH FILE COMMANDS	DESCRIPTION
cd d:\tl\fsim copy d:\tl\plan\link?.asc	Copy SYSTEM II link volumes into freeway simulation section of interface.
copy plsbam.inp freql lpl.inp copy f3sbam.inp freql lpe.inp copy plpeeqsb.asc plpeequv.asc presim c copresb.ctl copy freqpe.out pesbam.out copy freqpl.out plsbam.out	Rename resident freq.INP files. (sb = southbound) Run PRESIM, produce altered .INP files. (*.OUT) Rename PRESIM output (altered .INP files).
copy plnbam.inp freq 1 lpl.inp copy f3nbam.inp freql lpe.inp copy plpeeqnb.asc plpeequvasc presim < coprenb.ctl copy freqpl.out plnbam.out copy freqpe.out penbam.out	Rename resident freq.INP files. (nb = northbound) Run PRESJM, produce altered .INP files. (*.OUT) Rename PRESIM output (altered .INP files).
freql 11x < plsbam.out	Run F'REQPL and FREQPE using .OUT files from PRESIM

freql lex < pesbam.out copy frqplaux.out plsbam.aux copy frqpeaux.out pesbam.aux	Rename auxiliary output from FREQPL and FREQPE
postsim link1.asc link2.asc link3.asc equvcosb.pst 3	Run POSTSIM, produce speeds for freeway links in ASCII format (hour?.out)
freq 111x < plnbam.out freq 1 lex < penbam.out copy frqplaux.out plnbam.aux copy frqpeaux.out penbam.aux	Run FREQPL and FREQPE using .OUT files from PRESIM Rename auxiliary output from FREQPL and FREQPE
postsim link1 .asc link2.asc link3.asc equvconb.pst 3	Run POSTSIM, produce speeds for freeway links in ASCII format (hour1 .out, hour2.out, hour3.out).
copy hour?.out d:\tl	Copy freeway speed files to base directory D:\TL
cd d:\tl\asim copy d:\tl\plan\link?.asc copy d:\tl\plan\turn?.asc	Copy SYSTEM II link volumes and turning movements into arterial simulation section of interface.
call runsys.bat	Run TRANSYT 7F.
cd.. copy d:\tl\asim\artspd*.out	Copy arterial simulation speed files into base dircetory D:\TL
copy hour 1 .out+artspdl .out copy hour2.out+artspd2.out copy hour3.out+artspd3.out	Append freeway simulation speed files w/arterial simulation speed files.
copy hour*.out d:\tl\plan	Copy fully appended speed files into SYSTEM II's active directory.
cd d:\tl\plan	Set directory to the planning directory.

Table 9-5 cont'd

9.4.1.1 Freeway Simulation Input Interface (PRESIM)

The PRESIM module converts one-hour freeway link volumes produced by the planning model into FREQl 1 compatible 15-minute link volumes. The PRESIM module also converts the street volumes produced by the planning model into separate 15minute volumes for calculation of street speeds. The steps involved in using the PRESIM interface are described below:

1. The user inputs a typical 15-minute (or any time interval duration) distribution of traffic volumes for each of the three hours in the peak period for each facility type. The traffic volume distribution factors may be based on base-year observations at different highway facility types, or on default values defined by national transportation research.

2. The user establishes an equivalence file equating links in the planning model with links in the FREQl 1 model. The equivalence file establishes the correspondence between node and link numbers used for freeway segments and ramps in the network.

3. One-hour volumes are loaded from the peak spreading interface for each link for each analysis hour. Based on the one-hour volumes and on the 15minute distribution factors, the PRESiM interface converts the hourly volumes to 15-minute volumes to be used in the simulation models. Based on 15-minute volumes and capacities, the interface computes the v/c ratio for each link for each 15-minute time interval.

4. The PRESIM interface inputs 15-minute volumes into both FREQl 1 and the street speed calculation module within FREQl 1. The street speeds module calculates more accurate speeds for all link segments in the network. This module performs the following steps:

   - Computes congested travel time for each link using either the BPR (Bureau of Public Roads) speed-flow curve or a user-specified speed-flow curve. The design of this module focuses specifically on areas of the speed-flow curve with v/c ratio greater than 1.00.
   - The module computes volume-weighted average travel speed for each link for each hour in the peak period.
   - The module loads the weighted average speeds for streets into the POSTSIM interface.

9.4.1.2 Freeway Simulation Output Interface (POSTSIM)

The POSTSIM interface computes one-hour volume-weighted speeds for the freeway, ramps and streets. It then loads these speeds into the SYSTEM II ASSIGN program using the DATAEDIT utility. The POSTSIM interface performs the following steps.

1) The POSTSIM interface loads 15-minute speeds and volumes, for freeway mainline links and ramps, generated from FREQ. (The user specifies ramp length and ramp free-flow speeds for each ramp.)
2) Based on ramp length, ramp free-flow speed and ramp delays, the POSTSIM interface calculates 15-minute average speeds for each ramp.
3) The POSTSIM interface computes one hour volume-weighted average speed for the freeway, ramps (computed in the previous step) and streets, using 15-minute speeds and volumes determined previously, for each analysis hour.
4) The POSTSIM interface loads the hourly freeway, ramp and street speeds for assignment in SYSTEM II and updates the speeds in the planning model for each iteration.

9.4.2 Arterial simulation

The purpose of the arterial street modeling process is to simulate the flow of traffic on signalized arterial streets that are part of a regional integrated traffic control system. Using this modeling process, the impacts of traffic signal progression on arterial street speeds and travel delays can be estimated. TRANSYT-7F is used for traffic simulation and timing optimization to determine changes in arterial street travel speeds as a result of shifts in regional travel paths, and the quality of traffic signal progression.

The framework modeling process established for arterial street simulation is based upon a group of five software modules which, when combined with the TRANSYT-7F program, provide the necessary components for an automated, multiple time period arterial street simulation model. The arterial street simulation modeling process is described by the following steps:

1) Using the link and node equivalence data files associate turning movement volumes produced by the planning model TURNDUMP program with specific TRANSYT-7F network intersections (via SYSEDIT).
2) Generate turning movement volumes for different time intervals using volumes from several time periods of planning model runs and peak spreading factors (using TMCGEN/NETMAKE).
3) Search base TRANSYT-7F network files and update previous turning movement volumes with current volumes from the planning model (UPDATVOL).

4) Create a DOS batch file to execute multiple TRANSYT-7F runs for each signal network and each 15 minute time interval (BATMAKE).
5) Execute the DOS batch file and complete all necessary TRANSYT-7F simulation and optimization runs (TRANSYT-7F).
6) Summarize the results of multiple TRANSYT-7F runs and use link and node equivalence data to reassociate TRANSYT-7F link traffic characteristics with the appropriate planning model links (SPEEDCMP).
7) Export traffic characteristics necessary for supplemental fuel consumption and air quality analysis.

The arterial street simulation modeling process is controlled using two DOS batch files that run in succession. The first batch file, RUNSYS.BAT, is called by PLINTRFC.BAT, PEINTRFC.BAT, C1INTRFC.BAT or C2INTRFCBAT batch files after the freeway simulation process has been completed (refer to Table 9-5). RUNSYS.BAT executes the arterial simulation by invoking the modules TMCGEN.EXE, NETMAKE.EXE, UPDATVOL.EXE and BATMAKE.EXE in succession. Table 9-6 lists the instructions included in the "RUNSYS.BAT" batch file.

Table 9-6: Arterial Simulation Batch File

RUNSYS.BAT DOS Batch File Commands	Description
TMCGEN.EXE	Create individual turning movements.
NETMAKE.EXE	Configure each signalized sub-network.
UPDATVOL.EXE	Copy turning movements into sub-networks.
BATMAKE.EXE	Create batch file to simulate all sub-networks.
RUNT7F.BAT	Invoke TRANSYT-7F for each sub-network.

The last command of the arterial simulation batch file (RUNSYS.BAT) transfers framework control to another batch file called RUNT7F.BAT. This batch file is created by the BATMAKE.EXE utility, which is the last program executed in the RUNSYS.BAT batch file. Batch file RUNT7F.BAT contains specific process instructions to control traffic simulation, cycle length optimization, phase length and split optimization using TRANSYT-7F. (Refer to appendix C for listing of RUNT7F.BAT.) The exact sequence of these options is based on the traffic signal control scenario selected by the user. Upon completion of all TRANSYT-7F simulation and optimization runs the RUNT7F.BAT file executes the final program module, SPEEDCMP.EXE, to summarize the results of individual TRANSYT-7F runs and returns updated link travel speeds to the planning model. After this operation, control is returned to either PLlNTRFC.BAT, PEINTRFC.BAT, ClINTRFC.BAT or C2INTRFCBAT batch files which are controlling execution of the framework for a particular ATMS scenario iteration.

Based upon available data and improvement plans pertaining to the study area, three parallel arterial signal control strategies are provided in the framework and are defined as the no-build, mid-build and a full build scenario for achieving integrated traffic control. These three signal control scenarios can be combined in a number of different ways with other ATMS service scenarios (HOV, ramp metering, and HOV ramp bypass) to produce an overall ATMS test scenario for evaluation by the framework. The parallel arterial traffic scenarios are defined as:

a) No-Build Scenario - Runs the arterial street simulation model assuming fixed time coordination using baseline signal coordination networks and peak interval timing plans. In this scenario, TRANSYT-7F will be used to optimize cycle lengths, offsets and phase lengths during the peak interval of the peak period. TRANSYT-7F will then simulate conditions for all other time intervals based on the peak interval timing plan. This scenario will only cover a limited number of intersections (20) in the study area, since few intersections are coordinated under baseline conditions. (five signalized sub-networks.)

b) Mid-Build Scenario - Runs the arterial street simulation model assuming fixed time coordination based on peak interval timing plans with an expanded network of coordinated signals. This scenario is similar to the first scenario, except that the number of signals under coordinated control is substantially expanded (80) over baseline conditions to cover all study area corridors that are part of the regional traffic control system. (eight signalized sub-networks.)

c) Full-Build Scenario - Runs the arterial street simulation model assuming traffic demand responsive coordination based on the same expanded network of coordinated signal intersections defined by the Mid-Build Scenario. Under this scenario, cycle lengths, offsets and phase lengths are optimized for every time interval to simulate the impact of a demand responsive traffic control system. Therefore, TRANSYT-7F will run a full cycle length optimization, followed by an offset and phase length optimization using the optimum cycle length during every time interval. (eight signalized sub-networks.)

The above arterial street traffic control strategies are combined with freeway services such as ramp control, incident management, HOV restrictions and others to produce a comprehensive group of ATMS test scenarios that can be evaluated by the modeling framework.

Table 9-7 summarizes the different data files that are used for modeling arterial streets. This list does not include temporary files created while the framework is executing. Rather, only file types that are an integral part of the framework are listed.

Table 9-7: Description of Arterial Modeling Data Files

File Name	File Description
DEMO.MCF	Master Control File (Type of Traffic Signal Control, Number of Networks and TRANSYT-7F Link Orientation Codes)
DEMO.PSD	Traffic Volume Peak Spreading Data and Time Interval Duration
DEMO.LNA	Planning Model/TRANSYT-7F Link-Node Association Equivalence File
NETb.TIN	Base TRANSYT-7F Input File ("b" represents the network no.)
NETb-c.TIN	TRANSYT-7F Input File ("c" represents the time interval no.)
NETb-c.TOF	TRANSYT-7F Output File
TURNa.ASC	Planning Model Turning Movement Volumes ("a" represents the time period hour)
LINKa.ASC	Planning Model Link Attributes and Loaded Volumes and Speeds
TURNb.TMV	Intersection Turning Movement Volumes ("b" represents the network no.)
ARTSPDa.OUT	Planning Model Link Attributes with Revised Arterial Street Link Travel Speeds for Updating Planning Model Travel Speeds
FAQSPDa.OUT	Planning Model Link Attributes with TRANSYT-7F Traffic Flow Data for Fuel Consumption and Air Quality Modeling

9.4.2.1 Turning Movement Volume Generation for Peak Spreading (TMCGEN)

The TMCGEN program converts the hourly turning movement (TURNa.ASC) files (where a = 1,2 or 3) from the planning model to individual turning movement volume (TURNb.TMV) files for each traffic signal network. Turning movement volume data files have coded filenames of the form TURNb.TMV, where "b" represents which TRANSYT-7F network they are associated with (b = 1, 2, 3 . . . 8). The TMCGEN module begins by reading the database of node turning movement counts (TURNa.ASC) provided by the planning model and the link-node association file (DEMO.LNA). Using peak spreading factors from the DEMO.PSD file, the peak hour turning movement volumes for each intersection are factored to represent smaller time intervals. For the prototype study area, 12 fifteen-minute periods (3 hours of data) are used. Turning movement volumes for each intersection over all time interval are then stored in separate sub-network files for TRANSYT-7F processing.

Peak spreading factors are used in TMCGEN to divide volumes provided by the planning model assignments into shorter time intervals for more detailed simulation. The turning movement volumes from each planning model time period are multiplied by the peak spreading factor to model the increase or decrease in 15-minute flow rates that occur during the peak period time span. Normally, the turning movement volumes from the planning model assignments will represent a one-hour time period. To divide this assignment up into flow rates for 15-minute periods, peak spreading factors are used to compute hourly flow rates for each 15-minute period. The peak spreading factors should be normalized such that the average of the factors over each one-hour period is 1.00. This is necessary so that 15-minute volumes are expressed in terms of a hourly flow rate, which is required by TRANSYT-7F.

9.4.2.2 Input File Duplication Utility (NETMAKE)

The NETMAKE utility duplicates the base TRANSYT-7F input signalized sub-network (NETb.TIN) files by copying and renaming these files to separate files for each simulation time interval (where b = 1,2,3 . . . 8). For example, if eight traffic signal networks are included in the study area, and twelve 15 minute simulation intervals are used over the course of the simulation, then this utility duplicates each NETb.TlN file twelve times. As a result, 96 separate NETb-c.TJN files are created from the original eight (where c = 1,2,3 . . . 12).

9.4.2.3 Traffic Volume Update Pre-Processor (UPDATVOL)

The UPDATVOL pre-processor copies traffic volumes from the turning movement volume (TURNb.TMV) files to the appropriate TRANSYT-7F input (NETb-c.TIN) files. The NETb-c.TIN files for each time interval will have already been created by the NETMAKE utility or by batch file commands. Within the UPDATVOL module, the software searches for specific turning movements and upstream feeder turning movements in each NETb-c.TIN file and replaces the current volumes with updated volumes from the planning model. The volume update process is repeated for every time interval and for every TRANSYT-7F sub-network in the study area.

9.4.2.4 TRANSYT-7F Batch File Creation Utility (BATMAKE)

The BATMAKE utility creates the RUNT7F.BAT batch file which controls execution of parallel arterial simulation (TRANSYT-7F). Depending on which signal scenario and optimization options are selected, BATMAKE creates the batch file necessary to execute TRANSYT-7F runs in succession to achieve the desired results. Currently, three simulation/optimization strategies are available to emulate a particular type of traffic signal control.

9.4.2.5 Speed Computation Post-Processor (SPEEDCMP)

The SPEEDCMP program reads TRANSYT-7F output files (NETb-c.TOF) and link-node association files (DEMO.LNA), computes approach link travel speeds, delays, and total volumes, and summarizes this data for multiple time intervals in a hourly link speed file (ARTSPDa.OUT). Within the SPEEDCMP module, the link-node association data from the DEMO.LNA file is used to search for TRANSYT-7F approaches associated with directional street links from the planning model. If multiple time periods are involved in computing average speeds and delays, then the approach volume information is used to compute the volume-weighted average traffic characteristics of each street link.

Two output files are produced by SPEEDCMP. The first file ARTSPDa.OUT summarizes the average link travel speeds computed by the TRANSYT-7F simulations for each analysis hour. If another iteration of the overall framework is required, the ARTSPDa.OUT files are combined with freeway simulation speed results (HOURa.OUT) and passed back to the planning model database. The second file FAQSPDa.OUT provides a more detailed summary of the simulation results for use in fuel consumption, air quality and safety modeling.

9.5 Convergence

The convergence element of the framework requires the use of the SYSTEM II utility DATAEDIT for processing link speed data from each iteration. Convergence testing involves reading the link speed values produced by the simulation models, processing the speed data, and returning the updated speed data back into the SYSTEM II planning model network file. This function takes the new speed value from the current iteration and updates the data file used in the assignment operation. The convergence process feeds the improved speed predictions back into the dynamic Planning Model assignment element (ASSIGN) so that the reassignment of trips can be based upon updated speeds. It should be noted that this feedback does not occur for the final framework iteration.

Steps involved in the convergence operation are repeated for each hour of the analysis period and are summarized as follows:

1) ASCII formatted link record files (HOURa.OUT and ARTSPDa.OUT) containing updated speeds are taken from the two simulation model elements and combined into a single file for each analysis hour. This procedure is performed using the DOS copy command (refer to batch file C2INTRFC.BAT in Table 9-5).
2) The new speed value for each link is read from the combined ASCII file and is loaded into the planning model network link database using the READSPDb.BAT batch file. The speed value is placed in the same run number as the volume used for that iteration. This step, in essence, completes one iteration of the dynamic process. For all but the final iteration, the current speed value from the combined ASCII file is used to update the maximum speed value in the planning model network file using the DATAEDIT utility called from batch file READSPDb.BAT.
3) The revised network file is then "fed back" to the planning model element for re-execution of the assignment procedure by invoking the REASSGNb.BAT batch file ("b" represents the interface iteration number).
4) The MOE results from any iteration (volumes, speeds, etc.) can be reported and plotted using several available performance utilities (e.g. PERF, PLOTNET, etc.).

Procedures used within the convergence element have been incorporated within two batch files to facilitate execution. For each iteration, the two batch files READSPDb.BAT (Table 9-8) and REASSGNb.BAT (Table 9-9) are invoked from the controlling scenario batch file (COMl_RUN.BAT, COM2_RUN.BAT, PL_RUN.BAT, PE_F_RUN.BAT or PE_D_RUN.BAT listed in Appendix C).

Note that the DATAEDIT READHRab operation, performed within READSPDb.BAT converts loaded speed data from ASCII format into the SYSTEM II link file database format. (Loaded speeds are produced by the two simulation models.) The use of separate DATAEDIT control programs is required to ensure that the speed values are read into the appropriate run number in the SYSTEM II link network files. The run number varies depending on the hour and iteration number.

The PERF program is a performance processing utility designed to generate summary reports for various performance measures, traffic accidents, fuel consumption, and vehicle emission parameters. The program can also compare the performance of two different networks or two alternative assignments. Summary statistics can be reported by area type, functional class, screen line, district, and by total network. The links included in the summaries can also be restricted by an extensive set of link selection criteria. The use of separate PERF control program names is required to ensure that the appropriate run number is designated when generating the performance statistics.

Table 9-8: Convergence Batch File

Convergence Batch File READSPDb.BAT (where b= 1, 2, 3...8)	Description
dataedit readhr1b perf area1b 100 perf art1b 100 dataedit readhr2b perf areab 100 perf art2b 100 dataedit readhr3b	For each hour, reads the speed values from combined ASCII file into the SYSTEM II network file. The "b" represents the interface iteration (1 through 8).
perf area3b 100 perf art3b 100	Report performance statistics for selected study areas and parallel arterial.

Reassignment is performed using the batch file contained in Table 9-9. The DATAEDIT MAXHRab operation modifies the maximum speed in the SYSTEM II Link Database using speeds produced by past iterations of the simulation programs. Revised maximum speeds are used to limit the speeds operated on in the volume-delay equation of the trip assignment program (ASSIGN). Separate maximum speed values are stored for each hour. These values are stored in run numbers 15, 35, and 55 for hours 1, 2, and 3, respectively. Separate DATAEDIT control programs are required to ensure that the correct run number is modified and to ensure that the appropriate CALIB record is called. The CALIB record varies according to the iteration number because the maximum speed calculation varies. This calculation is determined by the following equation:

$$\textit{Maximum link speed for iteration } i = \frac{1}{i+1} \sum_{n=0}^{i} speed_n$$

Table)-9: **Assignment Batch File**

Assignment Batch File REASSGNb.BAT (where b= 1,2,3...8)	**Description**
dataedit maxhrlb assign amhrl dataedit amtotal 1 b dataedit dumphr 1 b turndump turn1 .dat turn1 .asc 2 dataedit maxhr2b assign amhr2 dataedit arntotal2b dataedit dumphr2b turndump turn2,dat turn2.asc 2 dataedit maxhr3b assign amhr3 dataedit amtotal3b dataedit dumphr3b turndump turn3.dat turn3.asc 2 turnadj turn1 .dat turn2.dat turn3.dat turnl.avg turn2.avg turn3 .avg	For each hour, updates the maximum speed value in the SYSTEM II network link file using speeds from the previous iteration for each hour. Uses the revised network speeds created by simulation models as feedback into the planning model reassignment process. This is not performed after the final iteration*. After reassignment by hour combine SOV & HOV volumes and then weight volumes and speeds. Convert volumes and speeds to ASCII for each hour.

* Note: The I880 simulations are run f eight iterations. For more on this see section 11, Framework Qualification.

9.6 Emission and Fuel Consumption

Emissions and fuel consumption impacts were modeled using data produced by the planning and simulation elements of the framework. Multiple programs are used within this component of the framework to estimate fuel consumption, trip based emissions and running exhaust emissions. A new program, EMIS, was developed and is used in conjunction with two other programs within SYSTEM II (TOD and EMISSIONS) to estimate emissions and fuel consumption.

Two emission rate models, MOBILE 5a and EMFAC7F, are incorporated into the framework emission component to support the prediction of emissions and fuel consumption impacts. MOBILE 5a was developed by the Environmental Protection Agency and is used in every state except California. EMFAC7F is the emission rate model developed by the California Air Resources Board (CARB) to determine mobile source emissions. The fuel consumption rates used in the model framework were developed by Caltrans during the 1980s and are based on the same research as the fuel consumption rates used by FREQ, MOBILE 5a and EMFAC7F.

Link-specific vehicle volumes produced by the framework are sorted by vehicle type for calculating both trip-based emissions and running emissions. Trip-based emissions are determined, for the six vehicle types, by using the time-of-day distribution program TOD followed by execution of the EMISSION program. Running exhaust emissions are then determined for each of the six vehicle types by using the EMIS programs. Both EMISSION and EMIS require ASCII files that contain emission and fuel consumption rates as input. Similarly, both TOD and EMIS require ASCII files with vehicle type distribution factors as input.

9.6.1 Emission Rate Models

Both MOBILE 5a and EMFAC7F estimate hot and cold start emissions and hot stabilized exhaust emissions for carbon monoxide (CO), hydrocarbons (HC), and oxides of nitrogen (NO_x). Hot stabilized conditions are produced by a vehicle that has been operating for a period of time and does not have a cold engine. The difference between hot and cold start emission rates is the incremental difference between the emissions produced by a vehicle operating from a cold or hot start condition and the emissions produced by a vehicle during hot stabilized conditions.

The emissions rate models incorporated into the framework estimate trip-based emissions separately from running emissions. Trip-based emissions occur when starting or stopping the vehicle's engine and are based on the number of vehicle trips forecast by the planning model. Trip-based emissions are calculated as the product of the number of trip starts or trip interruptions multiplied by the corresponding emission rate.

Running emissions are produced when the vehicle is in motion. Running emissions are calculated as the product of the emission rate for the average speed increment on a link in a given direction, the corresponding volume, and the distance of the link. By differentiating running emissions from tripbased emissions, the impacts of changing the total number of trips may be differentiated from the impacts of changing vehicle miles of travel (VMT). The running emission rates produced by MOBILE 5a and EMFAC7F represent travel at speeds ranging from 2.5 mph to 65.0 mph in 2.5 mph increments.

The emissions rates for passenger cars and light-duty trucks in both MOBILE 5a and EMFAC7F are based on the LA4 driving cycle. The LA4 is based on research performed in Los Angeles in the early 1970s. As part of this research, a route representing a "typical trip" was defined and an average driving cycle for the route, referred to as the Federal Test Procedure (FTP), was developed. The driving cycle defines the average speeds and emissions associated with the different operating modes (acceleration, deceleration, cruising and idling) of a vehicle driving the FTP Average emissions for the route were estimated based on measurements of average speed at specific points in the driving cycle. Federal standards for allowable automobile emissions are based on testing vehicles over the FTP driving cycle. Both MOBILE 5a and EMFAC7F use speed correction factors to adjust the emission rate at the LA4 average speed to revise estimates of emissions for speeds ranging from 2.5 mph to 65 mph.

Neither MOBILE 5a or EMFAC7F provide emission rates stratified by facility type. Instead, both rate models provide emission rates as a function of average operating speed by vehicle type for each pollutant studied (CO, HC, and NO_x). The emission rates for both rate models are stratified by the following six vehicle types:

1) Light duty gasoline automobiles (LDGA)
2) Light duty diesel automobiles (LDDA)
3) Light duty trucks (LDT)
4) Medium duty trucks (MDT)
5) Heavy duty trucks (HDT)
6) Motorcycles (MC)

While the model parameters for user-defined items such as temperature and speed are the same in both rate models, there are basic differences in their emissions estimation procedures. For instance, MOBILE 5a and EMFAC7F estimate hot and cold start emissions differently. EMFAC7F has separate emission rates for cold starts and hot starts. MOBILE 5a, however, does not provide rates for cold and hot start emissions. Instead, MOBILE 5a includes these emissions with hot stabilized emissions based on user-defined percentages. The LA4 research indicated that a vehicle reaches a hot stabilized condition after operating for 505 seconds. Assuming an average speed of 25.6

mph as identified by the FTP for a vehicle under cold or hot start conditions, an engine achieves a hot stabilized condition after traveling 3.59 miles. The MOBILE 5a cold start emission rate is the incremental difference between the emissions produced by a vehicle driven 3.59 miles under cold start conditions and a vehicle driven 3.59 miles under hot stabilized conditions.

Within the framework hot stabilized running emissions are estimated separately for each link. An underlying assumption of the framework methodology is that all vehicle trips are at least 3.59 miles in length. This assumption may result in a slight overestimation of emissions for shorter trips. Incremental hot start emissions are not estimated in the emissions modeling for this study, reflecting EPA endorsement of other research indicating that no additional emissions should be added for hot start conditions. The ratio of cold starts to hot starts by trip type for the San Francisco Bay Area was obtained from the Caltrans Direct Travel Impact Model (DTIM). For each traffic analysis zone, the ratio of cold starts to hot starts was calculated as the weighted average of that ratio for the following three trip types: home-based work (HBW), home-based shopping/other (HBSO), and non-home-based (NHB) trips.

9.6.2 Trip Based Emissions

The TOD (Time-of-Day) program, a program within SYSTEM II, is used in conjunction with the EMISSION program to estimate trip-based emissions. TOD generates hourly volumes by vehicle type for each link in the study area network by time of day. Because three one-hour periods are modeled separately in this study, only the vehicle type distribution capability in the TOD program is used. TOD's primary strength in analyzing ATMS services is that it stratifies volumes by vehicle type. TOD also generates loaded speeds for each link by time of day.

EMISSION, a program within SYSTEM II, is used to estimate trip-based emissions. The EMISSION program uses the average vehicle type speeds, provided by the TOD program, to estimate hourly trip emissions. The EMISSION program tabulates daily vehicle emissions by area type, by functional class, or other parameters for the three pollutants CO, HC and NOx. While EMISSION estimates emissions for each hour of the day, the program is only used to estimate trip-based pollutants and hydrocarbon evaporative emissions. The output of the EMISSION program includes detailed reports identifying the quantity of emissions produced for each pollutant type.

The trip-based emissions are not affected by the various ATMS services being evaluated and therefore, need to be only estimated once. Trip-based emissions are dependent upon vehicle cold and hot starts and include CO, HC and NOx as well as evaporative HC emissions. The process used to estimate trip-based emissions follows:

1) The hourly volumes in the completed SYSTEM II network link file are disaggregated into the six vehicle types described above using the TOD program. The factors used to estimate volumes by vehicle type are the same as the values used in the EMIS program. These factors are loaded into a TOD calibration file using the SYSTEM II utility program, LOADTOD.
2) MOBILE 5a and EMEAC7F emission rates for cold and hot starts by pollutant type, as well as evaporative HC emissions, are loaded into an EMISSION calibration file using the SYSTEM II utility program, LOADEMS.
3) The percentage of cold starts were obtained by trip purpose from Caltrans' DTIM and used to estimate the percentage of hot starts for each zone in the study area.
4) The number of registered vehicles for each zone is also entered into the zone file to estimate diurnal evaporative HC emissions. (Diurnal emissions are evaporative hydrocarbon emissions that occur from the rise in ambient air temperature causing fumes to leak from a vehicle's fuel system.)
5) The EMISSION program uses the TODLINK files created by the TOD program, along with emission rates entered in the calibration file, to estimate trip-based emissions.
6) The results from EMISSION are summarized for the study area in a report.

The EMISSION and TOD programs are executed once using the sequence of commands contained in Table 9-10.

Table 9- 10: **Trip Based Emission Commands**

DOS COMMANDS	DESCRIPTION
	Alter link file to reset zone connector speeds to 15 mph.
tod i8808am tod i8809am tod i88010am	Trip-based emissions=Start emissions & HC evaporative emissions
emission i8808am_mob emission i8809am_mob emission i88010am_mob	Emissions estimate using MOBILE 5a rates.
emission i8808am_emf emission i8809am_emf emission i88010am_emf	Emissions estimate using EMFAC7F rates.

9.6.3 Running Exhaust Emissions

The EMIS program was developed specifically for this framework and is used to estimate running exhaust emissions. EMIS uses five ASCII input files to estimate emission and fuel consumption impacts for three hours in the peak period. Three ASCII input files, one for each of the three hours analyzed, contain hourly link volumes. The other two ASCII input files contain emissions and fuel consumption rates and the vehicle type distribution factors.

The following steps describe the procedures that are used to estimate running emissions and fuel consumption.

1) DATAEDIT is called to modify the finished SYSTEM II link file produced by the planning interface programs and to create three LINKa.ASC files for each hour of the analysis time period (where a = 1,2 or 3).
2) The EMIS program is executed using the three LINKa.ASC input files, a file with vehicle type factors (VEHTYPE%.PRN), and another file with emission and fuel consumption rates (EMRATE95.PRN). Emissions rates differ according to vehicle type and are directly related to vehicle weight. Traffic data is used to determine the factors that separate total hourly volumes into component volumes by the six vehicle types defined previously. Emission rates are estimated once by the MOBILE 5a and EMFAC 7F programs. The EMIS program accommodates both sets of emission rates simultaneously.
3) The EMIS program disaggregates the hourly volumes for each link in the model network into the six vehicle types and applies the appropriate emission rates by vehicle type.
4) The EMIS program results for running exhaust emissions for each link are transferred to an ASCII file (HOURa.EMS) that has designated fields for each of the different rate models by the three pollutant types CO, HC and NOx.
5) The results are summarized by study area, the freeway corridor and the parallel arterial route using PERF, a SYSTEM II program.

EMIS has the capability to display link-level emissions and fuel consumption estimates. EMIS was created to automate the process of using emission rates and fuel consumption rates that vary by facility type, number of lanes, and flow type for freeway links. EMIS will therefore, be capable of using facility-specific emission and fuel consumption rates when they become available. The EMIS program was also created to produce ASCII link files that contain link-specific emissions and fuel consumption estimates.

The EMIS program produces ASCII files containing link-specific estimates of emissions and fuel consumption, which are automatically loaded into a volume run number in a specially created link file so that the results can be reported using a variety of SYSTEM II utility programs. The SYSTEM II program DATAEDIT is used to convert link files from the SYSTEM II format to the ASCII format used by the EMIS program. DATAEDIT is also used to convert the ASCII emission and fuel consumption output files to a SYSTEM II link file.

The EMIS program is invoked by the EMISRUN.BAT batch file which is executed after the framework has finished all simulation iterations and the convergence function has completed. The batch file used to determine running emissions is shown in Table 9- 11.

Table 9-l 1: Running Emissions Batch File

EMISRUN.BAT BATCH FILE	DESCRIPTION
dataedit zone-speed	Alter link file to reset zone connector speeds to 15 mph in speed runs 28,48, and 68.
dataedit create-ems-file	Create the SYSTEM II file used for results.
dataedit emisdump_hrl dataedit emisdump_hr2 dataedit emisdump_hr3	Create ASCII link files LINKa.ASC from SYSTEM II volume and speed data for hours 1, 2, and 3.
emis < doemis.ctl	Run the EMIS program using the three ASCII files.
dataedit readmobile_hrl dataedit readmobile_hr2 dataedit readmobile_hr3	Load the MOBILE 5a results from ASCII files produced by EMIS into SYSTEM II file.
dataedit reademfac_hrl dataedit reademfac_hr2 dataedit reademfac_hr3	Load the EMFAC 7F results from ASCII files produced by EMIS into SYSTEM II file.
dataedit readfuel_hrl dataedit readfuel_hr2 dataedit readfuel_hr3	Load the results from the fuel consumption rates into specified volume run numbers into a special SYSTEM II tile.
perf mobile_co_hrl perf mobile_hc_hrl perf mobile_co_hr2 perf mobile_hc_hr2 perf mobile_co_hr3 perf mobile_hc_hr3	Report MOBILE 5a results for HC and CO for the study area and by freeway portion in three separate hourly print files.
perf mobile_nox_hr 1 perf mobile_nox_hr2 perf mobile_nox_hr3	Report MOBILE 5a results for NOx for the study area and by freeway portion.

perf fue1_hr 1 perf fuel_hr2 perf fuel_hr3	Report MOBILE 5a results for fuel consumption for the study area and by freeway portion.
perf mobile_co_hr1art perf mobile_hc_hr 1 art perf mobile_co_hr2art perf mobile_hc_hr2art perf mobile_co_hr3art perf mobile_hc_hr3art	Report MOBILE 5a results for HC and CO by parallel arterial portions in three separate hourly print files.
perf mobile_nox_hrlart perf mobile_nox_hr2art perf mobile_nox_hr3art perf fuel_hr1 art perf fuel_hr2art perf fuel_hr3art	Report MOBILE 5a results for NOx and for fuel consumption by parallel arterial portions.
volsum <mob_co.ctl volsum < mob_hc.ctl volsum < mob_nox.ctl volsum < vol_fuel.ctl	Sum the results for CO, HC and NOx from MOBILE 5a and for fuel consumption into a volume run number.
perf mobile_co_tot perf mobile_hc_tot perf mobile_nox_tot perf fuel_tot perf mobile_co_totart perf mobile_hc_totart perf mobile_nox_totart perf fuel_totart	Report MOBILE 5a results for HC, CO and NOx plus fuel consumption for the study area, freeway portion, and arterial portion for the total of the three-hour period.
perf emfac_co_hr 1 perf emfac_hc_hr 1 perf emfac_co_hr2 perf emfac_hc_hr2 perf emfac_co_hr3 perf emfac_hc_hr3 perf emfac_nox_hr 1 perf emfac_nox_hr2 perf emfac_nox_hr3 perf emfac_co_hr 1 art perf emfac_hc_hr 1 art perf emfac_co_hr2art	Report EMFAC 7F results for HC and CO for the study area and by freeway portion. Report EMFAC 7F results for NOx and for fuel consumption for the study area and by freeway portions. Report EMFAC 7F results for HC and CO for the parallel arterial in study area.

perf emfac_hc_hr2art perf emfac_co_hr3art perf emfac_hc_hr3art perf emfac_nox_hrlart perf emfac_nox_hr2art perf emfac_nox_hr3art	Report EMFAC 7F results for NOx and for fuel consumption for parallel arterial in study area.
volsum < emf_co.ctl volsum < emf_hc.ctl volsum < emf_nox.ctl perf emfac_co _tot perf emfac_hc_tot perf emfac_nox_tot perf emfac_co_totart perf emfac_hc_totart perf emfac_nox_totart	Sum the results for CO, HC and NOx from EMFAC 7F into a volume run number. Report EMFAC 7F results for HC, CO and NOx for the study area, freeway portion, and arterial portion for the total of the three-hour period.

Table 9- 11 cont'd

The fuel consumption rates used in the model framework are based on research by the California Department of Transportation (Caltrans) reported in 1983 and updated by the Institute of Transportation Studies of the University of California at Berkeley in 1991. The fuel consumption rates were disaggregated into rates for freeways and for arterials. Fuel consumption rates are stored in ASCII files with the emission rate information that is used by the EMIS program. Fuel consumption is calculated as the product of the fuel consumption rate at the assigned speed for a given link, the link volume and the link length.

9.7 The Safety Model

Safety related predictions are determined by using select MOEs calculated by the model framework in conjunction with a database table containing historical accident rate data obtained from the study corridor. The safety model estimates impacts using rate information accessed by three key factors; facility type, accident type and v/c ratio. The accident rates incorporated into the framework were derived by dividing the number of accidents for each facility type, accident type and v/c ratio range by the VMT for each facility type and v/c ratio range. (The VMT estimates were produced by the model framework.)

Accident rates used in the safety model were developed using comprehensive accident data obtained from the study corridor for the years 1989, 1990, and 1991. This information originated from the Caltrans Traffic Accident Surveillance and Analysis System (TASAS) database for state routes and from the Statewide Integrated Traffic Records System (SWITRS) database, which is maintained by the California Highway Patrol, for non-state routes. These databases represent a total of 8,920 accidents occurring on five state routes and a total of 23,475 accidents recorded for non-state routes in the study corridor. The accident rates that are used in the safety model, however, are based upon 4,157 freeway accidents and 3,413 non-state route accidents that occurred during weekday daytime hours (7:00 AM to 8:00 PM). This subset of accidents was used because the rates were applied to volumes from the commute peak period. The data provided by TASAS and SWITRS databases included, but were not limited to, the following information about each accident that occurred during that three year time period:

- Route number
- Location post mile
- Intersection or ramp location
- Accident date (month/day/year)
- Accident time (hours/minutes)
- Environmental conditions (weather, lighting and surface)
- Road condition
- Type of collision
- Number of motor vehicles involved in accident
- Direction of travel
- Persons killed
- Persons injured
- Object struck primary

To construct the accident rate table used within the model framework to calculate safety impacts the following steps were taken:

1) Identify the link location of each accident. The link location of each accident in the database was identified by cross-referencing the milepost location description for each accident record with the planning model network.

2) For each link, stratify accidents by time of day. Each accident record contains an estimate of the time the accident occurred. For each link, the number of accidents that occurred during each hour of the day was determined.
3) For each hour, stratify accidents by accident type. Each accident record identifies whether the accident involved fatal injury, injury, or property damage only. For each link, determine how many accidents of each type occurred during each hour.
4) Identify the congestion conditions under which each accident occurred. An estimate of the level of congestion was appended to each accident record. Level of congestion was defined in terms of v/c ratio. Each accident record was assigned a link-specific v/c ratio for the hour during which the accident occurred. The following steps were taken to calculate hourly v/c ratios for each link:
    - The model framework produced an estimate of average daily volume for each link.
    - The daily volume for each link was disaggregated into 24 one-hour volumes for each hour in the day using a 24-hour time-ofday distribution developed specifically for the study area.
    - The planning model component of the model framework was used to estimate an hourly v/c ratio for each link in the network by dividing the hourly volumes for each link by the link capacity.
    - The link on which each accident in the database occurred was identified by matching the milepost location in the accident record with the corresponding link in the network.
    - Each accident record was assigned the v/c ratio for the hour during which the accident occurred based on the link on which the accident occurred.
5) Sum the accidents. The accidents were summed by facility type, v/c ratio range and accident type to derive a master accident table.
6) Compute the accident rate matrix. The hourly volume estimates for the corresponding links to each facility type, v/c ratio range and accident type category were also summed. The link-specific hourly volume estimates were obtained from the output of the model framework and were factored to represent a three year period for consistency with the time period represented by the accident data. To calculate accident rate (accidents per million vehicle miles) for each facility type, v/c ratio range and accident severity category, the number of accidents was divided by VMT. The resulting accident rate matrix used by the SAFETY program is presented in Table 9- 12.

9.7.1 Accident Rates and Congestion

As part of the development of the accident rates, the relationship between accident rate and level of congestion was investigated. Accident rates were developed for three different time periods, combined weekdays and weekends, weekdays only, and weekday daytime hours only, to identify whether the accident rate would increase as the level of congestion increased. For all three time periods the freeway data demonstrated that accident rate does increase as level of congestion increases. The arterial data, however, indicated a slightly different pattern; for all three time periods, the accident rates are highest in the minimum v/c ratio range, are lowest in the next v/c range, but increase with v/c ratio ranges thereafter. This may be due to several factors, including the following:

- At lower v/c ratios, arterial travel speeds are higher,
- The sample size might not be large enough, and
- It is difficult to identify the capacity on arterials without performing micro-level traffic analysis.

Based on the relationship between the accident rate and the level of congestion demonstrated by the freeway data, the effect that an existing accident has on the accident rate for a facility was investigated. In the presence of an accident, congestion increases and speed variability increases as a result of stop-and-go travel. Given these conditions, it follows that accident rates may be higher when an accident already exists on a facility. The accident rate in the presence of another accident, referred to as secondary accident rate, was calculated using the data for the corridor. Secondary accidents were defined as those accidents that occurred within one hour after the primary accident and one-half mile from the accident during peak hours, and within one hour and one mile during off-peak hours. The secondary accident rate was derived by dividing the number of secondary accidents by the VMT that occurred within one mile (during off peak hours) or one half mile (during peak hours) of the primary accident. The accident database for the study corridor included 297 secondary accidents. Approximately two-thirds of those accidents occurred on the freeway. A secondary accident rate of 14.42 accidents/million vehicle miles was calculated for the study corridor during the peak period.

The large difference observed between all freeway accidents, presented in Table 9-12, and the secondary accident rate data determined above suggests a potential area of improvement for ATMS user services. A reduction of secondary freeway accidents may be one of the most significant benefits obtained by ATMS towards improving safety. Each time an accident occurs, on a non-ATMS configured freeway, the potential for another accident to occur increases at least 600 percent. Effective incident management systems, in particular, may significantly reduce the number of secondary accidents that occur and the amount of time required to detect, respond to and clear an accident from the road.

Safety impacts for casualty (injuries and fatalities), property damage only (PDO) and total accidents are determined in the framework by executing the SAFERUN.BAT batch file shown in Table 9-13. This batch file invokes the SAFETY program three separate times and uses ASCII interface files (LlNKa.ASC) along with accident rate matrix information to estimate the number of accidents per million vehicle miles of travel. The SAFETY program calculates the volume to capacity ratio (v/c) for each link before applying accident rates contained in Table 9-12 for that particular v/c range. When all links are evaluated a report is produced that summarizes the number of accidents by v/c range. The SAFETY program also creates a new ASCII file called SAFETYa.OUT that contains a safety impact prediction, given the particular invocation of SAFETY, for every network link. The exact nature of the safety MOE contained in the output file depends upon the particular iteration of the SAFETY program as called from the SAFERUN.BAT batch file.

The SAFETY program performs the following operations:

1) The SAFETY program calculates the v/c range for each network link and groups the results into one of four ranges for v/c ratios:

    a) 0.0-0.7

    b) 0.7-0.9

    c) 0.9-l .0

    d) greater than 1.0

2) By using the calculated v/c range and link functional class code the program estimates the number of accidents for the network according to accident type by using the accident rate data from Table 9-12. Safety impacts are predicted for either total accidents, casualty accidents and PDO accidents depending on the specified accident rate file.

3) SAFETY produces a report that includes the v/c range, functional class, VMT, accident rate and the predicted number of accidents.

4) Lastly, the program generates an ASCII result file SAFETYa.OUT containing the predictions for either casualty, PDO, and total accidents in units of million miles of travel.

Table 9-12: Accident Rates Used in Safety Model

Functional Class	V/C Ratio Range	VMT*	Total Accidents	Fatal Accidents	Injury Accidents	PDO Accidents	PDO/ Casualty	Total Rate	Injury + Fatality rate	PDO Rate
Arterial	0 to 0.7	577.47	2404	5	988	1411	1.42	4.163	1.720	2.443
Arterial	0.7 to 0.9	167.18	482	1	227	254	1.11	2.883	1.364	1.519
Arterial	0.9 to 1.0	58.45	196	0	71	125	1.76	3.353	1.215	2.138
Arterial	> 1.0	101.25	331	0	136	195	1.43	3.269	1.343	1.926
Freeway	0 to 0.7	1811.5	2492	9	934	1549	1.64	1.376	0.521	0.855
Freeway	0.7 to 0.9	557.6	876	0	321	555	1.73	1.571	0.576	0.995
Freeway	0.9 to 1.0	251.05	476	1	184	291	1.57	1.896	0.737	1.159
Freeway	> 1.0	153.1	313	1	117	195	1.65	2.044	0.771	1.276

* in million miles of travel

Note: Casualty accidents are a combination of Fatality + Injury accidents

Table 9-13: **Safety Impact Batch File**

SAFERUN.BAT BATCH FILE	DESCRIPTION
dataedit zone-speed	
dataedit emisdump_hrl dataedit emisdump_hr2 dataedit emisdump_hr3	Create ASCII link files LlNKa.ASC from the SYSTEM II volume and speed data for each hour.
safety < safe-pdo.ctl dataedit readsafety_1	Run the safety program using property damage only rates and load results into SYSTEM II.
perf pdo_fwy 1 perf pdo_fwy2 perf pdo_fwy3 perf pdo_art1 perf pdo_art2 perf pdo_art3 perf pdo_fwytot perf pdo_arttot rename safety?.pm pdo_acc?.pm	Report property damage only accidents for study area and freeway portion in hours 1,2, and 3 as well as the arterial portion for hours 1,2, and 3. Rename the safety report.
safety < safe-inj.ctl dataedit readsafety_2	Run the safety program using injury accident rates and load results into SYSTEM II.
perf inj_fwy 1 perf inj_fwy2 perf inj_fwy3 perf inj_art 1 perf inj_art2 perf inj_art3 perf inj_fwytot perf inj_arttot rename safety?.pm inj_acc?.pm	Report number of injury accidents for study area and freeway portions in hours 1,2, and 3 as well as the arterial portion for hours 1,2, and 3. Rename the safety report.
safety < safe_tot.ctl dataedit readsafety_3	Run the safety program using the combined property damage and injury accident rates.
perf acc_fwy 1 perf acc_fwy2 perf acc_fwy3 perf acc_art1 perf acc_art2 perf acc_art3 perf acc_fwytot perf acc_arttot rename safety?.pm tot_acc?.pm	Report the number of total accidents for study area and freeway portions in hours 1,2, and 3 as well as the arterial portions for hours 1,2, and 3. Rename the safety report.

10. Framework Limitations

While the analytical framework will reasonably reflect most adaptive control aspects of ATMS technologies and strategies, there are some ITS strategies and technologies that cannot be represented by the system. For example, the framework is not capable of representing route guidance systems because the framework methodology assumes a user equilibrium route choice. Thus, one of the significant deficiencies in the analytical framework is that there is no capability to represent travelers without a historical knowledge of available modes and routes or the average historical level of service on those modes or routes.

There is no capability in the framework to represent variation in driver behavior due to the quality and quantity of information received by a traveler through an ATIS system. This ATIS information will result in a range of possible choices that travelers can make concerning route selection. Where ATIS is deployed the traveler has available a host of information on real-time traffic situations as well as advisory route guidance data. In its current form the framework does not account for any impacts attributed to ATIS measures.

Many of the ITS technologies and strategies in the Advanced Public Transportation Systems (APTS) category are oriented toward vehicle fleet maintenance, monitoring of vehicle locations, schedule adherence, and design of operational responses to increase service productivity. None of these transit operational strategies are reflected in the current framework. Other APTS strategies are oriented toward providing travelers with real time information about transit schedules and schedule adherence. While this may improve transit ridership, the current modeling system assumes only initial knowledge of transit schedules, therefore, the present framework would not adequately represent this element of APTS.

The framework also excludes certain types of travel from analysis. The system does not include an explicit representation of commercial travel patterns. While there are factors incorporated into the model to “add in” commercial trips, there is no capability to evaluate the ITS strategies in the specific context of commercial travel patterns. The current framework only includes representation of average annual weekday activity. As a result, special conditions that might exist on weekends would not be adequately represented by the model.

During development of the emissions module for the framework, the strengths and weaknesses of several emission estimation models and emission rate models were reviewed. The most significant weakness of most emissions models currently in use is that they do not take into account differences in emissions resulting from differences in operating mode (acceleration, deceleration, cruising, idle). Instead, existing emissions models estimate emissions based on the average speed and volume on a link, regardless of the facility type of the link. The speed-time profile for a freeway link with an average speed of 30 mph, however, is likely to be significantly different than the speed-time profile for an arterial link with an average speed of 30 mph. On a signalized arterial, for instance, a vehicle repeats patterns of acceleration, deceleration, and idle that may represent an average speed of 30 mph, while a vehicle on the freeway may have an average speed of 30 mph with significantly different patterns of acceleration, deceleration, and idling. The emissions produced by these two speed-time profiles may vary significantly and yet are not being captured by most emissions models currently in use.

11. Framework Qualification

This section discusses the framework's assumptions, convergence process, and approach taken to validate the framework effectiveness in evaluating ATMS user services. A series of runs were conducted to determine how well the model framework replicated expected operating conditions in terms of volumes, speeds, and queues. It should be noted that the analysis and results described in this report do not reflect evaluation and assessment of actual traffic operations on the I-880 corridor, but are rather an analysis documenting the development and use of the model framework.

Four different feedback methodologies were employed to evaluate convergence between traffic simulation models and planning models from iteration to iteration. This section also discusses the sensitivity of the framework results depending on the convergence methodology selected.

11.1 Convergence

Several methodologies were evaluated to determine the best approach to use for achieving speed and volume convergence during the iteration process. Four of these were selected as potentially promising methodologies and are defined as:

a) Averaging link speed from iteration to iteration (50% change in each iteration in travel speeds).
b) Averaging speed and volume (50 % change in each iteration in both speeds and volumes).
c) Weighting link speed. Weighted speeds are derived from calculating the running average of speed from iteration to iteration.
d) Weighting link speed and volumes from iteration to iteration.

The four convergence methodologies are represented in Table 1 l-l which illustrates the various analytical approaches considered for calculating revised link speeds and volumes using results from each iteration. The fourth methodology (weighting of speeds and volumes) provided the best stable convergence results than the other three methodologies considered. Based upon extensive testing, methodology (d) using a weighting of speeds and volumes was selected as the preferred methodology to achieve speed and volume convergence.

Table 11-1: Convergence Methodologies

Convergence Methodology	Iteration #4	
	Speed	Volume
a) Average Speed	$S_4 = \frac{S^*_4 + S_3}{2}$	$V_4 = V^*_4 =$ *(Using S_4 in Assignment)*
b) Average Speed and Volumes	$S_4 = \frac{S^*_4 + S_3}{2}$	$V_4 = \frac{V^*_4 + V_3}{2}$
c) Weighted Speed	$S_4 = \frac{S^*_4 + S_3 + S_2 + S_1 + S_0}{5}$	$V_4 = V^*_4 =$ *(Using S_4 in Assignment)*
d) Weighted Speed and Volumes	$S_4 = \frac{S^*_4 + S_3 + S_2 + S_1 + S_0}{5}$	$V_4 = \frac{V^*_4 + V_3 + V_2 + V_1 + V_0}{5}$

S^*_4 = Speed directly from Simulation Model Iteration.
V^*_4 = Volume directly from Planning Model Iteration.

The FREQ model operates on the basis of speed/volume and demand/capacity relationships. Several speed/flow curves are resident in the FREQ program and can be selected by choosing an appropriate free-flow speed. The speed/flow curves are used to relate a link's calculated v/c ratio to an average speed value given a family of various free-flow speed curves. A sensitivity analysis was conducted for the weighted speed and volume convergence method (d) using FREQ speed curves for 55, 60, and 65 mph. Stable convergence was achieved for both the 55 and 60 mph speed curves as shown in Figure 11-1 using network data for a section of the I880 freeway in the vicinity of SR238 and the SR92 interchange. The 55 mph speed/flow curve was selected from this testing since it produced the best results in calibrating the baseline FREQ model.

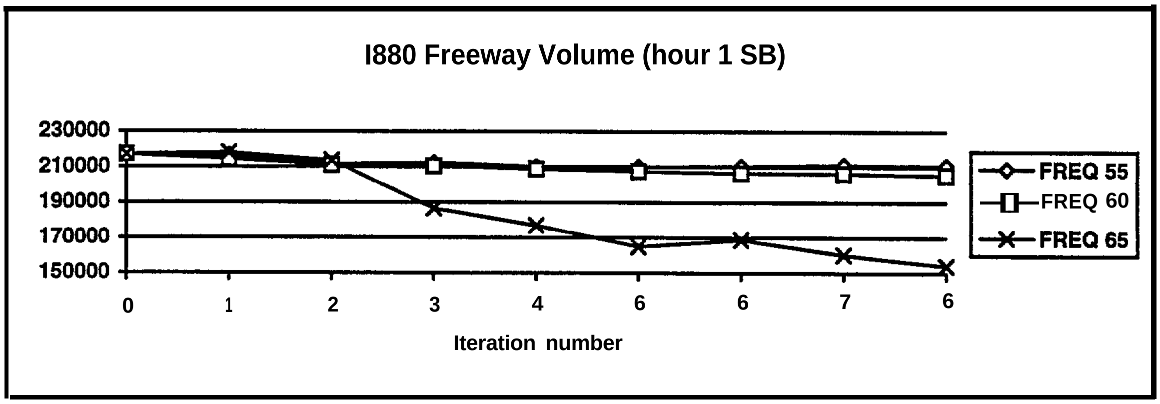

Figure 1 l- 1 a: Pre-peak hour in southbound direction

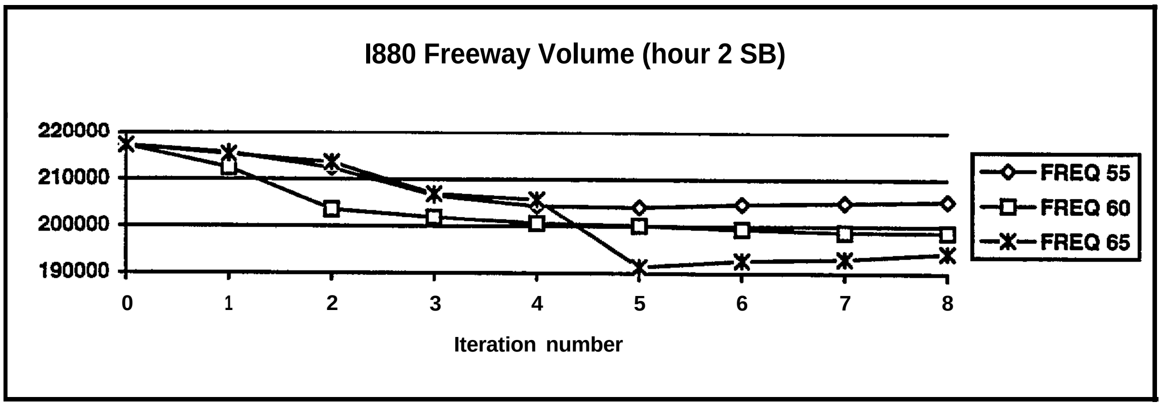

Figure 1 l-lb: Peak hour in southbound direction

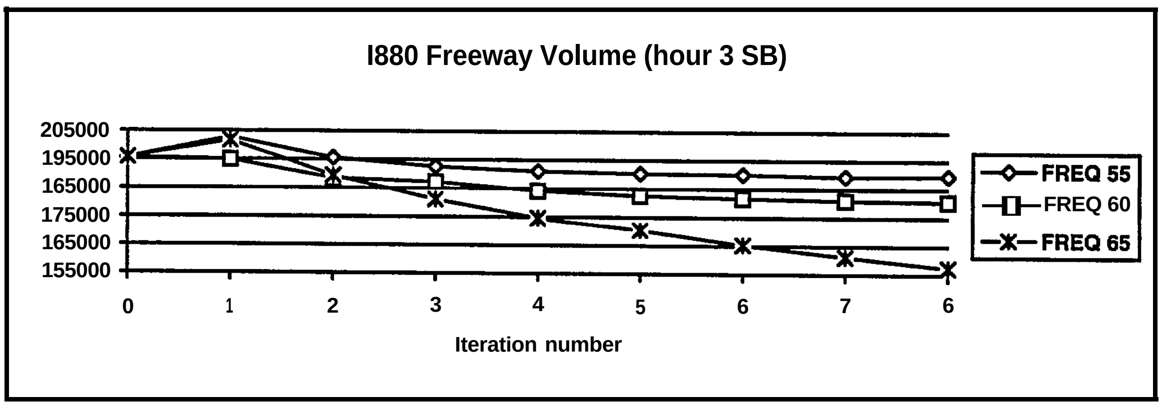

Figure 11-1c: Post-peak hour in southbound direction

Figure 1 l-l: Aggregrated Volume Convergence for Select I880 Freeway Links (in the Vicinity of SR238 and SR92 Interchange) using FREQ 55mph, 60mph and 65mph Free-flow Speed Curves

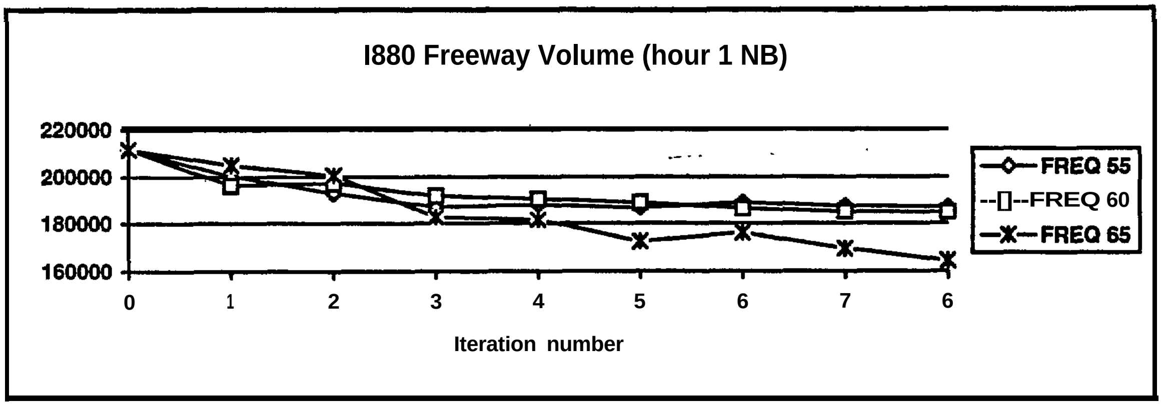

Figure 11-ld: Pre-peak hour in northbound direction

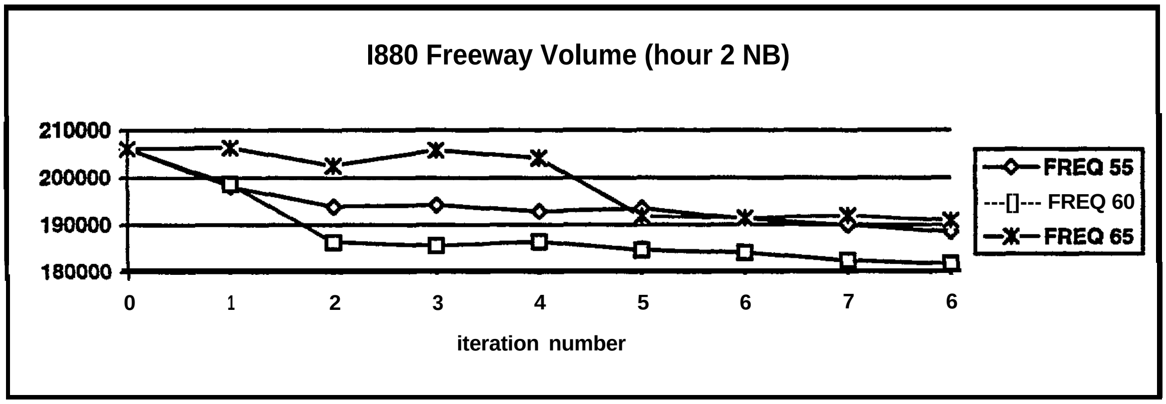

Figure 1 l- le: Peak hour in northbound direction

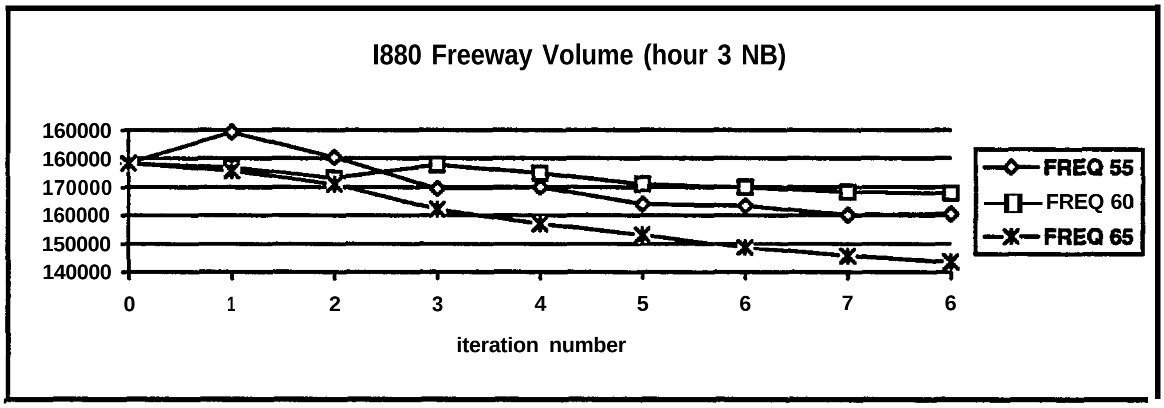

Figure 11-M Post-peak hour in northbound direction

Figure 1 l-l cont'd: Aggregrated Volume Convergence for Select I880 Freeway Links (in the Vicinity of SR238 and SR92 Interchange) using FREQ 55mph, 60mph and 65mph Free-flow Speed Curves

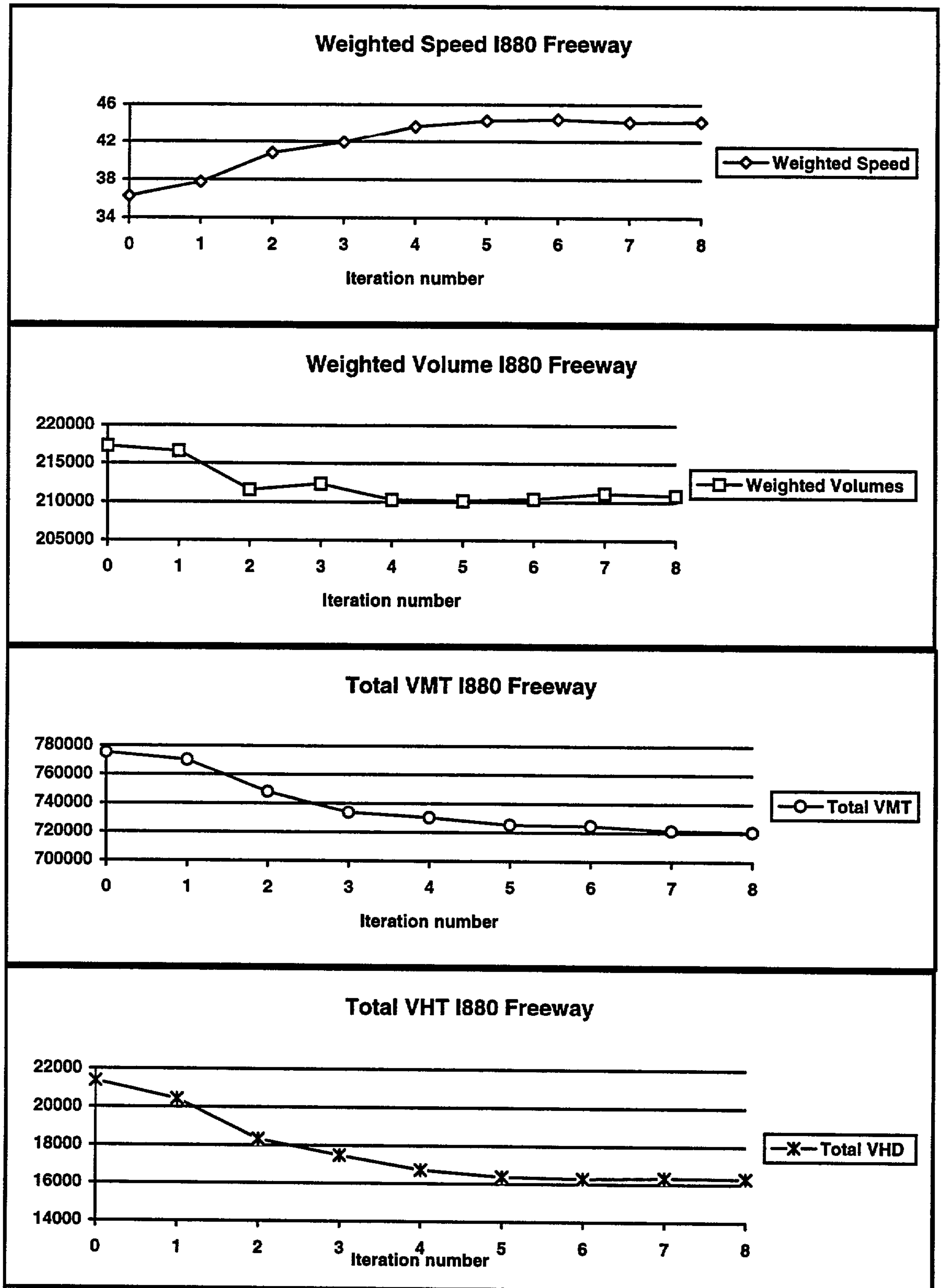

Figure 11-2: MOE Results Using Weighted Link Speed and Volume Convergence Methodology For Select I880 Freeway Links in Vicinity of SR238 & SR92 Interchange.

Using the preferred convergence method (d), Figure 1 l-2 indicates the difference in speed, volume, VMT and VHT between successive iterations for a portion of the I880 freeway mentioned above. The difference between initial iterations versus later iterations can be calculated. For example, the speed results for I-880, the percent change between iterations 1 and 2 equals 8% (40.81 - 37.71/ 37.71 = 0.08), the difference between iterations 2 and 3 equals 3% (41.95 - 40.81/40.81 = 0.03) while the percent change between iteration 6 and 7 is 1% (44.16 - 44.46/44.46 =0.0l) and between iterations 7 and 8 is approximately zero (44.2 - 44.16/44.16 = 0). This set of results is indicative of a stable convergence condition. The same pattern is reproduced for volume, VMT and VHT with the difference between later iterations being negligible.

11.2 Validation

Each of the three transportation models incorporated into the framework were validated independently in addition to the model framework as a whole. The regional planning model (SYSTEM II) was validated by comparing model results to actual field volume data. Usually planning models must validate certain variables to establish their credibility before they can be used in subsequent analysis. Several variables can be studied during the validation process but it is necessary to consider each variable independently because the performance of one variable may not be an indication of another variable's performance. For example, while validation may show that traffic volumes are reasonable, travel speed may not be.

Validation of the planning model involves the comparison of base year traffic volume estimates with actual base year traffic counts. Because of the general nature and structure of the model, this comparison is usually performed only for those locations where the planning model network has sufficient detail to truly represent the roadway networkand is done on an aggregate basis rather than a link-specific basis. This means that links are grouped together (by geographic area or by functional class) and the cumulative difference between the total estimated volumes and actual counted volumes is reported. In recognition of the inherent inaccuracies of the planning model, it is not expected to produce exact matches, but rather to produce volumes that are within an acceptable tolerance of the actual counted values. Typical tolerance criteria used for this type of comparison is shown in Table 1 l-2.

Validation results obtained from the SYSTEM II planning model, as shown in Table 1 l-2, indicate that the total volume percent difference between actual ground count data and planning model predictions for the freeway is 0.03%, and the total percent difference for the entire parallel arterial is 7.94%. These results are well within established validation criteria guidelines.

Table 1 l-2: Suggested Model Validation Criteria

Network Functional Class	Maximum Desirable Deviation in Total Volume	Actual Volume Deviation fromSYSTEM II model
Freeway	less than 7 %	0.03 %
Principal Arterials	less than 10 %	7.94 %

The FREQ freeway simulation model validation required replication of observed traffic congestion patterns. Based on available 1990 tachometric information, speed contour diagrams were constructed for the peak AM analysis hour. Observed congestion patterns were then replicated in FREQ by adjusting freeway and ramp demands and capacities along the corridor. Validation of FREQ was considered complete when the modeled congestion deviated from real congestion by only one subsection and/or one time slice. Based on this validation criteria FREQ model accuracy of 95% was achieved. The available I-880 corridor ground count data from 1990 was used to validate FREQ for both the northbound and southbound directions of travel.

Validation runs of the entire model framework were conducted to determine how well the model replicated actual 1990 baseline traffic conditions in terms of volume, speed and queues. The baseline scenario used in the framework validation exercise includes minimal traffic management services that were operational in the corridor during the base year 1990. By late 1995, sections of I-880 will have a new, continuous HOV lane and ramp metering installed at all on-ramps within the corridor. This new operating capability will provide the "after" information to validate predicted benefits of ATMS as derived from the model framework. New field measures of operating conditions can then be made including speed profiles, queue length and delay calculations, and vehicle classification under the new operating scenario. This information however, will not enable fuel consumption, emissions and safety models to be validated. Impacts in those areas will be based on the operating mode before and after implementation of ATMS technologies.

11.2.1 Framework Speeds and Queues

In 1990 observed delay and bottleneck locations were obtained along the southbound I-880 corridor during the AM peak hour. These observations were compiled from tachometer runs routinely collected by Caltrans. This data served as the basis for comparing the model framework results to the results from the SYSTEM II planning model alone.

What was found is that the planning model alone did not pinpoint traffic queues at the correct location, but estimated the queue to be downstream of the real location. This occurred because planning models allow traffic to flow through the bottleneck, when in reality traffic is queued behind the bottleneck. The model framework, however, correctly estimated the location of observed traffic bottlenecks.

The planning model when used alone has no mechanism available to show the effect of traffic queues on vehicle speed. That is, it does not show a ripple effect upstream of the bottleneck. In actual situations when a bottleneck occurs vehicles will slow up in the area behind the bottleneck. Most planning models treat each section independently, however, and because of this planning models cannot consider the effect upstream. By failing to properly locate a bottleneck and its upstream and downstream effects, the planning model misrepresents delay. Conversely, the model framework correctly locates queues behind the bottleneck, and free-flowing traffic downstream of the bottleneck, and can therefore, predict delay and spatial diversion more accurately than planning or simulation models alone.

11.2.2 Framework Volumes

The model framework was run to compare estimated volumes to observed traffic volumes. These results were then compared to the volumes predicted by using the SYSTEM II planning model only. Results obtained for the freeway and parallel arterial are presented in Tables 1 l-4 through Table 1 l-7. Table 1 l-4 presents the comparison of I-880 mainline volumes for the peak AM analysis hour by direction. For the overall I-880 corridor, the percent root-mean-square (RMS) difference between observed and estimated volumes for the planning model was 10.13%. The model framework generated equivalent volumes and produced a percent RMS difference of 13.17%. Tables 1 l-5 and 1 l-6 compare volumes on the parallel arterial during the AM peak hour for northbound and southbound lanes, respectively. Combining both the northbound and southbound volumes in Table 1 l-7 for the overall arterial, the percent RMS difference between observed and estimated volumes for the model framework is 52.75% compared to the planning model by itself at 52.42%.

The precise calculations used for these comparisons are as follows;

$$\text{RMS Difference} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(Ci - Fi)^2}$$

$$\% \text{ RMS Difference} = \frac{\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(Ci-Fi)^2}}{\frac{1}{n}\sum_{i=1}^{n}Ci}$$

Where: C_i - represents the actual link ground count volume
F_i - represents the predicted link volume
n - represents the total number of discrete volume counts

An analysis of freeway and parallel arterial links revealed that the percent RMS difference between actual volumes and predicted link volumes will decrease as the link volume increases. The analysis indicates that links with observed volumes above 2000 vehicles per hour exhibits a small percent RMS difference of 14% or less (most of these links are associated with the freeway). Higher values of percent RMS difference can be seen to occur as link volume decreases as shown in Table 11-3. When network links are grouped on the basis of observed volume the larger percent RMS differences are concentrated on low volume links. From Table 11-3 it can be seen that percent RMS difference can be as high as 122% for links with observed volumes of less than 500 vehicles per hour. The higher degree of error found among low volume links is consistent with previous studies.

Table 11-3: Comparison of Actual Volume to Framework Predictions Based Upon Grouping Links by Their Observed Volume Counts.

Link aggregation rule	Number of links	RMS Difference	% RMS Difference
< 500 vph	20	414	122 %
500 - 1000 vph	31	442	61 %
1000 - 2000 vph	31	451	31 %
> 2000 vph	22	523	14 %

Table 1 l-4: I880 Freeway Observed AM Peak Hour Traffic Volumes Compared to Planning Model and Framework Estimates.

Link number	Observed Volume (1990)	Planning Volume	Percent Difference	Framework Volume	Percent Difference
1	5801	6629	14.27%	6014	3.67%
2	5388	5262	-2.34%	4901	-9.04%
3	5055	5609	10.96%	4990	-1.29%
4	5252	4718	-10.17%	4151	-20.96%
5	5099	5095	-0.08%	4924	-3.43%
6	5950	5536	-6.96%	5458	-8.27%
7	5331	5536	3.85%	5458	2.38%
8	5038	5450	8.18%	6126	21.60%
9	3410	3601	5.60%	4524	32.67%
10	2030	1750	-13.79%	2411	18.77%
11	3499	3762	7.52%	3628	3.69%
12	3953	3993	1.01%	4195	6.12%
13	2897	2000	-30.96%	2477	-14.50%
14	4660	4402	-5.54%	4771	2.38%
Total =	63363	63343		64028	
		RMS diff.=	458.55	RMS diff.=	596.25
		%RMSdiff.=	10.13%	%RMSdiff.=	13.17%

Table 11-5: Northbound Parallel Arterial Observed AM Peak Hour Traffic Volumes Compared to Planning Model and Framework Estimates.

Link number	Observed Volume (1990)	Planning Volume	Percent Difference	Framework Volume	Percent Difference
1	575	102	-82.26%	108	-81.22%
2	375	100	-73.33%	155	-58.67%
3	438	317	-27.63%	308	-29.68%
4	286	186	-34.97%	173	-39.51%
5	363	304	-16.25%	290	-20.11%
6	517	232	-55.13%	229	-55.71%
7	525	390	-25.71%	329	-37.33%
8	553	575	3.98%	557	0.72%
9	458	551	20.31%	597	30.35%
10	398	712	78.89%	761	91.21%
11	375	448	19.47%	455	21.33%
12	175	929	430.86%	872	398.29%
13	163	915	461.35%	912	459.51%
14	751	459	-38.88%	787	4.79%
15	390	577	47.95%	521	33.59%
16	409	577	41.08%	500	22.25%
17	542	926	70.85%	860	58.67%
18	704	926	31.53%	872	23.86%
19	564	728	29.08%	520	-7.80%
20	689	860	24.82%	623	-9.58%
21	1390	1394	0.29%	618	-55.54%
22	100	560	460.00%	179	79.00%
23	958	718	-25.05%	162	-83.09%
24	853	696	-18.41%	161	-81.13%
25	1726	1371	-20.57%	1240	-28.16%
26	946	1317	39.22%	1329	40.49%
27	1354	1314	-2.95%	1333	-1.55%
28	1444	1350	-6.51%	1349	-6.58%
29	1757	2155	22.65%	2168	23.39%
30	1631	1834	12.45%	1763	8.09%
31	1934	2128	10.03%	2150	11.17%
32	1408	1674	18.89%	1363	-3.20%
33	1423	1425	0.14%	1469	3.23%
34	1054	1462	38.71%	1552	47.25%
35	944	1599	69.39%	1688	78.81%
36	1105	1550	40.27%	1479	33.85%
37	986	1526	54.77%	1310	32.86%
38	890	1889	112.25%	1428	60.45%
Total =	31153	36776		33170	
		RMS diff.=	368.87	RMS diff.=	384.48
		%RMSdiff.=	44.99%	%RMSdiff.=	46.9%

Table 11-6: Southbound Parallel Arterial Observed AM Peak Hour Traffic Volumes Compared to Planning Model and Framework Estimates.

Link number	Observed Volume (1990)	Planning Volume	Percent Difference	Framework Volume	Percent Difference
1	2209	2177	-1.45%	1947	-11.86%
2	2751	1961	-28.72%	1650	-40.02%
3	2703	2017	-25.38%	2290	-15.28%
4	1143	1889	65.27%	2464	115.57%
5	800	866	8.25%	1338	67.25%
6	1532	732	-52.22%	918	-40.08%
7	1497	472	-68.47%	924	-38.28%
8	1256	921	-26.67%	942	-25.00%
9	1123	829	-26.18%	904	-19.50%
10	708	982	38.70%	678	-4.24%
11	498	499	0.20%	235	-52.81%
12	426	427	0.23%	143	-66.43%
13	454	600	32.16%	300	-33.92%
14	502	669	33.27%	343	-31.67%
15	740	996	34.59%	1056	42.70%
16	1383	1069	-22.70%	1151	-16.78%
17	2177	1023	-53.01%	656	-69.87%
18	634	1248	96.85%	971	53.15%
19	791	1496	89.13%	1122	41.85%
20	739	1583	114.21%	1223	65.49%
21	600	1269	111.50%	958	59.67%
22	636	1265	98.90%	957	50.47%
23	679	1348	98.53%	1090	60.53%
24	916	1348	47.16%	1150	25.55%
25	762	806	5.77%	978	28.35%
26	137	948	591.97%	1050	666.42%
27	156	1041	567.31%	1185	659.62%
28	664	805	21.23%	953	43.52%
29	475	824	73.47%	937	97.26%
30	931	1022	9.77%	1069	14.82%
31	1065	1015	-4.69%	1141	7.14%
32	1129	924	-18.16%	1048	-7.17%
33	1023	365	-64.32%	543	-46.92%
34	1418	930	-34.41%	1144	-19.32%
35	1310	772	-41.07%	857	-34.58%
36	437	290	-33.64%	370	-15.33%
37	233	56	-75.97%	71	-69.53%
38	1084	80	-92.62%	111	-89.76%
Total =	37721	37564		36867	
		RMS diff.=	566.85	RMS diff.=	561.65
		%RMSdiff.=	57.1%	%RMSdiff.=	56.58%

Table 11-7: Combined North & Southbound Parallel Arterial AM Peak Hour Observed Traffic Volumes Compared to Planning Model and Framework Estimates.

Link number	Observed Volume (1990)	Planning Volume	Percent Difference	Framework Volume	Percent Difference
1	575	102	-82.26%	108	-81.22%
2	375	100	-73.33%	155	-58.67%
3	438	317	-27.63%	308	-29.68%
4	286	186	-34.97%	173	-39.51%
5	363	304	-16.25%	290	-20.11%
6	517	232	-55.13%	229	-55.71%
7	525	390	-25.71%	329	-37.33%
8	553	575	3.98%	557	0.72%
9	458	551	20.31%	597	30.35%
10	398	712	78.89%	761	91.21%
11	375	448	19.47%	455	21.33%
12	175	929	430.86%	872	398.29%
13	163	915	461.35%	912	459.51%
14	751	459	-38.88%	787	4.79%
15	390	577	47.95%	521	33.59%
16	409	577	41.08%	500	22.25%
17	542	926	70.85%	860	58.67%
18	704	926	31.53%	872	23.86%
19	564	728	29.08%	520	-7.80%
20	689	860	24.82%	623	-9.58%
21	1390	1394	0.29%	618	-55.54%
22	100	560	460.00%	179	79.00%
23	958	718	-25.05%	162	-83.09%
24	853	696	-18.41%	161	-81.13%
25	1726	1371	-20.57%	1240	-28.16%
26	946	1317	39.22%	1329	40.49%
27	1354	1314	-2.95%	1333	-1.55%
28	1444	1350	-6.51%	1349	-6.58%
29	1757	2155	22.65%	2168	23.39%
30	1631	1834	12.45%	1763	8.09%
31	1934	2128	10.03%	2150	11.17%
32	1408	1674	18.89%	1363	-3.20%
33	1423	1425	0.14%	1469	3.23%
34	1054	1462	38.71%	1552	47.25%
35	944	1599	69.39%	1688	78.81%
36	1105	1550	40.27%	1479	33.85%
37	986	1526	54.77%	1310	32.86%
38	890	1889	112.25%	1428	60.45%
39	2209	2177	-1.45%	1947	-11.86%

40	2751	1961	-28.72%	1650	-40.02%
41	2703	2017	-25.38%	2290	-15.28%
42	1143	1889	65.27%	2464	115.57%
43	800	866	8.25%	1338	67.25%
44	1532	732	-52.22%	918	-40.08%
45	1497	472	-68.47%	924	-38.28%
46	1256	921	-26.67%	942	-25.00%
47	1123	829	-26.18%	904	-19.50%
48	708	982	38.70%	678	-4.24%
49	498	499	0.20%	235	-52.81%
50	426	427	0.23%	143	-66.43%
51	454	600	32.16%	300	-33.92%
52	502	669	33.27%	343	-31.67%
53	740	996	34.59%	1056	42.70%
54	1383	1069	-22.70%	1151	-16.78%
55	2177	1023	-53.01%	656	-69.87%
56	634	1248	96.85%	971	53.15%
57	791	1496	89.13%	1122	41.85%
58	739	1583	114.21%	1223	65.49%
59	600	1269	111.50%	958	59.67%
60	636	1265	98.90%	957	50.47%
61	679	1348	98.53%	1090	60.53%
62	916	1348	47.16%	1150	25.55%
63	762	806	5.77%	978	28.35%
64	137	948	591.97%	1050	666.42%
65	156	1041	567.31%	1185	659.62%
66	664	805	21.23%	953	43.52%
67	475	824	73.47%	937	97.26%
68	931	1022	9.77%	1069	14.82%
69	1065	1015	-4.69%	1141	7.14%
70	1129	924	-18.16%	1048	-7.17%
71	1023	365	-64.32%	543	-46.92%
72	1418	930	-34.41%	1144	-19.32%
73	1310	772	-41.07%	857	-34.58%
74	437	290	-33.64%	370	-15.33%
75	233	56	-75.97%	71	-69.53%
76	1084	80	-92.62%	111	-89.76%
Total =	68874	73340		70037	
		RMS diff.=	475.02	RMS diff.=	478.07
		%RMSdiff.=	52.42%	%RMSdiff.=	52.75%

Table 11-7 cont'd

12. Methodology used for Scenarios

Determination of ITS benefits, using the framework, is based upon a detailed analysis of predicted measure of effectiveness (MOE) data. In this report MOEs are grouped into three categories that pertain to network operational parameters, pollutants emitted or safety related factors. Operational MOEs are used to quantify network characteristics and relate to vehicle miles traveled, average vehicle speed (mph), traffic volume, vehicle hours of delay and fuel consumption (gallons). Emission MOEs are expressed in units of kilo-grams and predict carbon monoxide (CO), hydrocarbons (HC) and nitrogen oxide (NO_x) pollutants. The last MOE category deals with safety issues and predicts personal injury levels, property damage only (PDO), and total accident predictions. All safety MOEs are expressed in units of incidents per million miles traveled.

As previously noted, the study area selected for this report consists of the I880 Bay Area corridor located in Alameda County, California, which extends from San Leandro through Fremont to just north of the town of Milpitas (refer to Figure 8-l). The study corridor consists mainly of I880 and an adjacent strip of transportation facilities that parallel the I880 freeway. This strip includes a major parallel arterial that intersects the freeway about midpoint in the study corridor. The corridor is composed of three main regions that include rural, residential and business district areas. These area classifications are used to support analysis of MOE impact upon the different community types. The I880 freeway consists of rural and residential areas while the parallel arterial is only located in business district and residential areas.

ITS benefit evaluation was performed by defining a set of six different ATMS service configurations referred to as scenarios. Each of the scenarios were sequentially executed by the framework and corresponding MOEs were generated and recorded. ITS impacts were obtained by comparing individual scenario MOEs against the baseline configuration. The baseline (scenario 1) represents study corridor services that were in place during 1990. Stated differently, a baseline of performance was established and alternate scenarios were compared against the baseline to identify ITS impacts.

The six scenarios considered during the analysis are listed below and include high occupancy vehicle (HOV) lanes as part of the simulation.

Scenario 1 - Fixed time signal coordination based on morning peak volume (PlFlT2).

Scenario 2 - Demand based signal coordination over a 3 hour morning period from 7:00am to 10:00am (PlFlT3).

Scenario 3 - Fixed time metered freeway ramps, based on morning peak volume, combined with fixed time signal coordination on the parallel arterial (P2FlF2T2).

Scenario 4 - Synchronized freeway ramp metering, optimizing free flow, combined with fixed time signal coordination on the parallel arterial (P2F1F3T2).

Scenario 5 - Synchronized freeway ramp metering combined with demand based signal coordination (P2F1F3T3).

Scenario 6 - Fixed time metered freeway ramps, based on morning peak volume, combined with demand based signal coordination (P2F1F2T3).

Selection of specific ATMS user services within each scenario is controlled using a set of input parameters to the framework batch files. These input parameters control execution of particular modules within the framework to achieve the desired simulation of ATMS services. The input parameters are referred to as P, F and T for the planning, freeway and arterial models respectively. Possible values for the control parameters are show in Table 12-1.

Table 12-1: Framework Control Input Parameters

ATMS User Services\Variables	P1	P2	P3	F1	F2	F3	T1	T2	T3
HOV Lane	Y	Y	N						
Metered ramp HOV by-pass	N	Y	Y						
HOV lane analysis				Y	n/a	n/a			
Fixed ramp metering				n/a	Y	N			
Dynamic ramp metering				n/a	N	Y			
Baseline signal coordination							Y	N	N
Fixed signal coordination							N	Y	N
Dynamic signal coordination							N	N	Y

13. Corridor Study Area Results

The evaluation of two different types of arterial signal coordination, along the study corridor, indicated that demand response signal coordination is superior to fixed time signal coordination. By using dynamic signal coordination, total speeds along the arterials were increased by 4.4% without impacting VMT. Freeway speeds decrease by 1.3% with implementation of arterial signal coordination.

As previously noted, the combination of ramp metering with signal coordination produced the most impressive results pertaining to the freeway. The benefits related to freeway MOEs appear to be mainly dependent upon application of ramp metering. Ramp metering may generate network wide traffic improvement if it is combined with dynamic signal coordination.

For the purposes of this study the results have been grouped and organized into the three MOE categories discussed in section 12. Detailed MOE results can be found in Appendix A for all scenarios considered.

13.1 Operational Measures

The impact of each scenario upon vehicle miles traveled, average vehicle speed, traffic volume, vehicle hours of delay and fuel consumption are documented below.

13.1.1 I880 Freeway (excluding ramps)

- Fixed ramp metering led to overall average freeway speed increases in the range of 2.4% to 3%. Speed increases were sensitive to density, with rural areas increasing by 11% to 12%.
- A decrease of 38% is observed in total VHD with the implementation of ramp metering. The largest impact is seen in rural areas, where VHD improved by 65%.
- Implementing dynamic signal coordination alone will cause VHD to increase on the freeway by 15.7%. Some form of freeway ramp metering, combined with a signal coordination strategy, appears to reduce VHD by over 37%.
- Fuel consumption experiences an increase of 1.2% to 3%, depending on the scenario. The largest fuel increase occurs using dynamic ramp and fixed signal coordination.

13.1.2 I880 Freeway including ramps

- Results are similar to the section above.

13.1.3 Parallel Arterials

- VMT and volume are generally unaffected on the parallel arterial when ramp metering is installed on the freeway. When dynamic signal coordination is introduced the business district VMT increases by 1.6% with a corresponding increase in total volume of 1.5%.
- Total average speeds improved by 2.6% to 4.4% when dynamic signal coordination is introduced on the parallel arterials. Speed improvements with fixed signal coordination are in the range of 0.5% to 1.2%.
- The greatest overall change in VHD occurs under dynamic signal conditions, with a reduction of between 18.6% to 24.6%.

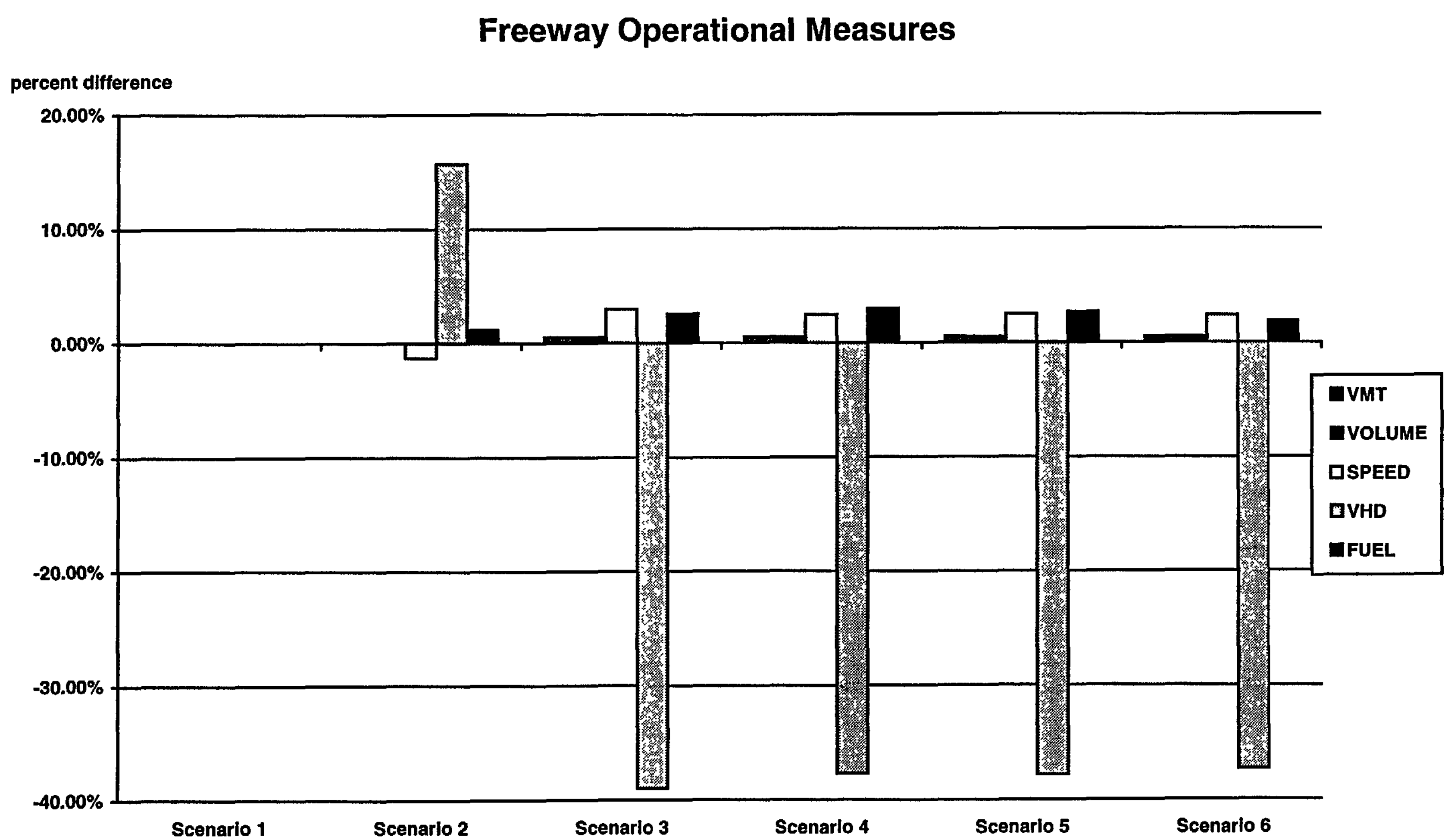
Freeway Operational Measures
percent difference
20.00%
10.00%
0.00%
-10.00%
-20.00%
-30.00%
-40.00%
Scenario 1
Scenario 2
Scenario 3
Scenario 4
Scenario 5
Scenario 6
VMT
VOLUME
SPEED
VHD
FUEL

figure 13.1

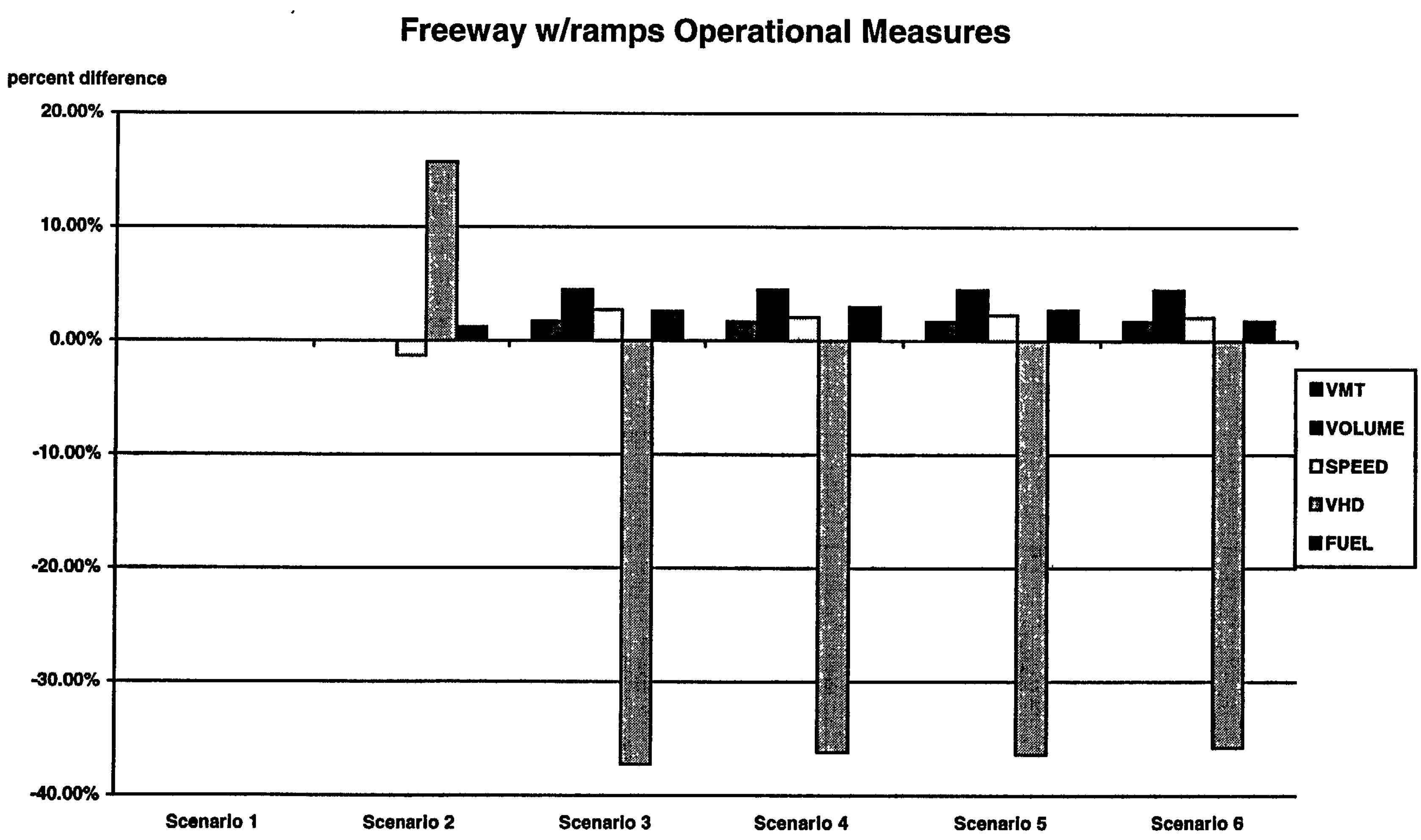
Freeway w/ramps Operational Measures
percent difference
20.00%
10.00%
0.00%
-10.00%
-20.00%
-30.00%
-40.00%
Scenario 1
Scenario 2
Scenario 3
Scenario 4
Scenario 5
Scenario 6
VMT
VOLUME
SPEED
VHD
FUEL

figure 13.2

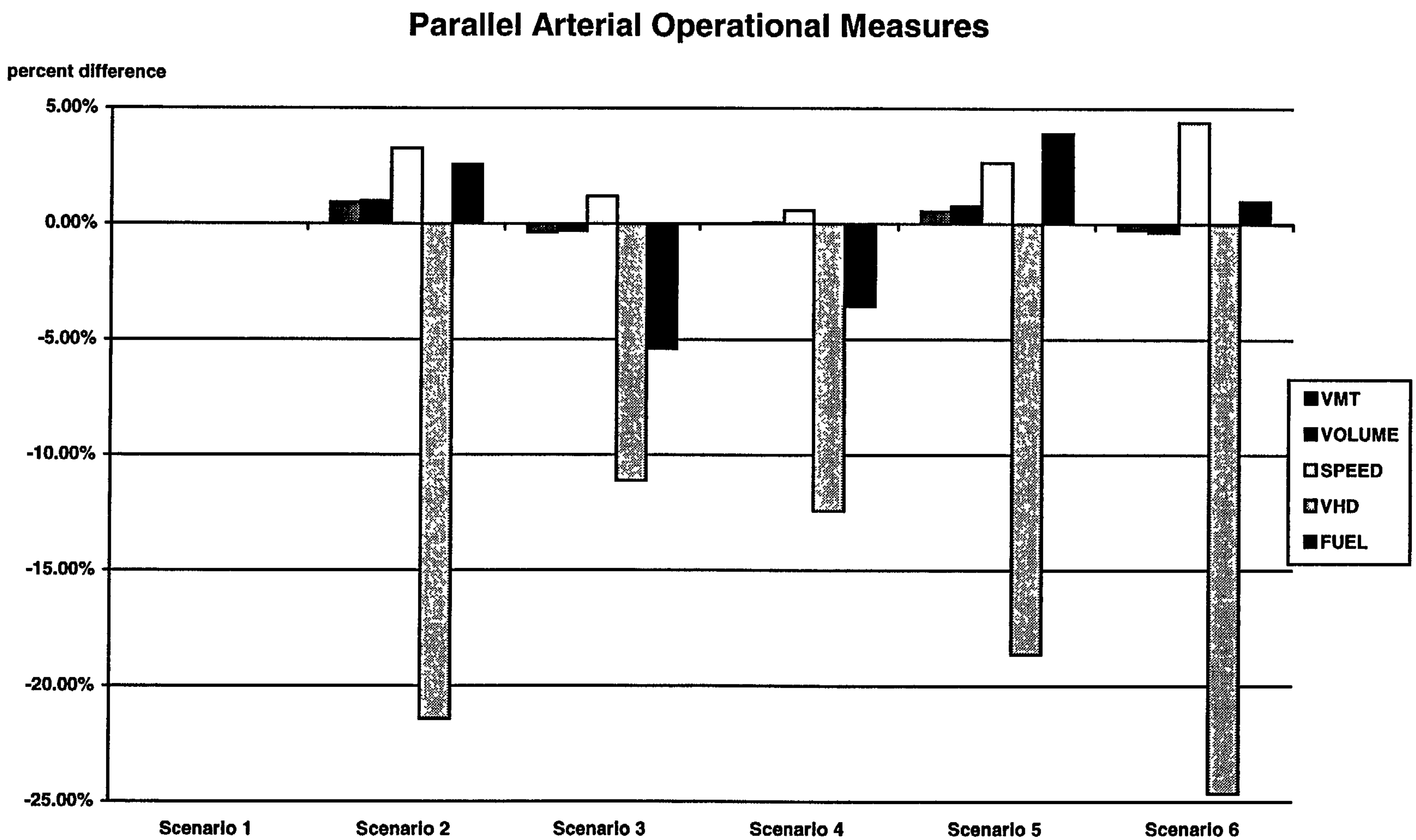
Parallel Arterial Operational Measures
percent difference
5.00%
0.00%
-5.00%
-10.00%
-15.00%
-20.00%
-25.00%
Scenario 1
Scenario 2
Scenario 3
Scenario 4
Scenario 5
Scenario 6
VMT
VOLUME
SPEED
VHD
FUEL

figure 13.3

13.2 Emissions

Impacts in terms of the pollutants, carbon monoxide (CO), hydrocarbons (HC) and nitrogen oxide (NOx) are documented below.

13.2.1 I880 Freeway (excluding ramps)

- CO and HC emissions decrease whenever ramp metering is available. Carbon monoxide emissions are reduced by 1% to 2%. Hydrocarbons are reduced by **1.6%** to 2.7%.
- The rural area experiences the greatest improvement in emissions. Whenever ramp metering is available CO is reduced by 15% to 18.5% and HC is reduced by 17% to 20%. (Refer to Appendix A)
- Nitrogen oxide emissions are increased by 7% to 10% under ramp metering conditions, probably due to slightly increased freeway speeds.

13.2.2 I880 Freeway including ramps

- All results are similar to those stated above for the freeway (excluding ramps).

13.2.3 Parallel Arterials

- CO, HC and NOx emissions all decrease when fixed signal coordination is installed with ramp metering. Rates of decline range from 3.6% to 13.8% in residential areas. (Refer to Appendix A)
- HC and NOx emissions appear to increase up to 4.5% using dynamic signal coordination with ramp metering.

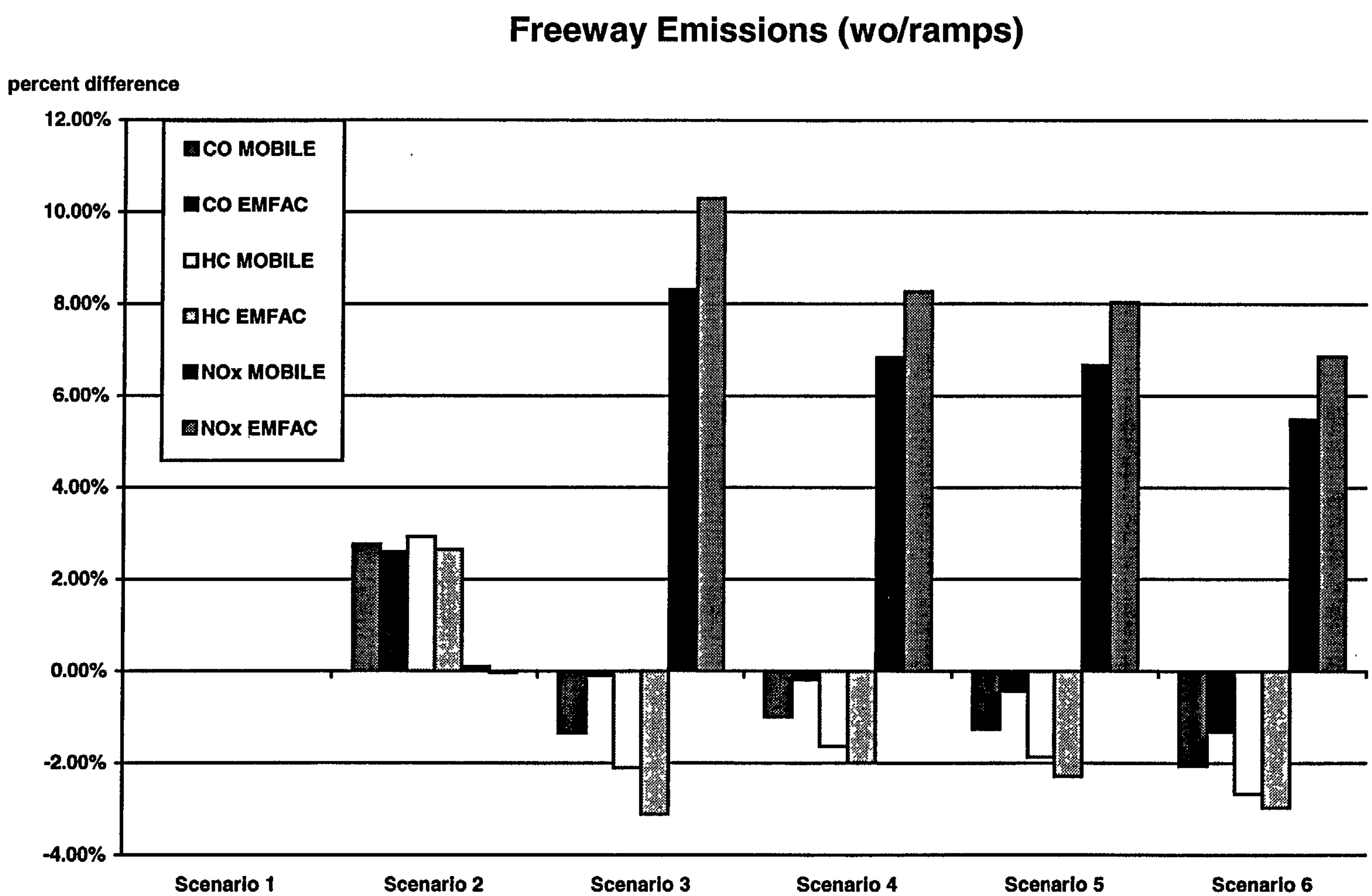
Freeway Emissions (wo/ramps)
percent difference
12.00%
10.00%
8.00%
6.00%
4.00%
2.00%
0.00%
-2.00%
-4.00%
CO MOBILE
CO EMFAC
HC MOBILE
HC EMFAC
NOx MOBILE
NOx EMFAC
Scenario 1
Scenario 2
Scenario 3
Scenario 4
Scenario 5
Scenario 6

figure 13.4

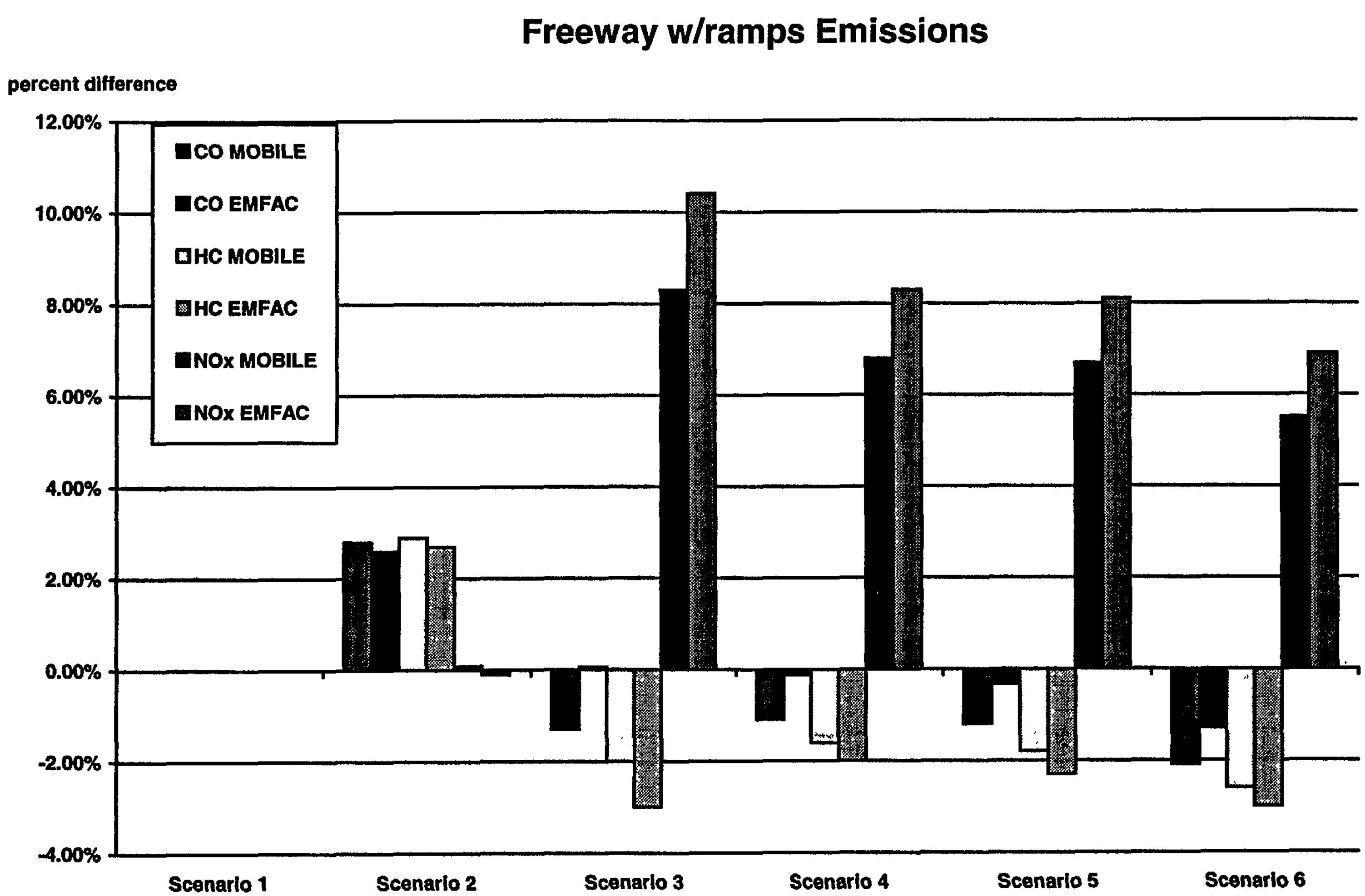
Freeway w/ramps Emissions
percent difference
12.00%
10.00%
8.00%
6.00%
4.00%
2.00%
0.00%
-2.00%
-4.00%
CO MOBILE
CO EMFAC
HC MOBILE
HC EMFAC
NOx MOBILE
NOx EMFAC
Scenario 1
Scenario 2
Scenario 3
Scenario 4
Scenario 5
Scenario 6

figure 13.5

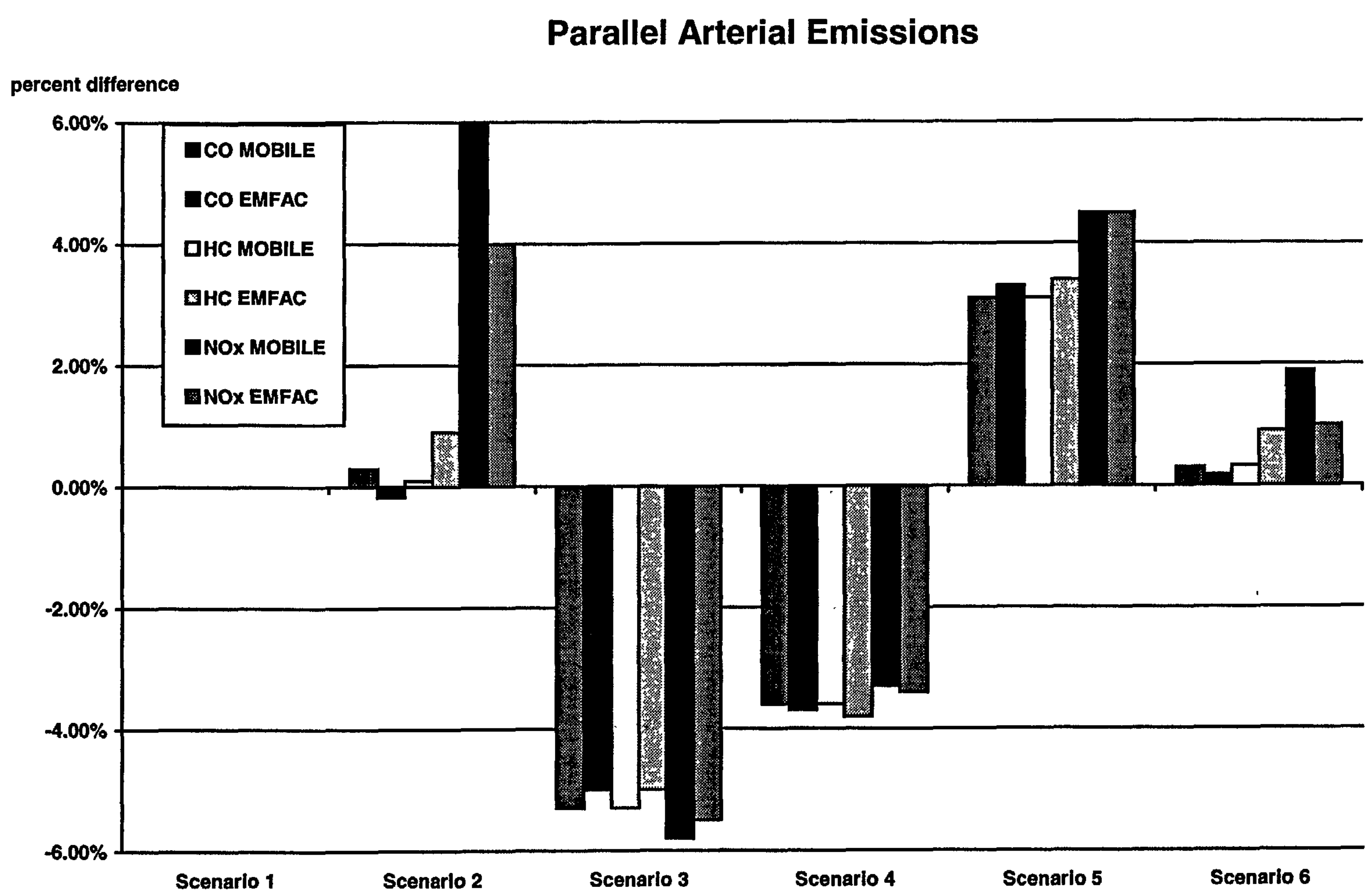
Parallel Arterial Emissions
percent difference
6.00%
4.00%
2.00%
0.00%
-2.00%
-4.00%
-6.00%
CO MOBILE
CO EMFAC
HC MOBILE
HC EMFAC
NOx MOBILE
NOx EMFAC
Scenario 1
Scenario 2
Scenario 3
Scenario 4
Scenario 5
Scenario 6

figure 13.6

13.3 Safety

The MOEs relating to safety encompass personal injury, property damage only and total accidents. The impact of ATMS services upon the safety MOEs is discussed below.

13.3.1 I880 Freeway (excluding ramps)

- The MOEs for personal injury and property damage (PDO) increase when ramp metering and signal coordination are used, due to increased speeds. No increase is observed with implementation of dynamic signal coordination alone.
- Personal injury increased by 4.2% to 5.3% while PDO increased by 4.3% to 6%.
- The largest increase of 5.4% for total accident rate was observed utilizing fixed ramp fixed signal coordination. This scenario has the largest increase in average speeds.

13.3.2 I880 Freeway including ramps

- Results are similar to the section above. (See Appendix A for details.)

13.3.3 Parallel Arteriais

- Personal injury, PDO and total accidents all decreased using a fixed signal coordination strategy. The improvements range between 3.6% to 5%, 1.7% to 4.9%, and 2.5% to 4.9%, respectively.
- Dynamic signal coordination, in isolation, produces the largest increase in personal injury, PDO and total accidents by 4.7%, 5.2% and 5% respectively.

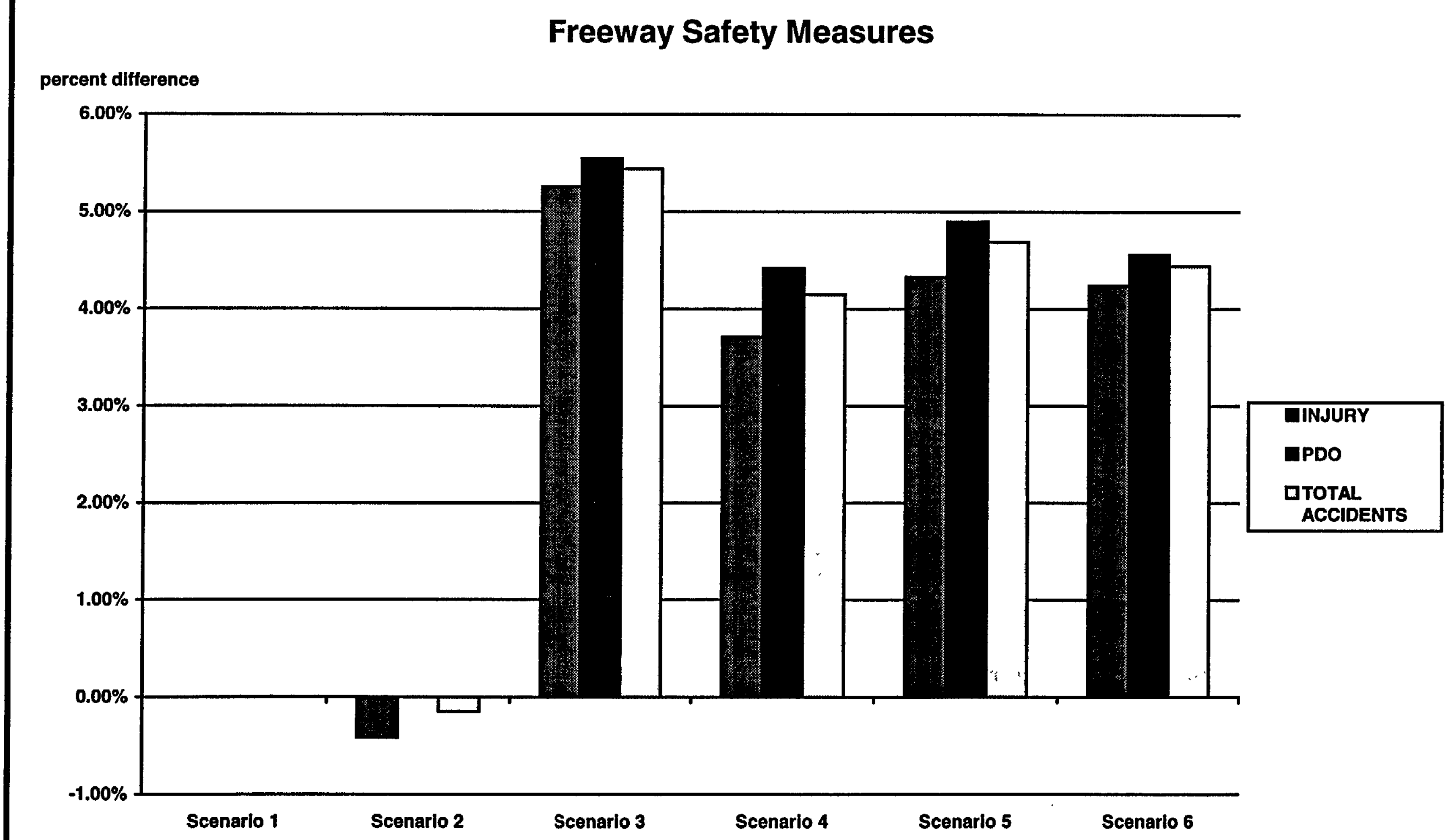
Freeway Safety Measures
percent difference
6.00%
5.00%
4.00%
3.00%
2.00%
1.00%
0.00%
-1.00%
Scenario 1
Scenario 2
Scenario 3
Scenario 4
Scenario 5
Scenario 6
INJURY
PDO
TOTAL ACCIDENTS

figure 13.7

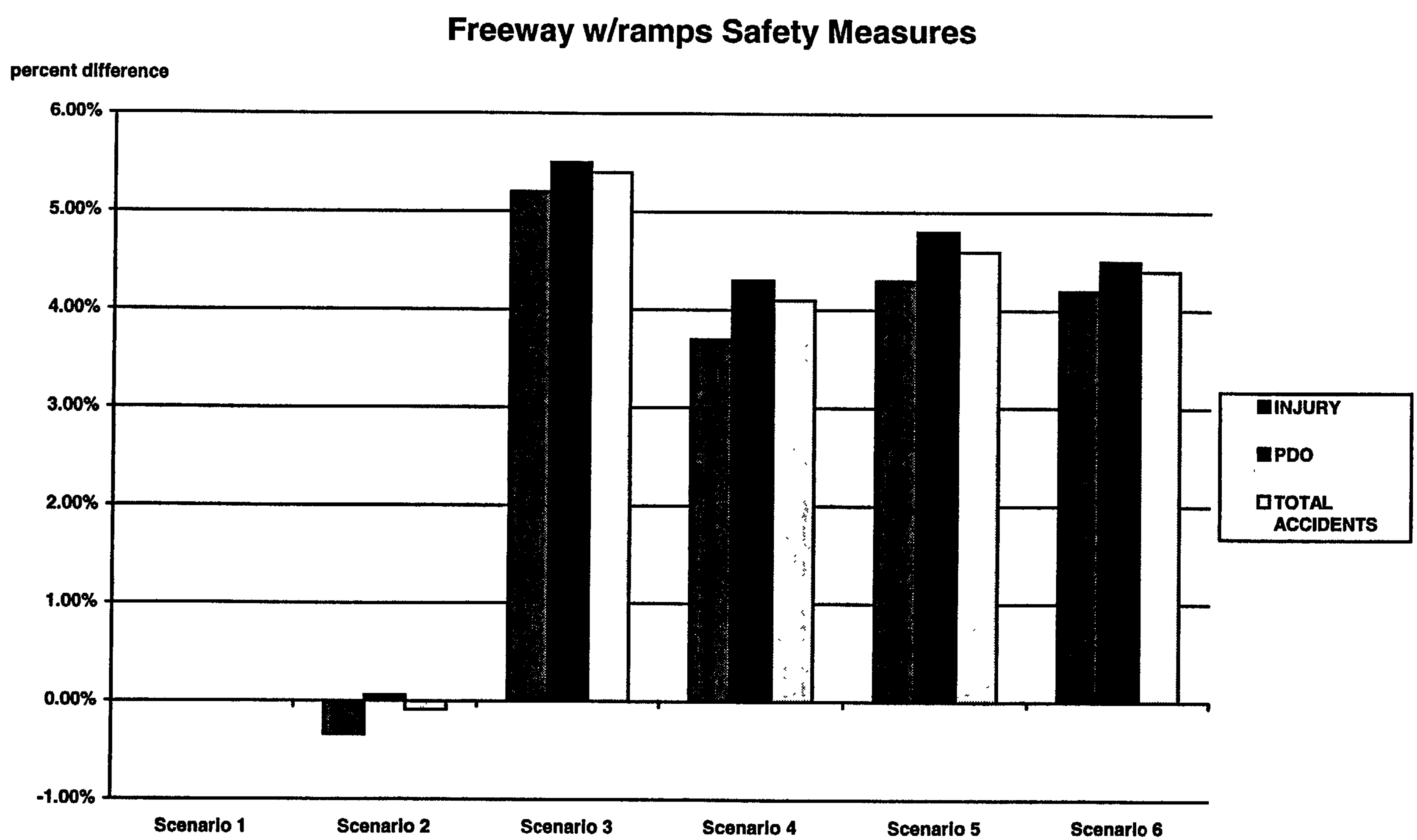
Freeway w/ramps Safety Measures
percent difference
6.00%
5.00%
4.00%
3.00%
2.00%
1.00%
0.00%
-1.00%
Scenario 1
Scenario 2
Scenario 3
Scenario 4
Scenario 5
Scenario 6
INJURY
PDO
TOTAL ACCIDENTS

figure 13.8

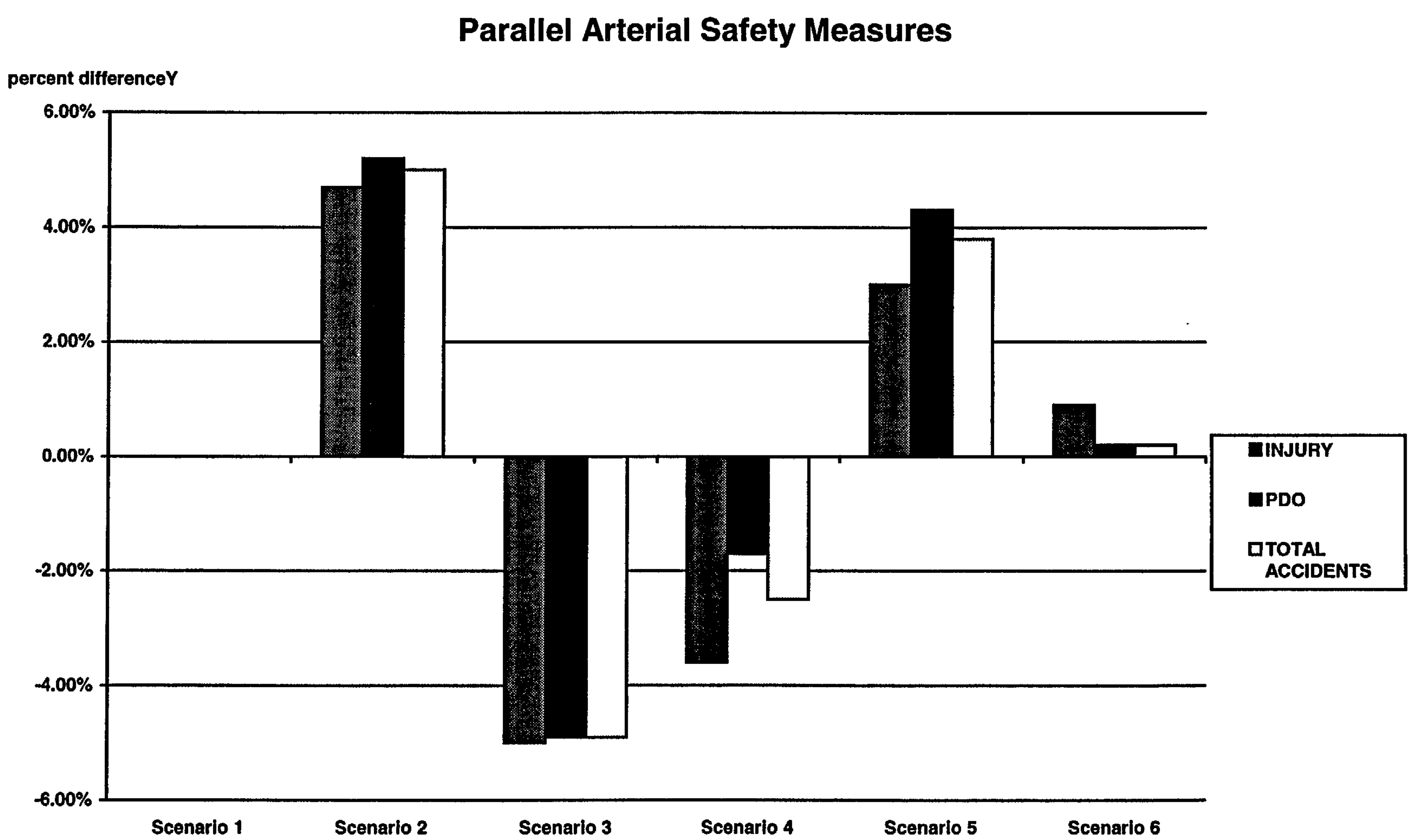
Parallel Arterial Safety Measures
percent differenceY
6.00%
4.00%
2.00%
0.00%
-2.00%
-4.00%
-6.00%
Scenario 1
Scenario 2
Scenario 3
Scenario 4
Scenario 5
Scenario 6
INJURY
PDO
TOTAL ACCIDENTS

figure 13.9

14. Conclusions

The study results indicate that a ramp metering strategy will have a positive impact upon freeway operational characteristics. The benefits obtained reflect a reduction in vehicle hours of delay without encountering an increase in freeway congestion. Application of fixed time and demand responsive signal coordination produces considerable improvements in speed and vehicle hours of delay on the parallel arterial.

The analyses suggest that MOEs should be considered collectively to determine ITS impact. The overall impacts of ITS technologies appear to be a compromise between many interdependent measures of effectiveness. For example, an improvement in speed and congestion will tend to have associated with them an increase in NOx emissions and vehicle incident rates.

The study demonstrated that the modeling framework is a useful tool in evaluating the impacts related to several signal control strategies in a region with integrated networks of freeways and signalized arterials. The ability of the framework is not limited to assessing the impacts on a localized network. System-wide impact assessment analysis can be performed to selectively target specific MOE improvements for particular areas where they are most needed. This approach leverages the dependent nature of MOEs and allows a practitioner to select specific ATMS services for obtaining optimal network-wide results. Finally, the results from implementing any of the strategies described here will vary with local network geometry and other region-specific conditions.

14.1 Recommendations for Framework Enhancement

Several areas have been identified as opportunities for enhancing the operation of the framework, improving its accuracy and extending the services modeled by the framework. These suggested improvement candidates are discussed below.

14.1.1 Enhanced HOV Lane Assignment Algorithm

The current HOV lane assignment algorithm produces an all-or-nothing allocation that assigns all eligible vehicles to HOV lanes whenever the speed differential favors the HOV lane. In reality, more HOV vehicles are likely to use the HOV lane as the speed differential increases. This relationship can be modeled using field data acquired from sample freeway observations.

14.1.2 ATIS Modeling

Two of the most significant elements of ITS are dynamic control of throughput through ATMS technologies and informing travelers of changes in roadway level of service through Advanced Traveler Information Systems (ATIS). The model framework was developed specifically to assess the impacts of ATMS user services. ATIS technologies can also be represented by segmenting the trip tables in the model framework into informed and uninformed travelers. Uninformed travelers will be assumed to have information only on the average historical level of service on alternate routes and modes. Informed travelers will be assumed to have information about real-time conditions. The model framework can be enhanced for ATIS impact assessment and for evaluation of the effect of ATIS on transportation system performance.

14.1.3 Facility Specific Emission and Fuel Consumption Rates

The framework support for facility-specific emission and fuel consumption rates only provides place-holders for separate rates on thirteen facility categories. Facility categories are used to distinguish the differences in emissions and fuel consumption based on differences in operating mode patterns. The framework currently provides for facility-specific rates for only light duty gasoline automobiles.

Facility-specific emissions and fuel consumption rates are developed from speed-versus-time data collected by instrumented “chase cars” following randomly selected vehicles. The chase car is driven on specific routes selected to represent typical driving trips during peak and off-peak hours within the region under study. The routes include travel on several facility types. Information needed to establish the facility category is documented throughout the route, including level of service of the facility, facility type, number of lanes, flow type (i.e. weave, straight pipe, or merge, for freeway sections only), and speed. With this data, the exhaust emission rates or fuel consumption rates for a specific facility type at different levels of service may be estimated.

While the framework includes support for facility-specific emission and fuel consumption analyses, the corresponding facility-specific emission and fuel consumption rates are not yet available and need to be added to the framework.

14.2 Recommendations For Future Safety Research

The accident data for the study corridor indicates that freeway total accident rates decrease as v/c ratio increases (refer to Table 9-12). Accident data on the parallel arterial indicates that a “U” shaped relationship exists between v/c ratio and the total accident rate for arterials. All arterial accident rates are highest in the lowest v/c ratio range and decrease with v/c ratios between 0.7 to 0.9. When the arterial v/c ratio exceeds 0.9 total accident rates begin to increase over mid range v/c ratio accident rates. This relationship may be explained by several factors, including travel speed, sample size and arterial capacity. It is unclear whether four v/c ratio ranges are sufficiently sensitive to capture changes in traffic flow influenced by implementation of ATMS user services.

The proportion of casualty (fatal plus injury) to property damage only (PDO) accidents was studied for the three time periods (AM, PM, off-peak) for which accident rates were calculated. While the proportion appears relatively consistent across the four v/c ratio ranges for both freeways and arterials, the freeway data ate more consistent than the arterial data. For all three time periods, for example, the percent of casualty accidents for arterials ranged from 36% to 47% while the percent of PDO accidents ranged from 52% to 63%. In contrast, the percent of casualty accidents for freeways ranged from 36% to 41% while the percent of PDO accidents for arterials ranged from 61% to 63%. It is also interesting to note that arterials in the 0.90 - 1 .00 v/c ratio range have the lowest casualty accident rates and the highest PDO/casualty ratio for all three time periods. For highways, however, this v/c ratio range represented the lowest PDO/casualty ratio for all three time periods. A study of the accident proportions also identified that the highest percentage of fatal accidents occurred in the lowest v/c ratio range for both freeways and arterials for all three time periods as well.

The accident data support the hypothesis that accident rate is dependent on facility type. Regardless of the time period for which the accident rates were developed, the highest freeway accident rate is significantly lower than the lowest arterial accident rate. This suggests that the obstacles to travel on an arterial, including pedestrians, buses, street parking and traffic signals significantly affect accident rates on arterials.

The current safety model used within the model framework represents a reasonable starting point for assessing safety of ATMS user services. The process, however, could be improved with some refinement of analytical methods and/or data. First, more rigorous statistical techniques could be applied to the data. For the prototype safety model, accident rates were grouped by v/c ratio ranges that were selected subjectively. A better approach would be to develop a model with a continuous dependent variable. For example, accidents per mile per year would be the dependent variable, while traffic volume would be included as an independent variable. An improved statistical technique that could be applied is Poisson regression, in which the error term is assumed to have a Poisson distribution rather than a normal distribution, and thus better conforms to theory.

Along with more sophisticated statistical techniques, consideration should be given to improving the extent and accuracy of the data. The primary problem with developing any safety model is measuring the conditions under which a particular accident occurred. Estimating the congestion condition under which each accident occurred was an integral part of the development of the safety model described in this paper. In this work, the v/c ratio for each hour was used as a measure of congestion and derived from hourly volumes that were output from the travel forecasting model. This approach, however, represents average congestion conditions rather than the actual congestion at the time of the accident. Two other shortcomings also exist as a by-product of using link-level estimates of v/c ratio:

1. The exact location of queues (where v/c > 1.0) are unknown, and
2. The capacity of arterial streets varies widely given signalized intersection conditions.

One approach to overcome these problems with the existing data would be to use hourly volume information and basic highway characteristics to perform traffic simulation analyses concentrating on hours during which queuing is present. These analyses would provide estimates of average travel speeds in queued and unqueued conditions, which would be a more direct measurement of the average congestion expected on a highway segment than v/c ratio would be.

Using traffic simulation models to refine estimates of congestion conditions does not eliminate all uncertainty regarding traffic flow conditions at the time of individual accidents. Simulation model results represent average conditions on the network and do not reflect the effect of non-recurring congestion, such as incidents or breakdowns, on traffic flow. Fortunately, an alternative method to synthesizing congestion and exposure data with travel forecasting and simulation models is available for freeways. Many urban areas have freeways that are instrumented with surveillance systems capable of measuring volumes and speeds at close intervals (usually l/2 mile apart) for short spans of tune. If these data were combined with accident data, it would be possible to measure the actual congestion level (measured in terms of travel speed) at the time of an accident. Use of freeway surveillance system data for safety studies would therefore improve estimates of the conditions under which accidents occurred. Similar data are also available for signalized arterials with centralized signal control. Data from midblock traffic counters, however, do not provide direct estimates of arterial capacity because flow at these locations is metered by upstream signals. Before a similar strategy can be applied to signalized arterials, a methodology to account for the effect of traffic signals on traffic conditions must be developed. In summary, there are many opportunities to improve.

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16. List of Acronyms

ADT	Average Daily Traffic
APTS	Advanced Public Transportation Systems
ATIS	Advanced Traveler Information Systems
ATMS	Advanced Traffic Management Systems
AVCS	Advanced Vehicle Control Systems
BPR	Bureau of Public Roads
CAAA	Clean Air Act Amendments (Federal)
CALTRANS	California Department of Transportation
CCTV	Closed Circuit Television
CMA	Congestion Management Agency
CMAQ	Congestion Mitigation and Air Quality Improvement Program
CMP	Congestion Management Program
CO	Carbon Monoxide
CVO	Commercial Vehicle Operations
DOT	Department of Transportation
DTIM	Direct Travel Impact Model (CALTRANS)
EPA	Environmental Protection Agency
FHWA	Federal Highway Administration
FSUTMS	Florida Standard Urban Transportation Modeling System
FTP	Federal Test Procedure
HAR	Highway Advisory Radio
HBS	Home-Based School Trips
HBSO	Home-Based Shopping/Other Trips
HBSR	Home-Based Social/Recreation Trips
HBW	Home-based Work Trips

HC	Hydrocarbons
HDT	Heavy Duty Trucks
HOV	High Occupancy Vehicle
INFORM	Information for Motorists
ISTEA	Intermodal Surface Transportation Efficiency Act
ITS	Intelligent Transportation Systems
IVHS	Intelligent Vehicle Highway Systems
JPO	Joint Program Office
LDDA	Light Duty Diesel Automobiles
LDGA	Light Duty Gasoline Automobiles
LDT	Light Duty Trucks
LOS	Level-of-Service
MC	Motorcycles
MDT	Medium Duty Trucks
MOE	Measures of Effectiveness
MPO	Metropolitan Planning Organization
MSA	Metropolitan Statistical Area
NAAQS	National Ambient Air Quality Standards
NCHRP	National Cooperative Highway Research Program
NEMA	National Electrical Manufacturers Association
NHB	Non-Home-Based Trips
NMHC	Non-Methane Hydrocarbons
NOx	Oxides of Nitrogen
O-D	Origin-Destination Node Pair
PDO	Property Damage Only
RMS	Root-Mean-Square
RTP	Regional Transportation Plans

SIP	State Implementation Plans
SOV	Single Occupancy Vehicle
SWITRS	Statewide Integrated Traffic Records System (CALTRANS)
TASAS	Traffic Accident Surveillance and Analysis System (CALTRANS)
TCM	Transportation Control Measures
TDM	Travel Demand Management
TIC	Traffic Information Center
TIP	Transportation Implementation Programs
TMC	Traffic Management Center
TOC	Traffic Operations Center
TOD	Time-of-Day
TRB	Transportation Research Board
v/c	Volume-to-Capacity Ratios
VHD	Vehicle Hours of Delay
VHT	Vehicle Hours of Travel
VIDS	Video Imaging Detection Systems
VMT	Vehicle Miles of Travel