Intelligent Vehicle Highway Systems (IVHS)

Volume 1: Inventory of Models for Predicting the Emission and Energy Benefits of IVHS Alternatives

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ILLUSTRATIONS

I. INTRODUCTION

This report has been prepared by the Volpe National Transportation Systems Center (VNTSC) to provide the Federal Highway Administration (FHWA) with an early look at the inventory of forecasting models VNTSC is examining under task one of its program to develop a state-of-the-art analytical framework for estimating the fuel and emissions benefits of Intelligent Vehicle/Highway Systems (IVHS) initiatives. The material in this report will be included in the final report of task one to be completed in September 1992. The work reported here includes both an inventory of models and a substantive discussion of the major models. A comparative analysis of the models will appear in the final task one report.

Forecasting and estimation of fuel and emission benefits is usuallly accomplished using models of three types. The fuel and emission estimates are generated from a model or models designed for this purpose, referred to here as *emission* models. Emission models require as key inputs; Vehicle Miles of Travel (VMT), fleet composition, average vehicular speed and ambient temperature. Estimates or forecasts of VMT and average speed are generated by the second and/or third types of models. The second type of models are *traffic engineering* models which simulate or otherwise estimate speeds and vehicular flow rates. The third type of models are transportation planning models *(planning* models for short) which are used to make longer-term forecasts of VMT and average speed. An inventory and description of all three types of the models is presented in this report.

The fuel and emissions benefits generated by the analytic framework developed in this project will be used for two purposes. To aid FHWA in IVHS program planning, forecasts will be made of the fuel and emissions benefits of various individual and combined IVHS alternatives. To aid in FHWA's evaluation of operational tests of IVHS the analytic framework will be used to calculate emissions based on measured before and after parameters. Emission calculations are used for evaluation of operational tests because direct measurement of emissions is not financially feasible with the current technological state-of-the-art.

The IVHS initiatives with which this study is concerned are those under the general categories of Advanced Traffic Control Systems (ATMS) and Advanced Traveler Information Systems (ATIS).

IVHS initiatives will have short, intermediate and long range impacts on trip generation, trip origins and destinations, mode choice, trip timing and route choice. For IVHS initiatives which have short range impacts (i.e., impact daily decision making) in most cases only trip timing, route choice and mode choice are variable. Thus, traffic models plus a mode choice estimator provide sufficient input to the emission models. For intermediate range impacts (one to two year decision framework) only marginal changes in the origin-destination (C-D) pattern would be anticipated. If these changes are significant then use of the planning models would be required. For long range impacts (five to twenty years out) full use of the planning models is required since major shifts in trip generation can be expected.

This report summarizes the transportation planning model state-of-the-art in Chapter 1. Chapter 2 provides a similar review of traffic engineering models. Additional detail on the input and output variables for major traffic engineering models is provided in the appendix. Chapter 3 examines key emission and fuel estimating models.

II. TRANSPORTATION PLANNING MODELS AND DATA REQUIREMENTS

2.1 INTRODUCTION

The dynamics of transportation and land use, travel demand and traffic distribution, and travel behavior are the central elements in transportation planning models. The key system variables that frequently have profound and interactive effects upon transportation programs and policies (including those in many IVHS applications) are changes in travel demand, traffic patterns, and congestion levels among others, all of which have consequent impact on emissions and energy consumption. An analyst, in order to predict the effect of these variables upon a transportation program or policy, must accurately assess the scope of the analysis and the data requirements, and then select the proper analytic tools, procedures and algorithms for the analysis.

Transportation planning models deal with very large and complex systems and subsystems. The dynamic and interactive relationships among the system variables are described in a series of those models. The key variables in a transportation planning model system are:

- inter-modal transportation service variables, (e.g., service level, capacity, speed, congestion),
- socioeconomic demographic characteristics, (e.g., population and income distribution, vehicle ownership),
- land use patterns (e.g., housing and employment distribution, density),
- travel behavior (e.g., value of travel time and other travel costs, congestion endurance, drive-alone vs ride-sharing, etc.),

A complete analysis requires a process involving sequential steps of modeling and multi-level data analyses. The scope of the analysis can be either system-wide or confined to a small area, depending on the option under screening. The types of changes to be evaluated include, for example, capacity improvement programs, transportation control measures (TCM), highway or parking user fees, or IVHS applications. The proposed actions, either institutional or technical, should be quantified and adequately represented in the modeling framework. A good model should be sensitive to the policy variables, along with other system and behavioral components.

Transportation systems, particularly regional systems are, almost without exception, politically and geographically multi-jurisdictional. Under the flexible provisions of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), the analysis, in order to be comprehensive and complete, must be sensitive to transportation program plans and policies of the agencies. Federal, state, and local interagency cooperation and private-sector coordination becomes particularly important where linked-trip and intermodal travel is planned.

Selection of proper data required and its processing is sometimes more crucial than the models used. The quality of data often affects the quality of an analysis and dictates the selection of an analytic approach. Validation of models and monitoring of transportation system performance also requires continuing data collection and analyses. While a regional model usually requires detailed level of a range of socioeconomic and physical measure for travel demand forecasting, collection and maintenance of these type data at small zone level (traffic analysis zones) is often very costly and time consuming. It is no coincidence that most of the travel demand models are calibrated with data from household Origin-Destination (O-D) travel surveys that are conducted in the 1950's and 1960's and have since been infrequently updated using small sample sizes. The validity of these models and the results relying on out-dated O-D data would encounter more and more scrutiny and legal challenge in a fast changing legislative and urban environment

Ideally, a comprehensive transportation data and modeling system should be comprised of two parts:

- a database containing the basic socioeconomic, land use, and transportation data that describes the current state and historical patterns of the region to be analyzed. There should also be routine procedures, likely interfacing with Geographic Information Systems (GIS), to present the system measures in an organized manner that can show the geographic and historical changing patterns of the region.

- a modeling structure consisting of multi-level analytic modules. The modules are logically designed and systematically integrated with one another to represent a realistic framework. The modeling system should be flexible to permit a variety of incremental policy analyses or long-range planning. In order to meet the analytical objectives, the modules should embody policy-sensitive and behavior-oriented variables to predict the effects resulting from a range of system changes including modification of the roadway network, institutional or technical changes, and behavioral patterns.

In addition to specially designed transportation demand and performance modules, the system should provide more generalized statistical or analytic procedures using GIS capabilities. An analysis can often be achieved more efficiently using a trend analysis method if a time-series database and timely-updated transportation system performance monitoring information are available. The geographic distribution and changing pattern of the system variables can be effectively represented in a graphically-oriented GIS system.

In this report, data and models are reviewed separately. Their linkages within and across each step of the modeling will be discussed later. New development and direction for improvement of the existing data and modeling system will be indicated as it is related.

2.2 CLASSIFICATION OF MODELS

This section describes several classes of transportation planning models. Figure 2-l describes the linkages and logical sequence of the models. While the conventional 4-step travel demand models have been the central part in the practice of transportation planning models, more attention will be increasingly emphasized on the enhancement of other model components and the integration with dstep travel demand models. Figure 2-l illustrates a dynamic, interactive process of urban economic development and transportation demand. It also indicates in the feedback loops the impact of traffic congestion on travel behavior and land use decisions. The variables *listed* on the right column under *ECONOMIC/TRAVEL BEHAVIOR VARIABLES* represent the key underlying factors in the dynamic process. While some of these variables are represented well in the model structures or parameters to reflect the dynamics of a real transportation system, many others are not well captured in the models. It is important to recognize the limitations and the necessary adjustments in the use of these models.

On the left column of Figure 2-l under *TECHNOLOGICAL VARIABLES,* new technologies, specifically focusing on IVHS systems in the areas of ATIS, ATMS,APTS, and AVCS, are linked to various aspects of travel behaviors and different phases in transportation planning models. It is unclear though to what extent each IVHS alternative would affect travel behavior and ultimately enhance the overall system performance.

While few of the existing transportation models are designed to fully address the time-varying aspect of an M-IS alternative and the effectiveness of these technologies on travel behavior and traffic pattern, it is suggested in the diagram that the impacts of an IVHS deployment would most likely occur on mode choice, route diversion, time of travel, and the enhancement of flow control strategies as the real time traffic information becomes more available and accurate. In order to quantify and assess the effectiveness and benefits of an MIS alternative in these areas, it is essential to further develop the understanding and definition of each M-IS technology and its operating characteristics for the incorporation of those variables into the modeling process.

In Figure 2-1, land use and socioeconomic forecasts are typically treated as exogenous variables and input to trip generation and trip distribution models. They are also frequently used for updating existing O-D trip tables. The 4-step travel demand models in the middle box (explained in more detail in Section 2.2.1) involve an iteration process and produce vehicle miles travelled (VMT) and average speeds at the link level. The impacts of transportation level of services on land use changes are usually perceived as a long term effect and are captured in some conventional land use and transportation models, relative to other economic factors, land use policies, and spatial constraints.

The effect of congestion is, however, more frequently focused in transportation network equilibrium and impact on emissions and fuel consumptions on a near term. As the network descriptions for traffic assignment in a conventional network model is usually simplified for the network representation at a system level, more accurate network simulation of changing

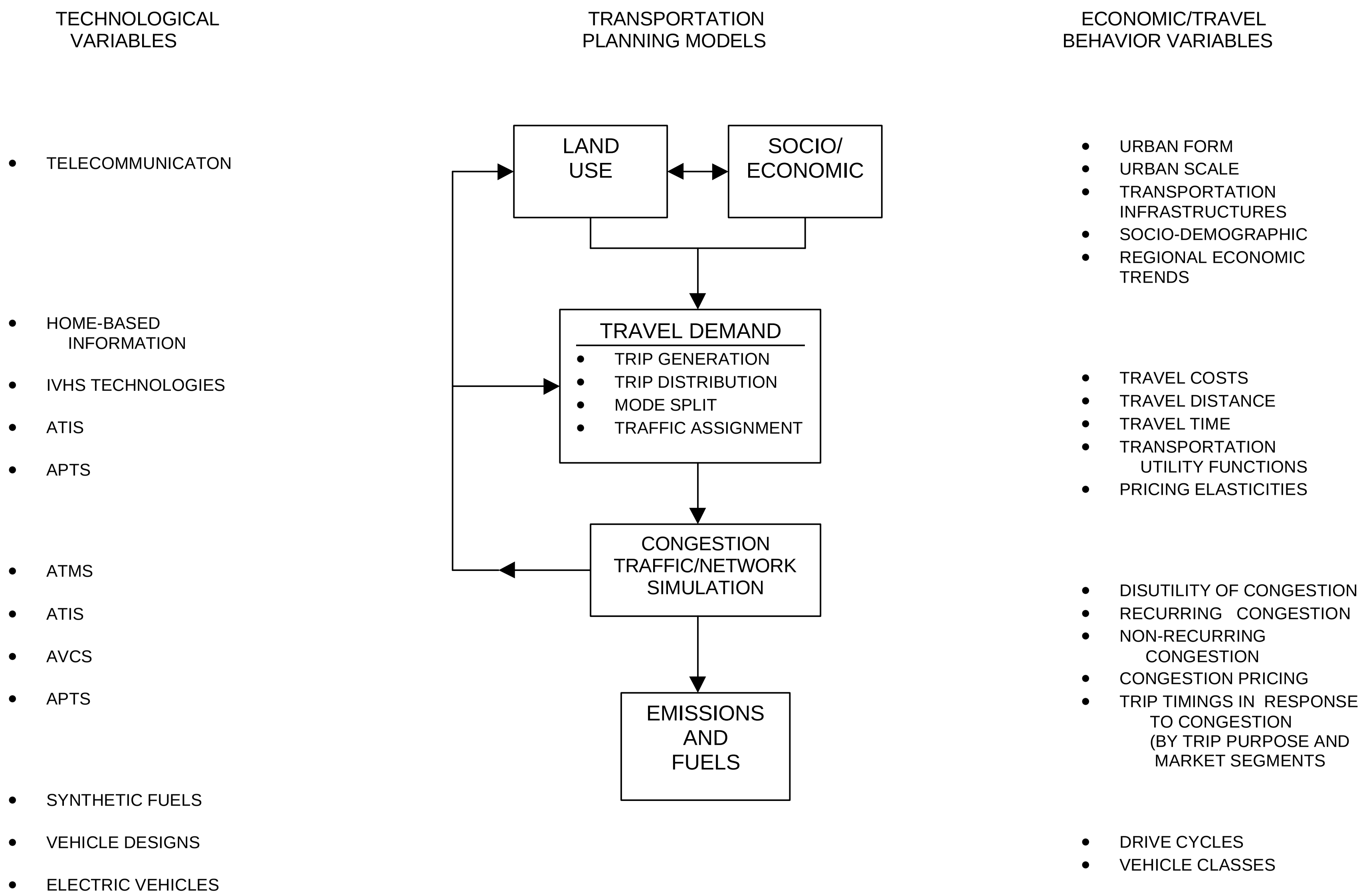

Figure 2-1 Linkage of Transportation Models for Estimating IVHS Emissions and Fuel Benefits

traffic patterns in response to varying traffic congestion would be performed more effectively on a time-dependent traffic simulation model. The review of the state-of-art traffic simulation models, as well as emissions and fuel consumption models will be discussed in more detail in the sections following the discussion of conventional transportation planning models.

2.2.1 Four-Step Transportation Planning Models.- The conventional transportation planning models describe urban travel demand in a Cstep modeling process as trip generation, trip distribution, mode split, and traffic assignment. The dstep process outlines an analytic framework with a logic sequence involving key control variables and the interrelationships between urban economic activities, trip making, and travel demand choices. It is established as a standard transportation modeling process (i.e., the UTPS) and widely used for forecasting urban travel demand (e.g., VMT) and transportation level-of-service performance measures at the link level (e.g., traffic volume vs. designed capacity).

Although the models are aimed, straightforwardly, for projecting inter-zonal traffic flows (O-D matrix) and spatial and temporal distributions among alternative modes (mode split) and traffic routes (traffic assignment), the underlying variables and interrelationships are complicated and often overly simplified in the models. Model assumptions, key parameters, and data requirements have to be frequently adjusted in order to reflect different conditions in modeling applications.

Figure 2-2 describes the Cstep process with an iteration loop that goes back to the step of trip distribution. It shows an equilibration process that, ideally, the speeds calculated from the network traffic assignment would be feedback to the steps of trip distribution, mode split, and traffic assignment. The iteration will continue until reaching an equilibration in which the speeds are consistent throughout the 4-step process. While this level of equilibration is highly desirable, it is rarely performed this way in practice. Most often the iteration is performed within the assignment and sometimes the feedback returns to mode split step depending on the network characteristics and the level of multi-modal analysis.

As there are many regional models which are developed or modified by the state transportation planning agencies or Metropolitan Planning Organizations (MPO) to reflect the regional land use and transportation characteristics, it is not an intent of this report to cover a complete inventory of all the existing models and compare their differences. Instead, the general characteristics and the structure of the Cstep modeling process are described in this section as follows:

a. **Trip Generation** describes the level of travel demand as a function of the land use patterns and household structures. It uses demographic and land use forecasts as input to predict trip productions and trip attractions. A trip generation model includes variables such as number of workers in a household, income level, number of cars owned to estimate trip production. Land use density and employment size are used to estimate trip attraction. The household level trip generation propensity is subsequently aggregated to the zone level.

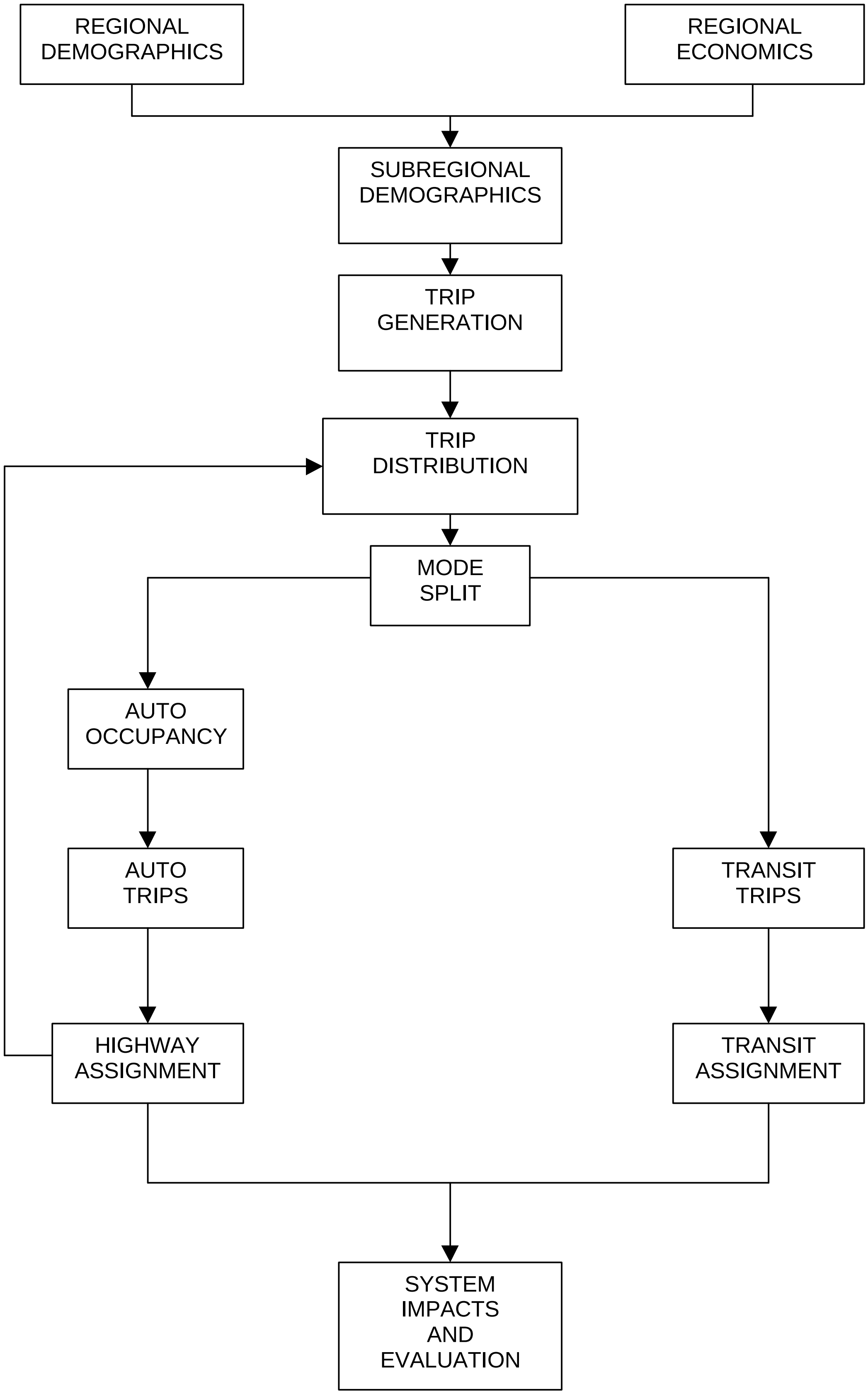

Figure 2-2. Conventional Four-step Travel Demand Models

transit incentives/disincentives, etc. There is no given way to measure and forecast these variables as land use development depends on several factors such as jobs, housing markets, urban design policies, zoning regulations, etc. The forecasts should, however, reflect regional trends and development patterns in a consistent way.

Key Variables

- housing units and growth forecasts,
- commercial and retail floor area,
- employment and floor-area ratios,
- commercial and retail-occupancy rates,
- parking/public transit availability, and
- densities.

Secondary Variables

- zoning,
- land use policies (growth management),
- tax revenues and revenue predictions, and
- parking/public transit incentives/disincentives.

2.3.3 Origin-Destination Trip Tables.- Origin-Destination (O-D) trip tables are based upon household O-D travel surveys and forecasted from trip generation and trip distribution models. The personal trip tables are designated by trip purpose (e.g., home-work/work-home, home-shop/shop-home), and by time-of-day (TOD). Personal trip tables are further divided by modes and converted into vehicle trip tables by vehicle occupancy rate and transit ridership factors.

Key Variables

- Origin-Destination trip volumes,
- time-of-day,
- trip purpose,
- minimum time path/travel length,
- minimum travel time,
- average speed,
- alternative travel routes.

2.3.4 Transportation Network Descriptions.- This subsection discusses the highway and transit networks, their nodes and linking between nodes, and the variables affectcting the networks.

a. Highway network.- The highway network is represented in a network map and a database which is comprised of numerous nodes and links. Each node is an intersection, highway ramp, zone centroid, or a transportation facility. Each link is a segment between two nodes with a number of attributes such as the designed capacity, speed, highway class, length, etc. With the more expanded computer speed and storage, along with the interface with graphic capability, the variations in zone and network scale associated with different levels of attributes and problems can be dealt with and displayed in a desk top computer environment. Note that for urban area analysis only the major streets and highways are included in the models.

Key Variables

- node characteristics:

  - node type,
  - intrazonal access time.

- link attributes:

  - facility type,
  - link length,
  - design capacity, and
  - design speed.

Secondary Variables

These more detailed network descriptions are important for micro-level traffic analyses and modeling.

- intersection signal control,
- phasing,
- geometric,
- turn restrictions, and
- turn bays.

b. Transit network.- Transit network data elements include: terminal stations, starting and ending nodes, routes, intermediate stops, intermodal transfer points, access times, link times, parking facilities, service schedules, etc. Transit service characteristics and performance measures include items such as access time, frequency, headway variance and reliability, or ridership factors. The FTA's Section 15 data provides the guidance for data requirements and data collection methods.

Transit Network and Service Variables

- terminal descriptions:

  - number of service routes,
  - fleet management, and
  - intermodal transfer.

- route descriptions:

  - starting node (access time, parking facility)
  - ending node (access time, parking facility)
  - intermediate stops (access time, parking facility)
  - service frequency,
  - transit fare structure,
  - route length,
  - link travel time, and
  - route travel time.

Transit Service Performance Variables

- by terminal or route:

  - access time,
  - headway time,
  - headway variance, and
  - ridership vs capacity.

2.4 NATIONAL DATA SOURCES

There are several key national data bases that provide supplementary but valuable information to the primary regional level data sources as described above. The contents and current state of each data base are described as follows:

2.4.1 Nationwide Personal Transportation Study (NPTS).- The NPTS is a nationwide inventory of households to determine the residents' travel characteristics on a typical day. The survey has been conducted on a 5- to 7-year basis since 1969. The travel characteristics collected include person-trips for all mileage by all modes. It also includes various other socioeconomic and demographic data related to subsequent analysis of travel characteristics. The NPTS is the only nationwide continuing, comprehensive survey of personal travel. It provides a valuable resource for current personell travel characteristics and for assessing trends in these travel characteristics over time. The 1990 survey collected 18,000 households spread over 12 months. In addition to these sample households included in the national database, arrangements have been made available for interested MPO's to acquire enhanced samples for their respective regional studies.

2.4.2 Highway Performance Monitoring System.- The Highway Performance Monitoring System (HPMS) was established by FHWA in 1978, and has become a comprehensive, and comparable national data system. The HPMS provides basic information on all highway mileage in the nation, and includes detailed information supplied from states such as extent, functional classification, jurisdictional responsibility, usage, pavement type, condition, performance, and operating characteristics, etc. Depending upon the needs and funding resources, each state also collects information on more roads and additional information such as vehicle classification, truck weight, traffic counts, flow speeds, etc.

HPMS has been used as a monitoring mechanism for the real-time checks on traffic counts and VMT forecasts. Data collection and representation in HPMS is generally good for interstate highways but less adequate for primary and secondary roads. Local systems are not well covered because of limited data samples and reporting difficulties.

There is an increasing need for improving the database in order to meet the more demanding data requirements from the CAAA and ISTEA. The system will be requested to include more data samples and detailed traffic information such as link volumes, speeds, vehicle mixes, locations of frequent stops, and accelerations, etc. Improved data collection and sampling are likely to be achieved through IVHS technologies such as automatic surveillance and vehicle identification systems.

Key Variables

- physical highway characteristics,
- link vehicle volumes,
- link average speeds,
- link vehicle mixes.

Secondary Variables

- number of accelerations,
- locations of cold starts (parking facilities and usage),
- congestion patterns.

2.4.3 Truck Movements.- The Truck Inventory and Use Survey (TIUS) and the Nationwide Truck Activity and Commodity Survey (NTACS), conducted by the Bureau of the Census and financed through FHWA, are the two primary sources of the nation's truck fleet and flow patterns. The TIUS provides data on the physical and operational characteristics of the nation's truck fleet and developed from a sample of private and commercial trucks drawn from vehicle registration files for all 50 states and the District of Columbia. The NTACS is a follow-on to the TIUS and measures detailed trip characteristics and other information for trucks on randomly sampled days. The NTACS provides the only effective, empirical link between data on truck characteristics, travel patterns, commodity flows, and highway condition.

Key Variables

Truck Inventory and Use Survey (TIUS)

- average weight,
- maximum gross weight,
- annual miles of travel,

- miles per gallon,
- products carrier,
- areas of operation,
- type of truck configuration, and
- type of motor carrier.

Nationwide Truck Activity and Commodity Survey (NTACS)

- origin-destination,
- vehicle type,
- shipment., and
- other economic characteristics.

2.4.4 Highway Capacity Manual.- The TRB Committee on Highway Capacity and Quality of Service is continuing to update and revise the analysis procedures contained in the 1985 Highway Capacity Manual (HCM). The HCM provides guidance to transportation planners in developing average speeds for projected facilities. A new chapter in the HCM uses free-flow speed for establishing the volume-speed-density relationships for multi-lane highways in suburban and rural areas. The input factors include:

Key Variables

- density, and
- free-flow capacity.

Secondary Variables (or Adiustment Factors)

- lane width,
- lateral clearance,
- median type,
- access points,
- peak-hour factor, and
- heavy vehicles.

III. TRAFFIC SIMULATION MODELS

3.1 INTRODUCTION

These are models that are used by traffic engineers to help test out a design or design changes. Some of these changes will be either signalization, sign or other type of control changes to either urban street networks, corridors or freeways. Another change could be adding or deleting lanes or changing the characteristics of ramps on freeways. Other possibilities include adding or removing turn pockets from urban streets, using arterials as alternate routes, and a host of other possibilities including some of the new emerging IVHS alternatives.

This simulation approach is far more appealing and practical than a strictly empirical approach for the following reasons:

- It is less costly.
- Results are obtained in a fraction of the time required for field experiments.
- The data generated by simulation include many MOE that cannot, in a practical sense, be obtained empirically.
- Disruption of traffic operations, which often accompanies a field experiment, is completely avoided.
- Many projects require significant physical changes to the existing facility; such changes simply are not acceptable for field experiments.
- Analyses addressing the operational impact of projected traffic demand patterns must be conducted by simulation or equivalent tools. Simulation provides the highest level of detail and accuracy of any existing technique.

Traffic simulation models are very complex computer programs and they require a great deal of work to accurately model a real life situation. The first major requirement of these models is a complete and accurate description of the road network under study. The level of detail required will vary somewhat between microscopic and macroscopic models. The major difference between the two is that the microscopic model is a time stepped simulation of every vehicle in the network. The macroscopic models on the other hand are event stepped, in other words the step is determined by an event, such as a vehicle arriving at a node. The macroscopic models need much less computation and not such a great level of detail describing the network. They all include in their output various Measures of Effectiveness (MOE's) to determine how various alternative strategies work. After all the data is input the model has to be calibrated, that is, the model has to be run against real world measured data to see if it performs the same as in the real world.

Six models have been chosen to go into detail about, they are: CORFLO, FREQ, FRESIM, INTEGRATION, ROADSIM, and NETSIM. These are not the only models available, however, they are the most widely used and the most suited to our purpose of examining M-IS benefits. It should also be noted that the set of arterial analysis tools such as: PASSER, TRANSYT, SOAP, and others generate traffic signal timings. These tools are used to optimize signal timings for intersections. These tools could generate signal timings to be input into our other models such as NETSIM. These arterial analysis tools don't readily lend themselves to the analysis of networks.

These models can be grouped together by type to further show how they are used. The corridor models are CORFLO and INTEGRATION. CORFLO consists of three sub-models NETFLOl, NETFL02, and FREFLO they are all macroscopic models NETFLOl and 2 are concerned with urban street networks and FREFLO with freeways. INTEGRATION is a combination micro - macro model. The freeway models are FREQ and FRESIM . FREQ is macroscopic while FRESIM is microscopic. FREQ also has the edge over FRESIM in evaluating ramp metering strategies and HOV lanes. FRESlM is better than FREQ at determining how arterials can be used as alternate routes and how incidents effect freeway traffic. There is the defacto standard rural road simulation ROADSIM. Finally, we have the urban street network defacto standard NETSIM.

Some of these models produce emission outputs these models have used different sources to determine their emissions modeling. NETSIM, CORFLO, and FRESIM uses emission modeling developed from a study done by Oak Ridge National Labs in 1985. The only other model that produces emissions outputs is FREQ based on 1980 emission rate tables for the 49 states and a separate table for California

Detailed inputs and outputs for all of the discussed models can be found in Appendix A.

3.2 CORFLO

3.2.1 Description.- CORFLO is a group of models used for analyzing transportation corridors. This group consists of three models:

- NETFLO 1, a macroscopic event based surface street network simulation model,
- NETFLO 2, a macroscopic platoon based surface street network simulation model and,
- FREFLO a macroscopic freeway simulation model.

The three models share a common traffic assignment model.

3.2.2 Background Information.- FREFLO's predecessor model was MACK which used a conservation equation and an equilibrium speed-density relationship. FREFLO includes a refinement in the equilibrium speed-density relationship in that it is dynamic. The FREFLO model involves two significant extensions beyond the earlier MACK model; (1) the restriction to a single linear segment has been removed: a fairly general network, including disjoint segments is now accommodated; (2) buses, carpools, autos and trucks are distinguished as three distinct vehicle types.

This model was developed to be used as a tool of traffic engineering. Traffic management places emphasis on optimizing urban resources to improve the movement of people and goods without -impairing community values. When a traffic system is represented by a computer simulation model, the effects of traffic management strategies on the 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 stops, vehicle-miles of travel, average queue length and fuel consumption. Thus, any strategy can be evaluated by analyzing these MOE. In addition, the MOE can provide valuable insight into the responsiveness of the traffic stream to the applied strategy; this insight, in turn, can provide the basis for optimizing the strategy.

3.2.3 NETFLO 1.- This is an event-based simulation of traffic operations. The traffic stream is modeled explicitly, each vehicle on the network is treated as an identifiable entity. Furthermore, each vehicle is identified by type, (i.e., auto, carpool, truck, bus), and a "driver behavioral characteristic" (passive, aggressive) is assigned. In addition, its kinematic properties are determined, as well as its status (queued, free flowing), turn movements are assigned stochastically, as are its free-flow speed, queue-discharge headways and other behavioral attributes. Consequently, each vehicle's behavior may be simulated in a stochastic manner, reflecting real world processes.

Each time a vehicle is moved by the program logic, its position (both lateral and longitudinal) on a network link and its relationship to other vehicles nearby is determined.

Actuated signal control and bus-auto interaction may be modeled. Most conditions experienced in an urban traffic environment can be realistically described.

This treatment appears to be comparable to that of the NETSIM microscopic traffic simulation model. The NETF'LO 1 model, however, differs in detail from NETSIM in many ways. The most important difference is the level of detail of the individual vehicle movements. NETFLO 1 moves each vehicle intermittently (i.e., whenever an "event" occurs), and moves that vehicle as far downstream as possible in a single "jump". No car-following logic is employed. Hence NETF'LO 1 does not generate detailed vehicle trajectories.

In summary, the NETF'LO 1 is a simplified treatment of individual vehicles in the traffic stream which describes the traffic environment at a lower level of detail than NETSIM. It produces the same MOE output as does NETSIM, with far lower requirements for computer resources.

3.2.4 NETFLO 2.- This model produces output MOE similar to NETFLO 1 and NETSIM NETF'LO 2 was adapted from the TRANSYT (Traffic Network Study Tool) flow model. Inputs were simplified and the ability to handle time varying traffic flow and multiple cycle lengths were added. TRANSYT use constant traffic volumes and one uniform cycle length for traffic signals.

The traffic stream is described in terms of a set of link-specific statistical flow histograms. These histograms describe the platoon structure of the traffic stream on each network link. The NETFLO 2 logic identifies five types of histograms:

The entry histogram describes the platoon flow at the upstream end of the subject link. This histogram is simply an aggregation of the appropriate OUTPUT turn movement specific histograms of all feeder links.

The input histograms describe the platoon flow pattern arriving at the stop line. These are obtained by first disaggregating the ENTRY histogram into turn movement specific component ENTRY histograms. Each such component is modified to account for the platoon dispersion which results as traffic traverses the link. The resulting INPUT histograms reflect the specified turn percentages for the subject link.

The service histograms describe the history of discharge service rates for each turn movement component of traffic, reflects the control device applied at the intersection.

The queue histograms describe the history of queue length (vehicle content) over time for each turn movement component of traffic.

The output histograms describe the pattern of traffic discharging from the subject link. Each of the INPUT histograms interacts with its associated SERVICE histogram and is transformed into an OUTPUT histogram by the control applied to the subject link. Each of these OUTPUT histograms is then added into the ENTRY histogram of its receiving link.

These histograms are generated to represent the flow of traffic on each link for each time interval.

Buses are treated as separate entities. Their travel time along each link is computed by employing kinematic relations and includes the effect of dwell time at stations. This treatment is at a lower level of detail than is used in NETFLO 1 for buses. The interaction of buses with general traffic is explicitly treated, however, cat-pools are NOT modeled. Also, traffic congestion is treated explicitly along with blockage due to spillback.

Since trucks cannot be modeled explicitly in a platoon dispersion model, their effect is accounted for by adjusting queue discharge rates based on their impedance of traffic flow

3.2.5 FREFLO-. This model is a macroscopic simulation model that represents traffic in terms of aggregate measures on each section of freeway. The aggregate measures used are flow rate, density, and space-mean-speed within each section.

FREFLO uses a conservation equation and an equilibrium speed-density relationship. A fairly general network including disjoint segments is accommodated. Buses, carpools, autos and trucks are distinguished as three distinct vehicle types.

Traffic flow is described in terms of aggregate measures associated with freeway sections. For each freeway section, entry flow rate, exit flow rate, density, and space-mean-speed are simulated. Further, these variables are distinguished by vehicle type.

Vehicles enter the freeway sub-network either at the upstream end of a freeway segment or through on-ramps. In the latter case, it is to be noted that FREF'LO represents the movement on the freeway mainline only, so that vehicles are introduced at the ramp gore and immediately merged. There are no connectors or ramps in the middle of the link.

Vehicles exit the freeway sub-network at the downstream end of a freeway segment, or through off-ramps. FREFLO does not model the dynamics of traffic on ramps except when the user explicitly requests it by coding the ramps as links rather than as ramps.

There are two types of lanes in FREFLO: (1) special purpose high occupancy vehicle (HOV) lanes that can be designated for use by buses and/or carpools, and (2) regular lanes that accommodate all other traffic and all vehicle types, including buses and carpools. Vehicles are not associated with a particular lane of traffic, but are considered to be uniformly distributed over the special purpose and regular lanes, separately. The number of lanes of each type is specified by the user.

The network which can be represented is quite general. The sub-network can consist of sections which are not physically connected. Freeway-to-freeway connectors, involving merge and diverge points, are simulated. Several connected freeways can be accommodated.

Bus traffic is handled in two steps. First, upon introduction at an entry node as an individual bus, a bus is "moved" individually through the freeway sub-network accumulating the transit time, and placed in the exit node with the appropriate time of arrival. Second, the bus is added to the bus entry flow rate so that proper accounting of the buses' impact on the aggregate measures can be made.

Carpools as a second vehicle type, and autos and trucks, together as a third vehicle type, are represented by the aggregate variables only.

Turn percentages, applicable to traffic exiting each section, apply to all vehicle types. However, restrictions on use of special purpose lanes are taken into account. This last feature can be used to provide for turn percentages specific to special purpose and to regular vehicles separately.

FREFLO provides for representation of an incident on the freeway. This is accomplished by allowing for the specification of a reduced number of lanes available and a constraint on the flow rate past the incident site.

3.2.6 Additional Model Information

a. Model Source

CORFLO is not released yet but when it is it will be available from:

McTrans
Center for Microcomputers in Transportation
University of Florida
512 Weil Hall
Gainesville, FL 32611
(904) 392-0378

or

PC Trans
Kansas University Transportation Center
2011 Learned Hall
Lawrence, KS 66045
(9 13) 864-5655

b. Agent for Maintenance and Upgrades

Same as source

c. Current Acquisition cost

CORFLO with graphics drivers	$350.00
CORFLO without graphics drivers	$ 250.00
Documentation	$ 50.00

d. Development Status

Currently unavailable from McTrans and PC Trans. FHWA has released the model to McTrans and PC Trans and they will release it in the Fall of 1992.

e. Data Requirements

These model is not as data intensive as NETSIM because it is a macroscopic model not a microscopic model.

f. Known Linkages to Other Models

It has linkages to all the TRAF family of models this includes: NETSIM - a microscopic urban street network model, FRESIM - a microscopic freeway model; which is under development, and ROADSIM - a microscopic rural road model; which is not integrated under the PC user interface, Traffic Software Integrated System (TSIS) which was developed by the FHWA and is a utility program that provides a user friendly, menu-driven environment for accessing these traffic engineering and design tools that are from FHWA, as of yet.

3.3 FREQ

3.3.1 Description.- The model is macroscopic and is intended to evaluate a directional freeway and its ramps on the basis of ramp origin-destination (O-D) information. Diversion to parallel alternatives is considered for vehicles queued at on ramps. There are two major sections of the model FREQlOPL for the evaluation of lanes on freeways reserved for carpools or buses, or both, and FREQlOPE for the evaluation of priority and normal entry control.

The major input is a set of O-D tables for each interval. These tables correspond to volumes or percentages of various vehicle-occupancy classes. The model can calculate the effect of weaving on capacity, and speed-flow relationships can be selected by the user. Ramp characteristics, including ramp metering, must also be described. FREQ will predict a time stream of impacts that includes both spatial and modal traveler responses. FREQ will also output freeway performance tables containing travel time, speed, ramp delays and queues, fuel consumption, and emissions gaseous and noise.

The priority entry section will optimize a control strategy through linear programming and predict traffic performance and traveler demand responses. The model will also output metering plans, contour maps, and impacts of priority-lane operation.

3.3.2 Background Information.- Demand-supply modeling efforts for freeway corridor operating environments were initiated in 1968 at the Institute of Transportation Studies, at UC-Berkeley, when a CALTRANS research project required the evaluation of alternatives for improving 140 miles of the existing San Francisco Bay Area freeway system. Because the existing freeway network was too extensive and the alternative improvements too numerous to consider manual analysis, a freeway computer model was developed. This first model, called FREQ or FREQl, was a forerunner of a family of deterministic macroscopic models for a linear directional freeway corridor, which has now reached a tenth-level version. of particular interest is the split of the model at the version 6 level into two separate models: FREQ6PL for the evaluation of HOV lane(s) and FREQ6PE for the evaluation of priority entry. The addition of SYNDOM, a synthetic O-D trip table generator, was added in 1987. The latest version of both models, FREQlOPL and FREQlOPE, run on the IBM PC with an integrated interactive interface.

FREQIOPL, a freeway priority lane simulation model, belongs to the FREQ family of freeway corridor models and is based on two of the existing models: FREQ8PL, a mainframe priority lane model and FREQlOPE, an IBM PC priority entry model. FREQlOPL maintains the original structure of the FREQ8PL model but contains many enhancements and revisions. FREQlOPL has an upgraded simulation module that incorporates the features of the more advanced simulation module of FREQlOPE, a new spatial shift module, a revised modal shift module, and a new HOV performance evaluation index.

3.3.3 Additional Model Information

a Model Source

University of California, Berkeley
systems unit
Institute of Transportation Studies
109 McLaughlin Hall
Berkeley, CA 94720
(510) 642 - 1008

b. Agent for Maintenance and Upgrades

Same as source

c. Current Acquisition cost

FREQ lO complete package for microcomputer	$500.00

d. Development Status

Currently available.

e. Data Requirements

This model is very data intensive it is approximately as data intensive as FRESIM.

f. Known Linkages to Other Models

Linkages to its own internal utility models such as synthetic O-D tip generation. No linkages to external models

3.4 FRESIM

3.4.1 Description.- FRESIM has been developed for use in studying freeway incident detection and control strategies. It is based on knowledge of freeway operations and surveillance systems and incorporates detailed traffic simulation logic developed and validated for this purpose.

To allow simulation of freeway control policies, including ramp metering and diversion, the capability of modeling the off-freeway environment is included in FRESIM. This "surface" traffic modeling is patterned after the logic of the UTCS-1 simulation model.

To facilitate the simulation of closed loop incident detection and control, as well as off-line traffic analysis, the FRESIM model contains a realistic surveillance system simulation capability. The ability to visualize vehicle trajectories, and contours of Measures Of Effectiveness (MOE's) in the time-space plane, is included in FRESIM via a digital plotting module, FRESIM also contains a statistical analyses module which permits comparison of MOE's from different simulation runs or field data, utilizing standard parametric and non-parametric tests.

Finally, a fuel consumption and vehicle emission evaluation module is built into FRESIM patterned after a similar module developed for the UTCS-1 simulation model.

3.4.2 Background Information.- FRESIM is developed directly from the INTRAS model used for the Roosevelt bridge study. FRESIM is basically INTRAS with modifications made to incorporate the model into the TRAF family.

3.4.3 Additional Model Information.-

a. Model Source

FRESIM is not released yet, but when it is it will be available from:

McTrans
Center for Microcomputers in Transportation
University of Florida
512 Weil Hall
Gainesville, FL 32611
(904) 392-0378

or

PC Trans
Kansas University Transportation Center
2011 Learned Hall
Lawrence, KS 66045
(913) 864-5655

b. Agent for Maintenance and Upgrades

Same as source

c. Current Acquisition cost

Currently unavailable for sale.

d. Development Status

Currently unavailable from McTrans and PC Trans. FHWA has not released the model to McTrans and PC Trans. The model is still under development by FHWA and is not ready for release. It might be ready for release by January 1993.

e. Data Requirements

This model is extremely data intensive. It could be described as the freeway equivalent of NETSIM.

f. Known Linkages to Other Models

It will have linkages to all the TRAP family of models this includes: NETSIM - a microscopic urban street network model, CORPLO - a macroscopic corridor model; which is made up of: NETPLO 1 - a macroscopic urban network model, NETFLO 2 - a macroscopic urban network model, & FREFLO - a macroscopic freeway model, ROADSIM - a microscopic rural road model.

3.5 INTEGRATION

3.5.1 Description.- The INTEGRATION traffic simulation model was developed to analyze a number of specialized problems related to the operation and optimization of integrated freeway/arterial traffic networks, real-time traffic control and route guidance systems. INTEGRATION was developed to address the problems of the busiest traffic networks which consist of a mixture of both freeway sections and traffic signal controlled surface streets. During peak traffic conditions and/or incident situations, congestion on one component of these networks will often spill over onto an adjacent network component. Under these circumstances these networks cannot be considered or controlled in isolation, but instead they need to be treated as an integrated unit. In other words, freeway control problems need to be examined in light of their impact on parallel arterials, while traffic signal problems may have to be considered in view of the surrounding freeways.

Due to the different characteristics of traffic flow that need to be modeled on freeways and at traffic signals, INTEGRATION analyzes traffic flows in terms of vehicles which are individual entities. This microscopic approach permits a traffic flow representation which is not only common to both types of component networks, but also permits a continuous dynamic queuing-based traffic assignment The model operates at essentially a macroscopic level because it steps models through links.

The common traffic flow representation is critical to modeling all network components in a consistent and compatible fashion, while the queuing-based dynamic traffic assignment technique is essential to dealing with diversion and re-routing of traffic during congestion and in response to any incidents. The model's consideration of individual vehicles is primarily for purposes of improving the analysis resolution during the model's internal calculations. However, it does not necessarily require the user to collect or input data at the individual vehicle level. Instead, traffic flow characteristics and traffic demands can be specified by the user at an aggregate level, leaving it to the model routines to derive the more microscopic measures.

The INTEGRATION model allows the analyst to specify any traffic flows in terms of any combination of five different driver/vehicle types. These different vehicle types are not intended to represent trucks, buses or passenger cars, Instead, they refer to the capability to represent different routing behavior or different access privileges to travel time information for each vehicle.

3.5.2 Background Information.- During a period of time from 1984 to the present, the INTEGRATION simulation model, for modeling dynamic traffic networks and controls, has been under development by Dr. Michel Van Aerde and his team of graduate and undergraduate students at Queen's University in Kingston, Canada. This development has been sponsored, in part, by the Ontario Ministry of Transportation, General Motors Research

Labs, Queen's University and the Natural Sciences and Engineering Research Council of Canada.

The INTEGRATION traffic simulation model was developed to analyze a number of specialized problems related to the operation and optimization of integrated freeway/arterial traffic networks, real-time traffic control and route guidance systems.

Despite the obvious need for integrated control, to date there has been a general lack of models which can appropriately model the coexistence and interaction of freeways, traffic signals, the routing/diversion between them, and the concurrent presence of IVHS technologies. Most existing models concentrate either on one sub network or the other, on IVHS technology or traditional traffic management, and consequently fail to adequately consider their important interactions. In response to this need for improved modeling of integrated networks, a modeling approach, called INTEGRATION, was developed.

3.5.3 Additional Model Information

a. Model Source

Michel Van Aerde and Associates
Department of Civil Engineering
Elis Hall
Queens University
Kingston, Canada K7L 3N6
(613) 545-2122

and/or

Ontario Ministry of Transportation
Transportation Technology and Energy Branch

b. Agent for Maintenance and Upgrades

Same as source

c. Current Acquisition cost

INTEGRATION: Integrated Traffic Simulation Model, $15,000

also available are:

QUEENSOD: Dynamic Synthetic O-D Generator, $5,000

ASSIGN: Pseudo-Dynamic Macroscopic Equilibrium Assignment Model, $5,000

DYNAMIC: Fully Dynamic Macroscopic Equilibrium Assignment Model $5,000

REAL-TRW: SCOOT-like Real-Time Signa Control Emulator, $5,000

d. Development Status

Currently available.

e. Data Requirements

This model is the least data intensive of any other combination of models that would come close to be similar to INTEGRATION: such as FRESIM used with NETSIM used with CORFLO.

f. Known Linkages to Other Models

None.

ROADSIM

3.6 ROADSlM

3.6.1 Description.- ROADSIM is a microscopic two-lane traffic simulation model. ROADSIM can evaluate traffic movement and report the measures of effectiveness affecting the flow of traffic on a two-lane highway. The simulation is performed using detailed information about each individual vehicle trajectory updated once every second (time-scan simulation).

Specifically, each vehicle in the traffic stream is treated as an individual entity which is moved once every second of simulated time. A vehicle’s movement is determined by many factors including its response to a lead vehicle’s movement, limitations imposed by the vehicle’s operating characteristics (i.e., its acceleration and deceleration capabilities, length, speed) and effects of local geometry (i.e., horizontal and vertical curvature, and sight distance).

In addition a vehicle may “decide” to initiate a passing movement, to extend a passing movement being undertaken or to terminate a passing movement. These decisions also depend on many factors including the deployment of oncoming vehicles, availability of passing sight distance, the presence of a permissive passing zone, driver aggressiveness, impeder speed, the platoon structure of lead vehicles downstream, local geometry, and vehicle operating characteristics.

Since ROADSIM is part of the TRAF family of models it shares the link-node notation. The nodes in ROADSIM are used to represent points where the geometry changes in some significant manner (e.g., a change in curvature or grade). The user may also specify up to 16 different vehicle types, each with specified operating characteristics.

The statistics gathered by the ROADSlM describe traffic operations in great detail. Many vehicle-type-specific, link-specific, direction-specific and overall measures of effectiveness are provided. In addition, data specific to the rural road environment are presented. These include a breakdown of travel time and delay according to source (i.e., due to geometric features and to impedance by other elements of the traffic stream) and passing statistics (passes attempted, completed, and aborted). Other statistics include distributions of speed, headways, and platoon sizes at locations specified by the user.

3.6.1 Background Information.- Micro ROADSIM is the final product of an evolutionary process which began in 1978. The original ROADSIM was not a new model with new methodology and logic but rather a reprogrammed version of an earlier model called TWOWAF.

TWOWAF, also a microscopic traffic simulation model, had been developed in 1978 as part of the National Cooperative Highway Research Program (NCHRP) Project 3-19. The model could “move” individual vehicles according to detailed parameters specified by the user. The vehicles were then “advanced” through successive 1 second intervals taking into account the roadway geometry, traffic control, driver preferences, vehicle type and performance characteristics, and passing opportunities based on the oncoming traffic. Spot data, space data, vehicle interaction data, and the overall travel data were accumulated, processed, and reported.

A microscopic two-lane simulation model was needed to become part of the TRAF family. TWOWAF’s basic logic was selected. However, before restructuring the model to meet TRAF specifications, logic from two other simulation models (INTRAS and SOVT) were adapted.

The basic car following logic was adapted from INTRAS, a microscopic freeway simulation model developed in 1976 for FHWA. This logic was based on the premise that a vehicle that is following another will always maintain a space headway relative to its lead vehicle which is linearly proportional to its speed. This premise was much simpler than the one contained in TWOWAF and thus easier to calibrate.

The vehicle generation logic was adapted from SOVT, a microscopic two-lane simulation model developed in 1980 at North Carolina State University. This logic emits vehicles onto the simulated roadway at each end. For low volumes, the Schuhl distribution used in SOVT provided a realistic approximation of vehicles generated. For high volumes, when traffic density approaches queuing, a shifted exponential headway distribution was used.

These two methodologies were adapted into the TWOWAF model and reported in Report NCHRP 3-28A. The resulting model was referred to an New TWOWAF. This model was then reprogrammed according to TRAF specifications, modified with new input and output subroutines, and renamed ROADSIM.

This mainframe version of ROADSIM was evaluated in the field to compare its output to real observed traffic data. The results, and the accompanying sensitivity analysis, proved to be satisfactory, Under the conditions tested, ROADSIM was proven a valid model.

With the proliferation of faster personal computers, the need for a microcomputer version of ROADSIM became evident. The mainframe FORTRAN source code of ROADSIM was downloaded to a microcomputer. Several program overlays were removed to reduce the program’s size. The resulting code was then recompiled. This recompiled version was named Micro ROADSIM and is the one in use today.

3.6.3 Additional Model Information.-

a. Model Source

ROADSIM is not released yet but when it is it will be available from:

McTrans
Center for Microcomputers in Transportation
University of Florida
512 Weil Hall
Gainesville, FL 32611
(904) 392-0378

or

PC Trans
Kansas University Transportation Center
2011 Learned Hall
Lawrence, KS 66045
(913) 864-5655

b. Agent for Maintenance and Upgrades

Same as source

c. Current Acquisition cost

Currently unavailable for sale.

d. Development Status

Currently unavailable from McTrans and PC Trans. FHWA has released the model to McTrans and PC Trans and they will release it in the near future.

e. Data Requirements

This model is not as data intensive as NETSIM even though it is also a microscopic model not as much data is required to simulate a rural road.

f. **Known Linkages to Other Models**

It will have linkages to all the TRAP family of models this includes: NETSJM - a microscopic urban street network model, FRESIM - a microscopic freeway model; which is under development, CORPLO - a macroscopic corridor model; which is made up of: NETPLO 1 - a macroscopic urban network model, NETFLO2 - a macroscopic urban network model, & FREFLO - a macroscopic freeway model.

3.7 NETSIM

3.7.1 Description.- The model applies interval based simulation to describe traffic operations. This means that every vehicle is a distinct object and is moved every second and every traffic signal and event are updated every second. Furthermore, each vehicle is identified by category (auto, car pool, truck, bus) and by type. Up to 16 different types of vehicles with different operating and performance characteristics may be specified defining the 4 categories of the vehicle fleet. In addition, a “driver behavioral characteristic” (passive, aggressive) is assigned to each vehicle. Also, its kinematic properties (speed, acceleration) are determined, as well as its status (queued, free flowing). Turn movements are assigned stochastically, as are its free flow speed, queue discharge headways and other behavioral attributes. Consequently, each vehicle’s behavior may be simulated in a manner reflecting real world processes.

Each time a vehicle is moved, its position (both lateral and longitudinal) on the link and its relationship to other vehicles nearby are recalculated. Its speed, acceleration and status are also recalculated. Actuated signal control and interaction between cars and buses are explicitly modeled.

Vehicles are moved according to car following logic, response to traffic control devices and response to other demands. For example, buses must service passengers at bus stops; hence, their movements differ from those of private vehicles. Congestion can result in queues extending throughout the length of a link and blocking the upstream intersection, thus impeding traffic flow there. Pedestrian traffic can delay turning vehicles at intersections.

3.7.2 Background Information.- Originally developed for FHWA and released in 1971 as NETSIM. The model underwent maior upgrades in 1973 and 1978. In 1981 the NETSIM model became a component of the integrated traffic simulation system, known as TRAF and has become known as TRAF-NETSIM. Between 1980 and 1989 several major enhancements were added to the model including: actuated controller logic, conditional turning-movements feature, identical traffic streams, and signal transition logic.

This model was developed to be used as a tool of traffic management. Traffic management places emphasis on optimizing urban resources to improve the movement of people and goods without impairing community values. When a traffic system is represented by a computer simulation model, the effects of traffic management strategies on the 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 stops, vehicle-miles of travel, average queue length and fuel consumption. Thus, any strategy can be evaluated by analyzing these MOE. In addition, the MOE can provide valuable insight into the responsiveness of the traffic stream to the applied strategy; this insight, in turn, can provide the basis for optimizing the strategy.

3.7.5 Additional Model information.-

a. Model Source

McTrans
Center for Microcomputers in Transportation
University of Florida
512 Weil Hall
Gainesville, FL 32611
(904) 392-0378

or

PC Trans
Kansas University Transportation Center
2011 Learned Hall
Lawrence, KS 66045
(913) 864-5655

b. Agent for Maintenance and Upgrades

Same as source

c. Current Acquisition cost

TRAF-NETSIM $ 200.00
TRAP-NETSIM documentation $ 35.00
GTRAF (Graphics software for displaying TRAF-NETSJM output in an animated manner on a computer) with GSS drivers (software for various graphic hardware)
$ 150.00
GTRAF documentation $ 75.00
GTRAF without GSS drivers $ 75.00
TRAF-NETSIM package includes GTRAF with GSS drivers
$ 300.00
TRAP-NETSIM documentation package includes all documentation
$ 50.00

A complete version of TRAP-NETSIM including all documentation will cost
$ 350.00

d. Development Status

Currently Version 2 is available from McTrans and PC Trans. Version 3 will be released in the Fall of 1992.

e. Data Requirements

This model is extremely data intensive. It requires a lot of work to supply the model with all the data input it needs. An example of this is that it requires all the signal timings for the city you wish to evaluate.

f. Known Linkages to Other Models

It has linkages to all the TRAF family of models this includes: CORFLO - a macroscopic corridor model; which is made up of: NETFLO 1 - a macroscopic urban network model, NETFLO2 - a macroscopic urban network model, & FREFLO - a macroscopic freeway model, FRESIM - a microscopic freeway model; which is under development, and ROADSIM - a microscopic rural road model; which is not integrated under the PC user interface TSIS as of yet.

IV. EMISSIONS AND FUEL CONSUMPTION MODELS

4.1 INTRODUCTION

This section surveys emissions and fuel consumption models, which are restricted to those involving on-road vehicles. The survey attempts to include all of the major models that could potentially be of help in the subsequent tasks of developing an analytical framework to estimate the emissions and fuel benefits of IVHS technologies and strategies. Previous sections have similarly surveyed planning and traffic models, which also will be part of the analytical framework.

A prime objective of the survey is to make known the available tools for use in creating the analytical framework and to communicate the issues involved in using these tools. It is important to understand what models seek to do, how such models differ from each other, and how the modeling approach differs from other emissions and fuel consumption estimating techniques. This knowledge will provide the foundation for developing an analytical framework to measure emissions and fuel consumption benefits of IVHS technologies and strategies.

A modeling approach for benefits estimation not only provides an understanding about systems and system interactions, but about feedbacks and long-range implications. Models also allow for the testing of strategies that might otherwise be expensive or risky to test in real driving environments of interest. However, the modeling approach cannot replace real world demonstrations of IVHS technologies and strategies. Rather, modeling and demonstrations are viewed as being mutually beneficial and reinforcing.

The survey does not include the entire population of emissions and fuel consumption models. Many emissions and fuel consumption models are bundled with other types of models. Traffic models (like TRAF-NETSIM) that include considerations of emissions and fuel consumption are surveyed in the section on traffic models. However, the survey describes some air quality models that have emissions components. Such air quality models are not viewed as being of primary importance to the activity of creating the intended analytical framework, which focuses on emissions as an end-state.

Numerous studies have been undertaken to better understand issues involved in creating emissions and fuel consumption models, for improving such models, and for supplying better input data to such models. These studies, which generally stop short of producing actual models, are not included in this survey. However, these studies address important issues concerning emissions and fuel consumption models. These issues include specific considerations of drive cycle measurements, remote sensing of emissions, inspection and maintenance, vehicle miles of travel (VMT) estimations, and alternative fuels. Such issues and studies may be discussed in subsequent tasks involved in creating the analytical framework.

Resides studies related to models, there is also a growing amount of work being done to sample emissions in real time. These efforts use the tools of analytical chemistry to measure emissions directly in the actual driving environment. Such efforts may have a bearing on modeling practices in the future. However, references to this work are not included in the survey.

The emissions and fuel consumption models surveyed can be classified in many ways. The relevance of classification depends obviously on the intent of use. One classification, often overlooked, involves the time of creation. Models to be predictive must include topical information. Some models, while theoretically sound, do not contain current estimations of parameters (particularly those concerning emissions rates) owing to changes in automobile technologies and fuels. Such models may not have been updated by different versions of the same basic modeling approach. However, some models, currently used by practitioners, are updated versions of older models while a few models are under development with anticipated use by practitioners. Emissions and fuel consumption models that are previous versions of present models, or are to be future versions, are not listed separately. These models, which really form a series or family of models, if discussed, are done so under the most recent versions.

In addition, the emissions and fuel consumption models surveyed, as well as the planning and traffic models, almost exclusively, were created for purposes other than those for which the benefit analytical framework is intended. As a result, the assumptions implicit in these models may not be appropriate for IVHS technologies and strategies.

This section, Survey of Emissions and Fuel Consumntion Models, is organized into several parts. After the "Introduction", two following parts, "Emissions Models' and "Fuel Consumption Models", give a general discussion of the issues involved with the respective models surveyed. A following part, "Listing and Description of Emissions and Fuel Consumption Models", gives a description of the models surveyed. The last part, "A Comparison of Selected Models", compares and contrasts selected emissions and fuel consumption models that are deemed most likely candidates for inclusion in the analytical framework. References are given at the end of this survey.

4.2 EMISSIONS MODELS

Emissions models for highway vehicles attempt to measure primary emissions from diesel- and gasoline-powered vehicles. These primary emissions of chemical compounds can have direct damaging effects upon receptors if concentrations develop. The primary emissions can also be involved in a variety of chemical and photochemical reactions, which can cause more harmful secondary pollution to develop. Emissions models stop short of predicting these secondary reactions or any effects upon receptors. Determining such effects require air quality and toxicology considerations.

It is important to be clear about what emissions models attempt to do compared to what air quality models do. Most emission models, as mentioned previously, stop short of estimating air quality. Emissions, rather, serve as inputs to air quality models. Air quality depends on atmospheric dispersion, topography, and photochemistry. The same level and mix of emissions can bring different levels of air quality.

Air quality models calculate concentrations and distributions of selected chemical species in the air resulting in part from emissions both from fixed and line sources. With the exception of ambient temperature, air quality models consider background conditions that do not concern emissions models. Such variables include wind characteristics, inversions, and ambient concentrations of other chemical substances.

Three types of emissions from highway vehicles have been the subject of extensive attention in modeling: carbon monoxide (CO), hydrocarbons (HC), and oxides of nitrogen (NO_x).. CO has pollution potential in and of itself if concentrations develop along a line source or in localized 'hot spot' areas such as intersections and highway on-ramps. HC and NO, are compounds that combine with sunlight and other chemical substances to form ozone and other oxidants. (It is thought that CO also contributes to this process by converting nitric oxide (NO) to nitrogen dioxide (NO&-a precursor to ozone formation and by reducing concentrations of ozone-destroying hydroxyl radicals (OH)).' HC emissions may be speciated by some models to distinguish the more reactive, volatile types.

Other types of emissions may be generated from the combustion of hydrocarbon fuels in highway vehicles. However, for various reasons, these emissions – like sulfur, lead, and particulate matter -- have not been extensively modeled. (EPA released a model in the summer of 1992 that deals with particulate matter from mobile sources.)
In practice, emissions modeling has revolved around EPA's MOBILE series (the current version is MOBILE4.1 with a draft version of MOBILES.0 released in August 1992) and similar, historically-related California practices. In fact, an informal distinction has developed between models and practices used by federal agencies (EPA, FHWA) and methods used by the state of California. Because of this prominence in current and future anticipated practices, emphasis in this survey is given to these two approaches. There are many similarities between the approaches, but some important differences exist as well.

Both the EPA and California Air Resources Board have identified at least four specific categories of vehicle emissions: trip start emissions (cold start or hot start depending upon the period for which the vehicle has been turned off), running emissions, hot soak evaporative trip end emissions, and diurnal emissions (which occur regardless of vehicle use).

Most emission models focus on three primary variables to estimate emissions: basic emissions rates, speed, and amount of travel (VMT). The emission rate is very sensitive to the average speed with which vehicles are assumed to travel. Total emissions are the result of the speed sensitive emission rates (when so adjusted by speed and other variables it is often called the 'emission factor') being multiplied by the amount of travel as represented by VMT. Various levels of disaggregation have been attempted for these three variables in order to achieve accuracy in the estimation of emissions for various areas.

IV. EMISSIONS AND FUEL CONSUMPTION MODELS

4.1 INTRODUCTION

This section surveys emissions and fuel consumption models, which are restricted to those involving on-road vehicles. The survey attempts to include all of the major models that could potentially be of help in the subsequent tasks of developing an analytical framework to estimate the emissions and fuel benefits of MIS technologies and strategies. Previous sections have similarly surveyed planning and traffic models, which also will be part of the analytical framework.

A prime objective of the survey is to make known the available tools for use in creating the analytical framework and to communicate the issues involved in using these tools. It is important to understand what models seek to do, how such models differ from each other, and how the modeling approach differs from other emissions and fuel consumption estimating techniques. This knowledge will provide the foundation for developing an analytical framework to measure emissions and fuel consumption benefits of IVHS technologies and strategies.

A modeling approach for benefits estimation not only provides an understanding about systems and system interactions, but about feedbacks and long-range implications. Models also allow for the testing of strategies that might otherwise be expensive or risky to test in real driving environments of interest. However, the modeling approach cannot replace real world demonstrations of IVHS technologies and strategies. Rather, modeling and demonstrations are viewed as being mutually beneficial and reinforcing.

The survey does not include the entire population of emissions and fuel consumption models. Many emissions and fuel consumption models are bundled with other types of models. Traffic models (like TRAF-NETSIM) that include considerations of emissions and fuel consumption are surveyed in the section on traffic models. However, the survey describes some air quality models that have emissions components. Such air quality models are not viewed as being of primary importance to the activity of creating the intended analytical framework, which focuses on emissions as an end-state.

Numerous studies have been undertaken to better understand issues involved in creating emissions and fuel consumption models, for improving such models, and for supplying better input data to such models. These studies, which generally stop short of producing actual models, are not included in this survey. However, these studies address important issues concerning emissions and fuel consumption models. These issues include specific considerations of drive cycle measurements, remote sensing of emissions, inspection and maintenance, vehicle miles of travel (VMT) estimations, and alternative fuels. Such issues and studies may be discussed in subsequent tasks involved in creating the analytical framework.

Resides studies related to models, there is also a growing amount of work being done to sample emissions in real time. These efforts use the tools of analytical chemistry to measure emissions directly in the actual driving environment. Such efforts may have a bearing on modeling practices in the future. However, references to this work are not included in the survey.

The emissions and fuel consumption models surveyed can be classified in many ways. The relevance of classification depends obviously on the intent of use. One classification, often overlooked, involves the time of creation. Models to be predictive must include topical information. Some models, while theoretically sound, do not contain current estimations of parameters (particularly those wnceming emissions rates) owing to changes in automobile technologies and fuels. Such models may not have been updated by different versions of the same basic modeling approach. However, some models, currently used by practitioners, are updated versions of older models while a few models are under development with anticipated use by practitioners. Emissions and fuel consumption models that are previous versions of present models, or are to be future versions, are not listed separately. These models, which really form a series or family of models, if discussed, are done so under the most recent versions.

In addition, the emissions and fuel consumption models surveyed, as well as the planning and traffic models, almost exclusively, were created for purposes other than those for which the benefit analytical framework is intended. As a result, the assumptions implicit in these models may not be appropriate for MIS technologies and strategies.

This section, Survey of Emissions and Fuel Consumption Models, is organized into several parts. After the “Introduction”, two following parts, “Emissions Models’ and “Fuel Consumption Models”, give a general discussion of the issues involved with the respective models surveyed. A following part, “Listing and Description of Emissions and Fuel Consumption Models”, gives a description of the models surveyed. The last part, “A Comparison of Selected Models”, compares and wntrasts selected emissions and fuel consumption models that are deemed most likely candidates for inclusion in the analytical framework. References are given at the end of this survey.

4.2 EMISSIONS MODELS

Emissions models for highway vehicles attempt to measure primary emissions from diesel- and gasoline-powered vehicles. These primary emissions of chemical compounds can have direct damaging effects upon receptors if wncentrations develop. The primary emissions can also be involved in a variety of chemical and photochemical reactions, which can cause more harmful secondary pollution to develop. Emissions models stop short of predicting these secondary reactions or any effects upon receptors. Determining such effects require air quality and toxicology considerations.

It is important to be clear about what emissions models attempt to do compared to what air quality models do. Most emission models, as mentioned previously, stop short of estimating air quality. Emissions, rather, serve as inputs to air quality models. Air quality depends on atmospheric dispersion, topography, and photochemistry. The same level and mix of emissions can bring different levels of air quality.

Air quality models calculate wncentrations and distributions of selected chemical species in the air resulting in part from emissions both from fixed and line sources. With the exception of ambient temperature, air quality models consider background conditions that do not concern emissions models. Such variables include wind characteristics, inversions, and ambient concentrations of other chemical substances.

Three types of emissions from highway vehicles have been the subject of extensive attention in modeling: carbon monoxide (CO), hydrocarbons (HC), and oxides of nitrogen (NO_x).. CO has pollution potential in and of itself if concentrations develop along a line source or in localized 'hot spot' areas such as intersections and highway on-ramps. HC and NO, are compounds that combine with sunlight and other chemical substances to form ozone and other oxidants. (It is thought that CO also contributes to this process by converting nitric oxide (NO) to nitrogen dioxide (NO_2)--a precursor to ozone formation and by reducing concentrations of ozone-destroying hydroxyl radicals (OH). HC emissions may be speciated by some models to distinguish the more reactive, volatile types.

Other types of emissions may be generated from the combustion of hydrocarbon fuels in highway vehicles. However, for various reasons, these emissions – like sulfur, lead, and particulate matter – have not been extensively modeled. (EPA released a model in the summer of 1992 that deals with particulate matter from mobile sources.)
In practice, emissions modeling has revolved around EPA's MOBILE series (the current version is MOBILE 4 1 with a draft version of MOBILES.0 released in August 1992) and similar, historically-related California practices. In fact, an informal distinction has developed between models and practices used by federal agencies (EPA, FHWA) and methods used by the state of California. Because of this prominence in current and future anticipated practices, emphasis in this survey is given to these two approaches. There are many similarities between the approaches, but some important differences exist as well.

Both the EPA and California Air Resources Board have identified at least four specific categories of vehicle emissions: trip start emissions (cold start or hot start depending upon the period for which the vehicle has been turned off), running emissions, hot soak evaporative trip end emissions, and diurnal emissions (which occur regardless of vehicle use).

Most emission models focus on three primary variables to estimate emissions: basic emissions rates, speed, and amount of travel (VMT). The emission rate is very sensitive to the average speed with which vehicles are assumed to travel. Total emissions are the result of the speed sensitive emission rates (when so adjusted by speed and other variables it is often called the 'emission factor') being multiplied by the amount of travel as represented by VMT. Various levels of disaggregation have been attempted for these three variables in order to achieve accuracy in the estimation of emissions for various areas.

Basic emissions rates are very much a function of drive cycle, average speed, temperature, and load. The drive cycle represents the pattern or mode of accelerations, decelerations, cruising, and idling. Average speed is an important variable. As determined by the EPA and California agencies, the three pollutants, CO, HC and NO,, have different profiles relative to vehicle speed. Temperature is an important variable that influences tailpipe and evaporative emissions. Load on the vehicle also appears to be important, but is not generally modeled. To the extent that actual driving is modeled by representations of drive cycle, speed, and load, emissions models will be validated. However, validation has not generally been achieved. Because of this, emphasis is now being given to better conceptional definitions and estimates of drive cycle, speed, and load.

Emissions output of most models are given on a rate basis (or time, or occurrence, basis). Actual physical quantities of emissions depend on multiplying this rate by an activity measure, usually VMT. Exogenous estimations of VMT are thus needed. Increased accuracy in predicting the emissions rate, however, will not compensate for inaccuracy in VMT estimates when determining the absolute physical quantity of emissions.

While emissions models express outputs in physical terms, the question of whether such outputs can be validated with actual physical conditions is debatable. In addition, the calculation of all emissions rates among, and even within, models may not be from a common test procedure having the same experimental design. Hence, emissions rates for different emissions may not have the same validity. This can make interpretations difficult. However, even if there is a lack of validation with actual levels, emissions models are still useful in making comparisons in relative terms among different activities, technologies, and strategies.

Generation of emissions can be viewed from a number of geographic perspectives: world, nation, regional, local, and 'hot spot'. These area focuses are sometimes described as ranging from 'mesoscale' to 'microscale'. While air quality regarding CO is usually considered on a local and 'hot spot' basis, air quality regarding secondary pollutants, such as ozone formed in part from HC and NO,, are normally considered at a minimum on a regional basis. This perspective is adopted because local emissions from one area can contribute to the development of secondary pollution in another area. Hence, air quality models must generally focus on a larger area. Some highway vehicle emission models can focus nearer the source on a regional, local, or 'hot spot' basis. However, many emissions models assume uniform spatial distribution of emissions. This assumption may be adequate when looking at a wide area, but may prove inaccurate for more localized modeling efforts.

It must be kept in mind that the purpose of this survey is to identify the emissions and fuel consumption models that are appropriate for measuring benefits of IVHS interventions. This requirement may require emissions estimates by time of day and in a grid-area form similar to air quality estimates. Because IVHS technologies and strategies are primarily aimed at affecting the drive cycle (e.g., increasing speed and reducing delay caused by stops and starts), the emissions models are categorized with respect to their inherent assumptions concerning this parameter.

4.3 FUEL, CONSUMPTION MODELS

Fuel consumption models for highway vehicles measure fuel consumption in internal combustion engines given a set of attributes about basic engine design, emission controls, fuel type, driving conditions, etc.

Some of these models will allow not only the calculation of fuel consumption, but the individual contribution to consumption of the various attributes on which fuel economy depends. Such facility is important to policy decisions. The degree to which individual contributions can be estimated and differentiated depends on the validity of statistical procedures used to estimate model parameters. Sometimes independent data do not exist on which to base individual parameter estimations.

Fuel consumption models also can fulfill the important function of answering questions of interrelationships among emissions and fuel consumption. Such questions include the impact of fuel volatility on consumption and evaporative emissions. Questions like these are important in doing benefit work like that intended to get at the net cost (which includes adjustments for trade-offs among benefits) of a particular technological change or intervention.

There are many different types of fuel consumption models. To help clarify the different types of fuel consumption models, and the appropriateness of each, a hierarchical classification developed by Akcelik, et al, is adopted.* This fuel consumption model hierarchy has four levels. The main basis for classification is whether a model is appropriate for micro or macro considerations, or both. That is, whether fuel consumption is desired for a particular individual vehicle at a particular instant, or for an average vehicle on a link, or for the average vehicle by trip.

> Level 0 models consider single vehicle systems and are clearly micro models. Such models are useful for considering questions of engine design relative to optimal fuel consumption given a stated goal or goals. Inputs to these models include drive cycle, speed and acceleration, and vehicle-engine mappings. Instantaneous fuel consumption in some of these models is given as a function of power requirements. The functional parameters may have been determined using a dynamometer. These models are very data intensive in input requirements.
>
> Level I models are based on an instantaneous fuel consumption function. These models can be considered either micro or macro. Vehicle characteristics are required as inputs. These models are also data intensive.
>
> Level II models are derived from Level I models. These models are also considered micro or macro. Less detailed (and costly) information is required as input. Outputs of traffic models such as average speeds, range of speed, idle time, and number of stops can be used to approximate driving conditions.

Level III models are based on regression analysis. A function is determined statistically predicting fuel consumption based on speed and drive cycle type variables. These are decidedly macro models.

EPA's MOBILE 4.0 emission model has the feature that emissions rate outputs can be used as inputs to an EPA fuel consumption model. Fuel consumption rates thus calculated can be multiplied by VMT on the road segment or region under study for determination of total fuel consumption. EPA's fuel consumption is determined on a material balance basis as the difference between the amount of carbon known to exist in a given volume of fuel before combustion and that which is residual in emissions.

4.4 LIST AND DESCRIPTION OF EMISSIONS MODELS

The following emissions models are listed along with descriptions. If an emissions model is also used to calculate fuel consumption, as several are, these models are listed here.

4.4.1 FTP-based models

The Federal Test Procedure (FTP) forms the basis for estimating basic emissions rates in the major models, namely the MOBILE series and the California (EMFAC) family of models. The FTP is a specific driving sequence of start, acceleration, deceleration, cruising, and idling, with speed averaging 19.6 mph over the cycle. The EPA developed a table of vehicle emission rates by speed by interpolating between the emissions from the FTP cycle and other cycles with different average speeds. Therefore, the base emission rates do not reflect the rate produced at a steady cruising speed, but is instead an average speed over a cycle. Therefore, models that use FTP-based emission factors will not be a very sensitive measure of benefits of programs, such as IVHS technologies and strategies, that seek to "smooth out" the drive cycle.

a. MOBILE Series

Without question, the MOBILE series of emissions models have been the most widely used and accepted, primarily because their use has been mandated by the EPA in preparing 1990 baseline and future mobile source emissions inventories for the State Implementation Plans (SIPs), MOBILE 4.1 is EPA's latest version in the MOBILE series. An updated version was released in draft form in August 1992 with the final version due in Fall 1992.

MOBILE 4.1 is the latest in a series of EPA computerized models to estimate emissions from highway vehicles on public roadways. Emissions estimated are of three types: carbon monoxide (CO), hydrocarbons (HC), oxides of nitrogen (NO_x). Total HC estimates can be further disaggregated to specify volatile organic compounds (VOC), which are the most likely to participate in atmospheric photochemical reactions.

All emissions are given in rates. Actual physical emissions are derived from these rates by multiplying VMT for the area under study. VMT is determined exogenously of MOBILE4.1.

These rates are described in a number of ways and output can be obtained for different subset combinations. One important way that emissions are classified is by vehicle type. There are eight vehicle classes used in MOBlLE4.1.

Another way rates are classified is by source. Emission rates are calculated from two main sources, evaporation and combustion. Evaporation emissions, which are HC, are further designated as occurring from refueling, diurnal, hot soak, crankcase (blow-by), resting, and running loss.

Default scenarios can be selected that represent EPA's estimate of distributions of such factors as vehicle registrations, VMT accumulation, vehicle type, fuel type, trip length, operating modes (cold start/stabilized/hot start), catalytic equipage, and maintenance.

MOBILE was designed to measure the effects of changes in emissions technologies, fuel composition, inspection and maintenance (I/M) programs. Naturally the variables used reflect those ends. Using MOBILE to estimate emissions benefits of IVHS technologies and strategies focuses on only a small set of these variables. This selection is driven by two issues. First, the use of MOBILE to represent the mix of vehicles and driving conditions in the area selected. Second, the appropriate emission rate (BER) given that IVHS may change the drive cycle.

A number of default variables can be selected. These values have been selected by EPA as representative of the distribution of vehicles and driving activities of those vehicles on a road network. Values other than defaults can easily be selected. Variables that must be inputted include daily temperature, Reid vapor pressure of gasoline, calendar year of evaluation, whether region evaluated is at high or low altitude.

Although MOBILE4.1 will estimate emission factors for any calendar year between 1960 and 2020, it cannot model any changes in emission standards beyond 1993. MOBILE5 extends this range through 2010 with updated emission factors that account for improved tailpipe standards, reformulated and oxygenated fuels and other 1990 Clean Air Act mandates.

The important linkage of this model is to EPA's MOBILE4 Fuel Consumption Model (M4FC). This linkage allows for the calculation of the rate of fuel consumption from the emission rates. Total consumption of fuel depends, as does total emissions, on exogenously determined VMT.

b. UROAD

UROAD model, developed for the FHWA, will accept trip assignment data from traffic submodels and calculate total emissions and fuel consumption for user specified years and geographic regions. UROAD uses composite CO, HC, and NO, emission rates from EPA's MOBILE series models.

c. SAPOLLUT

The U.S. Department of Transportation developed the Special Area Pollution (SAPOLLUT), a noise and air quality model, as part of the 1974 National Transportation Study of urban areas. The model can estimate potential cold-start, running, and evaporative emissions associated with an urban network or constructing a new highway. The model outputs HC, and NO, emission inventories in kilograms for specified evaluation years on an hourly basis. Base emission rates are based on a 1973 EPA publication, "Compilation of Air Pollution Emission Factors," a predecessor to the EPA's expanded factor determination used in the MOBILE model series.

The emissions factors program accesses an internal table of HC, CO, and NO, base exhaust and evaporative emission factors as well as vehicle deterioration and speed adjustment factors for three vehicle types (light passenger vehicles, light and heavy trucks) and fourteen model years. These 26 factors (3 pollutants x 3 vehicle types x 14 model years) are multiplied by the link VMT to provide hourly emissions on each link.

Travel information is provided by an FHWA historical record and default values (or user specified values), which delineate the volume on each link in the network according to the functional classification (freeway, arterial) and area type (central business district, central city, suburbs) of the link. The VMT estimate is also specified for the three vehicle types and by model year for each type. The traffic data used in SAPOLLUT include hourly distribution of average daily traffic, distribution of directional split, truck movements, and speed versus volume-to-capacity ratio. SAPOLLUT can interface diitly with FHWA urban transportation planning programs to generate most travel information. In order to calculate the number of cold starts, the model accesses a series of tables that relate land use to trip origins.

The model outputs total HC, CO, and NO, in kilograms emitted by hour or a range of hours and for a specific area type and functional classification. The model also provides vehicle miles of travel for each hour as well as emission factors in grams per vehicle mile and grams per passenger mile. SAPOLLUT can also quantify total emissions in specific pollution districts on a daily basis for freeways and arterials.

d. California Air Resources Board Emissions Models

The California Air Resources Board (ARB) uses three models to estimate the state's emissions inventory: CALIMFAC, EMFAC, and BURDEN. CALIMFAC generates basic emission rates for HC, CO, and NO, with and without the benefits of inspection/maintenance (I/M) programs. EMFAC corrects the basic emission rates from CALIMFAC for speed, temperature, vehicle operating mode, vehicle load, and other non-standard influences. BURDEN considers vehicle population and activity to adjust gram per mile emission rates into tons per day inventories.

The California's emission factor assumptions are based on nine surveillance programs performed by the ARB, in which vehicles, procured at 'random', were tested using the

Federal Test Procedure (FTP). The ARB relied on EPA analyses to develop correction factors for speed and temperature.

The California model also estimates running, diurnal, and hot soak HC evaporative emissions, which are also corrected for temperature and speed. However, EMFAC7E did not correct for fuel vapor pressure, but was being corrected (as of October 1990) to reflect California's clean fuels regulations.

The California model is similar to EPA's MOBILE series of models in some of its basic assumptions for calculating basic emission rates.[3] Both models assume that:

- Vehicles equipped with different emission control technologies will react differently to in-use conditions.

- Emission characteristics of similar vehicles can be grouped into discrete categories.

- Vehicle deterioration and emission control malfunctions can be represented by a change in the distribution of vehicles among these discrete groups.

However, the California model uses a different data base than the MOBILE series and has different fleet characterization data, operating mode corrections, emitter categories, and I/M program and anti-tampering program benefits.[4] In addition, California refines its data to a greater degree than the MOBILE series by defining a higher number of vehicle technology groups and emitter categories.

In the future, the ARB hopes to develop a modal emission factor model that can calculate emissions associated with idle, cruise, acceleration, and deceleration operating modes. These types of models are discussed in Section 4.4.2.

<u>CALIMFAC</u>

The ARB developed the California I/M Factor model to evaluate the effectiveness of the state's biennial "smog check" program. CALIMFAC calculates baseline (no inspection program) exhaust emission factors for 1965 to 2004 model year gasoline-powered passenger cars, light-duty trucks and medium-duty vehicles, and predicts emissions benefits for calendar years 1980 to 2020 for up to five different I/M program designs.

<u>EMFAC7/lRS</u>

EMFAC is the ARB's model for estimating emission factors for on-road motor vehicles. EMFAC7 calculates composite emission factors for seven vehicle classes with respect to their technology (catalyst, non-catalyst, and diesel). EMFAC predicts tailpipe emissions (for cold start, hot start, and hot stabilized operating modes), emissions from crankcase blow-by, and HC evaporative emissions (running, diurnal and hot soak).

BURDEN

BURDEN requires vehicle population, model year distribution, miles per day, and trips per day information. BURDEN assesses the adjusted emission factors generated by EMFAC to develop aggregate vehicle emission inventories. BURDEN obtains country-specific data from either local travel demand models or the California DOT's travel demand models.

d. Direct Travel Impact Model

The Direct Travel Impact Model (DTIM) developed by the California Department of Transportation combines a regional travel model and an emissions factors model to determine emissions inventories. The model predicts HC, CO, and NO, emissions as a function of VMT, number of trips, park duration, temperature, vehicle type mix and speed by square grid and hour.

DTM accesses emission impact rates produced by the California Air Resources Board's EMFAC/IRS model (previously described). Therefore, DTIM can evaluate scenarios between 1987 and 2010, inclusive of future California Clean Air Act mandates (e.g., low emitting vehicles, clean fuels).

Running exhaust emissions are computed for each individual roadway link as a function of the average travel time (or speed) on the link. From each link's coordinates, the emissions are spatially allocated into grid cells. Starting exhaust emissions are estimated by applying starting impact rates to trip starts compiled by time of day and traffic analysis zone. The model computes evaporative (hot soak and diurnal) emissions in a similar fashion, but considers average parking durations as well as number of "parks" by time of day.

The model is typically run by taking travel estimates for three daily periods: am peak, pm peak and off-peak. Hourly variation in emissions within these periods is then based on input hourly temperature variations and trip starts or "parks" data.

Network link data is obtained from a transportation planning model and includes node numbers to identify link endpoints, link distance, link speed, link travel time, and link type (such as an arterial or freeway).

Trip assignment data is input to DTIM from a single file containing three types of information: Profile (link) volumes, Intrazonal volumes and Terminal (trip end) counts. The profile record contains vehicle volumes by travel period (e.g., am peak, pm peak, and off-peak) for each of the network links. The intrazonal record contains estimates of vehicle volumes throughout an urban area, which is comprised of irregularly shaped traffic analysis zones, each containing a number of individual links that represent the roadways in the zone. From socio-economic data, trips between each of the zones are developed and volumes are assigned to links between each zone pair based on the "resistance" assumptions in the network. The terminal record contains the number of trips by travel period for each zone pair in the roadway system.

DTIM is considered one of the most sophisticated models for developing mobile source emissions inventories.

e. SANDAG TCM Emission Analysis Model

In 1991, Sierra Research and JHK & Associates developed a model for the San Diego Association of Governments (SANDAG) to estimate the emission effects of 25 transportation control measures (TCMs). The model's emissions module provides an estimate of the area's baseline pollutant emissions of reactive organic gases (ROG), CO, NO,, and particulates. The model predicts both absolute and percent changes from baseline caused by a TCM's or combination of TCMs' implementation.

The model uses three separate computer programs to quantify the impacts of TCMs: a transportation module, an emissions module, and a cost module.

The fist module, the transportation module, written in Lotus l-2-3, estimates the effect of each TCM on the travel parameters that influence emissions: the number of trips, VMT and speed. The module combines information on local travel (for specific California counties and air basin areas) with assumptions about how travelers will change their behavior in response to individual TCMs. The transportation spreadsheet uses various methodologies to quantify the effect of travel changes caused by the implementation of TCMs. The methodologies are based on JHW's review of the literature and largely use elasticities to quantify travel changes.

In the transportation module, the user supplies information on the area being analyzed (e.g., urban, rural), baseline travel characteristics (e.g., total number of person trips, percent of commute trips in peak and off-peak periods) and information about the TCM as prompted by the model (e.g., percent gasoline tax). The user has the option of modifying the analytical assumptions (e.g, elasticity) to reflect local conditions. The outputs from the transportation module include the baseline travel characteristics and the effects of each TCM on peak and off-peak period trips, VMT and speed.

The emissions module, written in Fortran, combines estimates of the TCM-specific travel impacts with the emission factor data contained in EMFAC7E and BURDEN7C to develop an estimate of baseline emissions and pollutant reductions for each TCM. The model can determine emissions estimates from 1987 to 2010. The module accounts for the effect of trip type (e.g., commute, shopping, etc.), vehicle class, hour of the day, and operating modes on emissions. BURDEN provides a distribution of vehicles and operating conditions experienced in each air basin and county in California and contains default assumptions on the distribution of trips and start fractions occurring by the hour of the day.

The last module, the cost-effectiveness module, written in Lotus l-2-3, uses the travel impacts and percent emission reductions along with other data, to calculate costs (in 1991 dollars) and cost-effectiveness estimates for each TCM of interest.

f. System II Emissions Model

JHK & Associates developed and incorporated a vehicle emission module into their System II traffic analysis software. The System II Emission program applies emission rates by vehicle type and travel speed to time of day volumes for each link in the roadway network. The program also considers both trip start, trip end (hot soak), and diurnal emissions.

The model predicts HC, CO and NO, by vehicle type (light duty passenger, light duty truck, medium duty truck, heavy duty truck) and by speed. These rates are based on assumed distributions of trips by hot and cold start and by age of the vehicle, and the prevailing temperature in the region of interest. The model calculates emission rates using the EMFAC program to evaluate California scenarios and MOBILB4.1 for the remaining states. As discussed previously, these two programs consider the analysis year, the vehicle fleet age, the type of vehicle inspection programs, local temperature characteristics, and other regional policies in developing the emission rates. These rates are entered into the emission database and are applied to each link in the network.

JHK uses data from a regional modeling system to obtain data on travel by time of day and vehicle type distribution. Much like the DTIM model, the JHK uses various combinations of assignments to replicate am peak, pm peak and off-peak periods. This data is supplemented with detail on trips and VMT by hour of the day and by vehicle classification. With the hourly estimates of emissions for each zone and link, the model can aggregate emissions geographically to zone, district, county, or regional grouping and can aggregate emissions temporally to periods of the day or to a daily total. Geographic aggregations can also be used to develop grid cell estimates of emissions or to define hot-spot areas.

The model draws upon data collected in the region to provide estimates for the average distribution of travel by hour of the day for trips of a particular area type (central business district, commercial, suburban residential, rural) and facility type (freeway, arterial, collector, minor).

4.4.2. Modal Models

Pollutant emissions are very much dependent on the operating mode of the engine as well as local environmental conditions. It is widely acknowledged that transient engine modes, which occur during acceleration and deceleration, are generally more polluting than steady speed cruising. Modal models attempt to differentiate emission generation associated with cruise, accelerating, decelerating, and idling operating modes. In this respect, the models are receptive to evaluating the emissions impact of different driving cycles.

a. Modal Analysis Exhaust Emission Model

EPA developed the Modal Analysis Exhaust Emission Model in the 1970's to evaluate the impact of specific vehicle operating modes on exhaust emissions. The model calculates HC, CO, and NO, for both individual vehicles and groups of vehicles over user specified driving cycles. The driving cycles consist of four operating modes: idle, cruise, acceleration, and deceleration. As such, and at least conceptually, the model predicts instantaneous emissions rates.

The model analysis exhaust emission model makes it possible to calculate the amounts of emission products emitted by individual vehicles or groups of vehicles over an arbitrary driving sequence. The user specifies the driving sequence by inputting the speed for each time increment (generally one second), which establishes the acceleration during each increment of time.

The model is based on data from vehicles tested under the Surveillance Driving Sequence (SDS) cycle in 1972, which measured emissions over a variety of steady state and transient driving conditions. The acceleration and deceleration modes represented in the SDS consist of all possible combinations of the following five speeds: 0, 15, 30,45, 60 mph.

The model's focus on vehicle driving modes are easily related to traffic movements at intersections. However, the model has no future year prediction capabilities and is outdated (the last update was in 1977).

b. University of Leeds Integrated Model

The Institute for Transport Studies at the University of Leeds in London developed a program that integrates traffic, emissions, and air quality models. The emissions portion of the model is based on four vehicle operating modes: cruise, deceleration, queuing (idling), and acceleration.

The model accepts traffic data, emission rates, and meteorological data and outputs air pollutant concentration for a network in both numerical and graphical form. The model predicts the spatial variability of HC, CO, NO, and lead emissions on urban roads. The dispersion model uses empirical modifications to gaussian diffusion theory in order to account for the effects of moving vehicles on air turbulence. However, the model does not handle photochemical pollution, such as ozone formation.

Most traffic modeling is performed by the SATURN traffic queuing model, which can predict at any point on the network, the percentage of vehicles that decelerate, queue, accelerate or cruise. The traffic model accepts network and trip matrix details and produces traffic flows, speeds, signal settings, road capacities, and type of intersection (signalized, roundabout, etc.). Because different intersections impose different rules on traffic, the model contains separate queuing and emission modules for signalized, priority, and roundabout intersections.

The emissions model incorporates base emission rates associated with the four operating modes. The duration and location of the operating modes are provided by the traffic module, which allows the production of emissions on every link. Emission distributions can also be graphically presented over single links or complete networks. The vehicle emission and acceleration/deceleration rates are based on 198 studies performed by the Warren Spring Laboratory on cars in the U.K. The results from these studies, however, is tentative and emission factors must be changed to reflect local conditions and vehicle mix.

The dispersion model reads the emissions distributions as well as the meteorological data, wind speed and direction, and the network and receptor geometries and outputs the pollutant concentrations in numerical or graphical form. Concentrations can be calculated at any receptor point or presented graphically as isopolluting contours over the entire network.

c. POSTRAN 7

JHK & Associates developed the TRANSYT-7F Traffic-Environmental-User Cost Program as a post processor for the TRANSYT-7F signal coordination and timing optimization program.

POSTRAN 7 reads traffic data directly from theTRANSYT-7F traffic model, which provides a method of consistently assigning green times to different turning movements to meet specific criterion. These criteria include minimizing stops and delays, as well as minimizing fuel consumption, air pollution and user costs.

POSTRAN7 estimates HC, CO, and NO, tailpipe emissions with base pollutant emissions factors expressed in units of grams per hour. In addition, the model estimates fuel consumption in gallons per hour. According to JHK, emissions and fuel consumption rates represent a mixture of vehicles in proportion to the U.S. vehicle fleet in 1986. However, the rates are based on passenger cars and light duty trucks only.

Emissions and fuel consumption parameters are provided using units and rates that allow for separation between the effects of constant speed travel and those of stops and delay. Consumption and emissions are broken down into a link component and an intersection component. The link component observes constant speed operation of vehicles. The intersection component is that part that is caused by stops and delay. The model attempts to predict the pollution and fuel consumed due to stops in excess of normal constant speed travel. The model will output total pollution produced and fuel consumed as well as a emission/consumption rates expressed per 1,000 vehicle miles of travel. These rates allow the user to compare the relative impacts on emissions and fuel consumption generated by traffic operations for individual turning movements, street segments, and intersections.

4.4.3 Other Models

The following models cannot be easily classified with respect to assumptions on drive cycle.

a. Vehicle Emissions Computer Simulation Model (VEMISS)

As part of its study to validate the FTP, EPA's Certification Division in Ann Arbor, Michigan developed a PC-based computer model to estimate vehicle tailpipe exhaust emissions over a user-specified driving cycle based on engine mapping.

VEMISS requires that the user input a drive cycle and then estimates emissions for each segment of the drive cycle. The model specifically outputs fuel consumption, pre-catalyst HC emissions, tailpipe HC emissions, pre-catalyst CO emissions, tailpipe CO emissions, pre-catalyst NO, emissions and tailpipe NO, emissions. At low loads and during decelerations, engine maps cannot be used to accurately predict fuel consumption and emission rates. As a result, separate idle and deceleration fuel consumption (pounds per hour) and emissions (grams per hour) rates are provided. The program can also calculate the average fuel economy in miles per gallon and the average emissions rates in grams per mile for the entire drive cycle.

EPA's efforts are based on an earlier simulation model, VEHSIM, a fuel economy model, which was developed at VNTSC in the early 1980's. VEMISS uses VEHSIM to estimate engine RPM and torque for a given drive cycle and vehicle configuration. The output from this module is used in a second module to predict fuel economy and emissions.

It must be emphasized that the current version of VEMISS, which the EPA informally released to interested parties in August 1992, is not a final version and only has preliminary engine maps and parts library files for the Saab 9000. In the future, the EPA plans to provide validated engine maps and parts files that can be used to estimate vehicle emissions for 29 late model automobiles. In addition, the EPA plans to include a cold-start algorithm, address the sensitivity of fuel consumption and emission rates to throttle position and make the program more user-friendly.

b. Proportional Rollback

The EPA developed the Proportional Rollback, which is as much an assumption as an actual model. Although more frequently used in air quality calculations, proportional rollback has been used in estimating effects of various interventions on emissions. The basic tenet is that a decrease (increase) in emissions activity such as travel (VMT) will bring proportional decreases (increases) in emissions. The present general consensus is that such an assumption can only be used for beginning analyses (for a first look).

The Proportional Rollback model can predict the emission reduction required to attain a certain air quality concentration (usually the applicable air quality standards) in some future year. The model uses the assumption that the ratio of future pollutant concentrations to present pollutant concentrations is proportional to the ratio of total future emissions to present total emissions. The model approximates only the regional and local pollutant air quality concentrations, but can not predict impacts at individual receptors.

c. CRC-Radian Evaporative Emissions Model

The Radian Corporation developed the CRC-Radian Evaporative Emissions Model (EVAP) in 1988 for the Coordinating Research Council. The model calculates diurnal and hot soak hydrocarbon evaporative emission rates. EVAP delineates the relationship between driving behavior and fuel tank temperature, and assesses the effect of fuel tank level on evaporation. EVAP considers such factors as fuel weathering, variations in ambient temperature, and automotive design.

EVAP uses the 1979 General Motors Automobile Usage Database as the basis for driving behavior assumptions, particularly time periods between trips. In addition, Radian tested five vehicles to evaluate the impact of trip duration on emissions. The model was last updated in June 1992.

4.4.2 Air Quality Models with Emissions Components

a. CALINE4

CALINE4 is an intersection analysis air quality model, developed for the California Department of Transportation, that can calculate driving mode emission rates. CALINE4 computes CO emission rates for idle, acceleration, cruise, and deceleration driving modes for a number of traffic situations, including special street canyons, parking lots, and intersections. The model can also estimate concentrations of nitrogen dioxide and aerosols.

Intersection emission factors were developed from Sun&lance Driving Sequence (SDS) test data from 1975-76 vehicles registered in California. CALINE4 also uses EMFAC emission factors as the basis for idle, acceleration, and deceleration emissions. The model was last updated in 1988.

CALINE4 normally requires that the user assign a composite emission factor for each link. At controlled intersections, however, the operational modes of deceleration, idle, acceleration, and cruise have a significant effect on the rate of vehicle emissions. Traffic parameters such as queue length and average vehicle delay define the location and duration of these emissions. The net result is a concentration of emissions near the intersection than cannot be modeled adequately by using a single, composite emission factor.

CALINE4 intersection link encompasses the acceleration and deceleration zones created by the presence of the intersection for one direction of traffic flow. A stop line distance is referenced to the link endpoints, and approach and depart traffic volumes are assigned. A full intersection can be modeled by using four of these links.

Cumulative modal emissions profiles representing the average deceleration, idle, acceleration, and cruise emissions per signal cycle per lane are constructed for each intersection link.

b. IMM

The EPA created the Intersection Midblock Model (IMM) in 1978 to evaluate carbon monoxide 'hot spots'. IMM, an air quality model, uses data from the 1977 update of the Modal Analysis Model to calculate CO emissions for cruise, acceleration, and deceleration driving modes. The model calculates idle emissions by adjusting MOBlLE1's idle rate. IMM accesses the HlWAY-2 dispersion model to determine the effects of emissions on air quality.

IMM includes intersection traffic methodologies to calculate the number of vehicles per lane, queue length, delay per stopped vehicle, and number of vehicles proceeding through the intersection without stopping.

c. MICRO2

Colorado Department of Highways developed MICRO2 in 1980 to assess air quality and fuel use effects of intersection traffic control projects. MICRO2 calculates HC, CO, and NO, emissions using data from the Modal Analysis Model and the MOBILE series for idle, cruise, acceleration, and deceleration driving modes. MICRO2 can provide an input file to the CALJNE3 dispersion model to predict CO emission impacts.

MICRO2 incorporates a conventional traffic procedure for signalized intersections. Vehicle emission rates were derived from Denver area data from the 1977 update of the Modal Analysis Model as well as the MOBILE series data.

d. TEXIN2

The Texas Intersection model is an air quality model that integrates intersection traffic analysis, excess emissions analysis, and dispersion modeling to predict CO concentrations near intersections.

Emissions at intersections are disaggregated into cruise, acceleration, deceleration, and idling driving modes. TEXIN2 uses data from the Modal Analysis Model and MOBILE2 to determine emission rates. The model will also accept cruise emission rates from tables developed by the FHWA. TEXIN2 uses a modified version of CALINE3 for dispersion analysis.

4.5 FUEL MODELS

The following fuel models are listed along with descriptions and are categorized according to their respective developers.

4.5.1. EPA Models

a. MOBILE4 Fuel Consumption Model

The MOBILE4 Fuel Consumption Model (M4FC) is EPA's latest version of its fuel consumption model. M4FC uses the outputs of MOBILE4 (note: M4FC is not linked to MOBILE4.1 or 5.0) to calculate fuel consumption rates for various vehicle types from 1982 to 2020. These rates must be multiplied by exogenously supplied VMT.

The MOBILE4 Fuel Consumption model was developed to estimate gasoline and diesel fuel used by motor vehicles. It is based on the MOBILE4 mobile source emissions model and predicts the amount of gasoline and diesel consumed for each of seven vehicle classes. Alternative fuels consumption factors are currently under review at EPA.

Both the registration and vehicle miles traveled distributions are at MOBILE4 levels. Separate city and highway fuel efficiencies have been included and allowance is made for the gradual shift to urban driving. M4FC estimates grams of carbon monoxide, hydrocarbons, and oxides of nitrogen emitted for each mile a vehicle travels. In general, these pollution estimates are not particularly sensitive to fuel economy. This is particularly true with respect to light duty vehicles and light duty trucks. Also, the model directly reads output from the MOBILE4 emissions model and estimates tons of hydrocarbons, carbon monoxide, oxides of nitrogen, and carbon dioxide.

Total fuel consumed is a function of the total number of vehicles, the number of miles each vehicle travels, and each vehicle's fuel economy. Therefore, the more vehicles there are and the more miles they travel, the more fuel they will consume. However, increased fuel economy will result in less fuel consumed. Fuel consumption is calculated using the following methodology:

Fuel consumption(i,j,k) = # of vehicles(i,j,k) x VMT(i,j,k)/fuel economy(i,j,k)

i = age (ranging from 1 to 30 years)
j = fuel type (gasoline, diesel, one of several alternative fuels)
k = vehicle class (one of seven vehicle classes)

Vehicle stock is based on estimates from the R. L. Polk Company while EPA's Fuel Economy Trends Report provides new vehicle test mpg for the 1975 to 1990 period. Absent any changes in the Corporate Average Fuel Economy (CAFE) standards, test fuel economy is assumed to remain constant at 1990 levels for all projection years. However, because projections are not fuel type specific, a diesel advantage factor is included to indicate the degree to which diesel fueled vehicles obtain a higher fuel economy than gasoline-powered vehicles. These two estimates, along with the model year specific diesel penetration rates for each model year, are combined to estimate separate gasoline and diesel fuel economies.

Test fuel economy is discounted to road fuel economy by applying a constant 0.90 multiplicative factor to city driving and a constant 0.78 factor to highway driving. These are weighted together using the calendar-year-specific proportion of urban driving listed in Highway Statistics to arrive at a road fuel economy.

4.5.2. Selected Traffic Models

a. TRANSYT-7F

TRANSYT-7F is a traffic model that can predict the fuel consumed within a network of signals as a function of the distance travelled, the total delay time, and the number of stops. The model was developed at the Transport and Road Research Laboratory in Britain and is essentially a signal optimization program. TRANSYT-7F is the Americanized version of TRANSYT-7F.

The coefficients used to relate the TRANSYT predictions of the distance travelled at cruise speed, the delay time, and the number of stops to the total fuel consumption reflect a 1983 average fleet mix.

b. **SATURN**

The Simulation and Assignment of Traffic to Urban Road Networks (SATURN) model was developed at the Institute for Transport Studies, University of Leeds, for the analysis and evaluation of traffic management schemes over relatively localized networks (typically in the order of 100 to 150 intersections). The primary purpose of the model is to simulate delays at intersections and can be used to analyze movement-based control systems such as one-way streets, changes to intersection controls, buses-only streets, etc. SATURN places great emphasis on intersections and specific turning movements as opposed to links.

SATURN calculates fuel consumption to represent a 1983 British average fleet mix using the following algorithm:

$$\text{Fuel consumption} = 0.07d + 1.2t + 0.016s_1 + 0.005s_2$$

where:

- f = fuel consumption in liters
- d = total travel distance in vehicle-kilometers
- t = total delayed (idling) vehicle-kilometers
- s_1 = total number of full stops at an intersection (where vehicle arrives at the end of a queue)
- s_2 = total number of secondary stops (e.g., stop-starts) while a vehicle moves up the queue

c. NETSIM

NETSIM calculates fuel consumption at each time step by relating each vehicle's speed and acceleration to tables of fuel consumption values. A table is included for each of three vehicle types: passenger cars, buses, and trucks.

d. NETFLO

NETFLO simulates traffic operations at any of three optional levels of aggregation, from treating traffic as a fluid (level III) to treating individual vehicles (level I). Fuel consumption is calculated internally for levels I and II by means of a fuel consumption model based on average speed. Level III does not have a fuel consumption capability.

e. FREFLO

FREFLO calculates fuel consumption by means of an internal fuel consumption model using the link specific average speeds and the interlink speed differences (which are treated as an acceleration wrrection).

4.5.3. Department of Energy Models

a. The Motor Fuel Consumption Model

The MFC model is used by the DOE to evaluate the impact of conservation policies on fuel consumption and on the disaggregate components of fuel demand. These components include passenger cars, light-duty trucks, and heavy-duty vehicles. The model is not a forecasting tool in that it does not provide detailed econometrically-based projections of fuel demand. The model is, however, calibrated to current statistics on fuel consumption, fleet size, travel growth, and to econometric forecasts of new vehicles sales.

The model estimates annual fuel demand for 1975 through 2000 by calculating two major parameters: annual vehicle miles of travel (VMT) and average on-road fleet fuel economy. The model computes total VMT and fleet mpg through the use of historical data and future estimates. Annual highway fuel consumption is calculated for diesel, leaded, unleaded, neat methanol, volumes of ethanol and methanol blended with gasoline as well as off-highway leaded and unleaded gasoline.

The MFC model has been used to evaluate the consumption impacts of revised projections of light duty truck Corporate Average Fuel Economy (CAFE) as well as the fuel consumption impacts of reductions in vehicle stock turnover.

b. Annual Energy Outlook Transportation Spreadsheet Model

The Energy Information Agency uses the transportation spreadsheet model to predict fuel efficiencies, vehicle-miles travelled, and other variables associated with energy consumption for four transportation models. These modes are personal highway travel, freight travel, aviation travel, and “other” transportation. The model is meant to be used for macro analysis and links fuel consumption to oil price and economic growth.

APPENDIX

TRAFFIC SIMULATION MODELS
INPUT/OUTPUT DATA TYPES

This appendix provides a listing of the six traffic models described in Chapter 3, with a detailed listing of the inputs and outputs of each. CORFLO, a wrridor model, is listed consisting of three submodels, NETFLO1, NETFLO2, and FREFLO. They are followed by another corridor model, INTEGRATION. Then two freeway models FREQ and FRESIM follow, in order, and conclude with two simulation models, ROADSIM and NETSIM. Each model is given individually with inputs listed first followed by outputs. Most models have elements wmmon with other models.

CORFLO Group - NETFLO 1 Inputs:

a. Run Control Data

Traffic assignments enabled.
Initialization period time.
Whether fuel consumption and emission output is required.
How many time periods will be simulated and the duration of the time period.
Graphical data output enabled

b. Link Description Data

Number of lanes.
Length of lanes.
Channelization data (such as car pools).
Lii specific traffic behavior (such as free flow speed).
Turning movement descriptions

c. Sign and Signal Control Data

Upstream node to intersection and intersection type: yield, stop, uncontrolled.
Upstream node to pre-timed signal intersection and durations for each signal interval.
Signal transition from one timing plan **to** another.
Actuated controller data:
Approaches and referenced links.

d. **Traffic and Vehicle Occupancy Data**

Traffic volumes entering from outside the network including percent carpools and/or trucks.
Traffic volumes entering or leaving the network from within the network are called source/sink links and are used to represent the behavior of minor traffic sources such as parking lots.
Vehicle occupancy: autos, car pools, trucks, and buses.

e. Traffic Assignment Parameters

Epsilon.
Maximum number of traffic assignment iterations.
Impedance function value either: FHWA or Davidson's.
Capacity smoothing factor.
Number of capacity iterations to be applied.
Line-search accuracy threshold.
Ratio of service discharge rate to saturation rate.
Percentage of impedances produced by an all or nothing network loading to be incorporated in the fist assignment iteration.

f. Origin-Destination Trip Table

Origin node.
Percent trucks leaving origin.
Percent car pools leaving origin.
Destination node(s) and volume from origin to destination.

g. Source/Sink Nodes

Source sink centroid number.
Upstream node number of internal link.
Downstream node number.

h. Bus Operations Data

Routes.
Frequency of service along the routes.
Type of bus stops.
Average dwell time at each bus stop.
Percent of buses not stopping at a stop.

i. Graphics Data

Location of each node relative to each other.
Curvature.
Overpasses and Underpasses.

CORFLO Group - NETFLO 1 Outputs:

Turning movement data table: link number, turn movement percent (left, through, right, diagonal), turn movement possible (left, through, right, diagonal), blockage (percent, seconds), pocket length (left, right).

Link table: link number, length, Lanes (full, pocket left, pocket right), grd percent, link type, lane channelization codes, destination node (left, thru, right, diagonal), opposite node, lost time, queue discharge headway, free speed, rtor code, ped code.

Signal wntrol data output table by node: interval #; offset duration in sec. and percent by approach, total cycle length.

Traffic wntrol table by node and phase: offset, cycle length, duration .

Traffic assignment result table: link, internal centroid, right turn (volume, percent), through (volume, percent), left turn (volume, percent), diagonal (volume, percent), source flow, sink flow, discharge volume, speed estimate.

Entry link volume table: link, flow rate, trucks, carpools.

Cumulative statistics by link: vehicle (miles, trips), Vehicle minutes (move time, delay time, total time), ratio move./ total, Min./ mile (total time, delay time), sec./ vehicle (total time, delay time), average (stops, volume, speed, occup. veh, storage).

Bus statistics by link: bus trips, person trips, travel time, moving time, delay time, M/T, # of stops.

Environmental MOE by link: avg. mph, veh-mi per gallon, person-mi. per gallon, gallons of fuel, grams per mile (CO, HC), Kilograms (CO, HC).

Person measures of effectiveness by link: person miles, person trips, delay person-min,. travel time person-min..

Run control: ID number, next case code, run type code, NETFLO fuel run code, input / output units code, clock time at start of simulation, random number seeds, duration of time period 1, duration of histogram time-slice, number of time slices per time interval, length of time interval, max. initialization time, number of time intervals between successive standard outputs, number of time intervals between successive intermediate outputs for macroscopic models.

Traffic assignment parameter data: epsilon, line search accuracy of obj. function, max. number of assignment iterations, max. number of capacity calibration, carry-over capacity factor, type of objective function, impedance function alpha, impedance function beta.

Trip table by origin node: destination node, volume.

Internal centroid table: centroid number, link.

Sink volume table: destination node, volume.

Source volume table: origin node, volume.

Trip table by estimation node: origin node, volume.

Network wide traffic assignment: geometric link, path-link receiver, length, free flow time (onlink, total), travel time, capacity, volume, speed, turn type, receiver **type.**

Network initialization statistics table by time interval: subnetwork type, prior content (vehicles), current content, percent difference.

CORFLO Group - NETFLO 2 Inputs:

a. Run Control Data

Traffic assignments enabled.
Initialization period time.
Whether fuel consumption and emission output is required.
How many time periods will be simulated and the duration of the time period.
Graphical data output enabled.

b. Link Description Data

Number of lanes.
Length of lanes.
Channelization data (such as car pools).
Link specific traffic behavior (such as free flow speed).
Turning movement descriptions

c. Sign and Signal Control Data

Upstream node to intersection and intersection type: yield, stop, uncontrolled.
Upstream node to pre-timed signal intersection and durations for each signal interval.
Signal transition from one timing plan to another.

d. Traffic and Vehicle Occupancy Data

Traffic volumes entering from outside the network including percent trucks.

Traffic volumes entering or leaving the network from within the network are called source/sink links and are used to represent the behavior of minor traffic sources such as parking lots.

Vehicle occupancy: autos, car pools, trucks, and buses.

e. Traffic Assignment Parameters

Epsilon.

Maximum number of traffic assignment iterations.

Impedance function value either: FHWA or Davidson's.

Capacity smoothing factor.

Number of capacity iterations to be applied.

Line-search accuracy threshold.

Ratio of service discharge rate to saturation rate.

Percentage of impedances produced by an all or nothing network loading to be incorporated in the first assignment iteration.

f. Origin-Destination Trip Table

Origin node.

Percent trucks leaving origin.

Percent car pools leaving origin.

Destination node(s) and volume from origin to destination.

g. Source/Sink Nodes

Source sink centroid number.

Upstream node number of internal link.

Downstream node number.

h. Bus Operations Data

Routes.

Frequency of service along the routes.

Type of bus stops.

Average dwell time at each bus stop.

Percent of buses not stopping at a stop.

i. Graphics Data

Location of each node relative to each other.

Curvature.

Overpasses and Underpasses.

CORFLO Group - NETFLO 2 Outputs:

Link table: link, length, lanes (full, pocket left, pocket right), grd percent, channelization codes, destination node (left, thru, right, diagonal), opp. node, lost time, queue discharge headway, free speed, rtor code, ped code.

Turning movement data table: link number, turn movement percent (left, through, right, diagonal), turn movement possible (left, through, right, diagonal), blockage (percent, seconds), pocket length (left, right).

Signal control data output table by node: interval #, offset duration in sec. and percent by approach, total cycle length.

Traffic control table by node and phase: offset, cycle length, duration .

Cumulative statistics by link: vehicle (miles, trips), Vehicle minutes (move time, delay time, total time), ratio move/ total, Min/ mile (total time, delay time), sec./ vehicle (total time, delay time), average (stops, volume, speed).

Bus statistics by link: bus trips, person trips, travel time, moving time, delay time, M/T, # of stops.

Environmental MOE by link: avg. mph, veh-mi per gallon, person-mi. per gallon, gallons of fuel, grams per mile (CO, HC), Kilograms (CO, HC).

Person measures of effectiveness by link: person miles, person trips, delay person-min, travel time person-min.

Run control: ID number, next case code, run type code, NETFLO fuel run code, input / output units code, clock time at start of simulation, random number seeds, duration of time period 1, duration of histogram time-slice, number of time slices per time interval, length of time interval, max. initialization time, number of time intervals between successive standard outputs, number of time intervals between successive intermediate outputs for macroswpic models.

Traffic assignment parameter data: epsilon, line search accuracy of obj. function, max. number of assignment iterations, max. number of capacity calibration, carry-over capacity factor, type of objective function, impedance function alpha, impedance function beta.

Trip table by origin node: destination node, volume.

Internal centroid table: centroid number, link.

Sink volume table: destination node, volume.

Source volume table: origin node, volume.

Trip table by estimation node: origin node, volume,

Network wide traffic assignment: geometric link, path-link receiver, length, free flow time (onlink, total), travel time, capacity, volume, speed, turn type, receiver type.

Network initialization statistics table by time interval: subnetwork type, prior content (vehicles), current content, percent difference.

CORFLO Group - FREFLO Inputs:

a. Run Control Data

Traffic assignments enabled.
Initialization period time.
Whether fuel consumption and emission output is required.
How many time periods will be simulated and the duration of the time period.
Graphical data output enabled.

b. Freeway Link Characteristics

Length of link.
Number of regular use lanes.
Number of HOV lanes
Equilibrium speed density relationship for link.
Lane use type for HOV lanes.
Nominal capacity in vehicles per lane per hour.
Free flow speed.
Freeway turning movements.

c. Freeway Incident Data

Number of lanes blocked regular use and special purpose.
Volume constraint for regular use and special purpose lanes.

d. Freeway Parameters

Relaxation time coefficient.
Anticipation coefficient.
Speed-density relationships.

e. Traffic and Vehicle Occupancy Data

Traffic volumes entering from outside the network including percent carpools and/or trucks.
Vehicle occupancy: autos, car pools, trucks, and buses.

f. Short Term Event Data

Mean frequency of event.
Mean duration of event.

g. Traffic Assignment Parameters

Epsilon.
Maximum number of traffic assignment iterations.
Impedance function value either: FHWA or Davidson's.
Capacity smoothing factor.
Number of capacity iterations to be applied.
Line-search accuracy threshold.
Ratio of service discharge rate to saturation rate.
Percentage of impedances produced by an all or nothing network loading to be incorporated in the first assignment iteration.

h . Origin-Destination Trip Table

Origin node.
Percent trucks leaving origin.
Percent car pools leaving origin.
Destination node(s) and volume from origin to destination.

i. Bus Operations Data

Routes.
Frequency of service along the routes.
Average dwell time at each bus stop.
Percent of buses not stopping at a stop.

j. Graphics Data

Location of each node relative to each other.
Curvature.
Overpasses and Underpasses.

CORFLO Group - FREFLO Outputs:

Link table: Number, length, number of lanes(regular & special), speed density relation, special purpose lane use (buses and carpools), nominal capacity, free speed, through node (first & second), ramp node (on and off).

Subnetwork parameters table: relation time coefficient, anticipation coefficient, time slice duration, coefficients for speed-density relationships.

Traffic assignment: link, First through movement (volume & percent), Second through movement (volume & percent),Off ramp movement (volume & percent), total discharge volume, estimated average speed.

Entry link volumes: link, flow rate, trucks, car pools.

Cumulative statistics by link: vehicle (miles, trips), Vehicle minutes (move time, delay time, total time), ratio move/ total, Min/ mile (total time, delay time), sec./ vehicle (total time, delay time), average (volume, speed), person miles, person trips, person-minutes (total time, delay time).

Run control: ID number, next case code, run type code, NETFLO fuel run code, input / output units code, clock time at start of simulation, random number seeds, duration of time period 1, duration of histogram time-slice, number of time slices per time interval, length of time interval, max. initialization time, number of time intervals between successive standard outputs, number of time intervals between successive intermediate outputs for macroscopic models.

Traffic assignment parameter data: epsilon, line search accuracy of obj. function, max. number of assignment iterations, max. number of capacity calibration, carry-over capacity factor, type of objective function, impedance function alpha, impedance function beta.

Trip table by origin node: destination node, volume.

Internal centroid table: centroid number, link.

Sink volume table: destination node, volume.

Source volume table: origin node, volume.

Trip table by estimation node: origin node, volume.

Network wide traffic assignment: geometric link, path-link receiver, length, free flow time (onlink, total), travel time, capacity, volume, speed, turn type, receiver type.

Network initialization statistics table by time interval: subnetwork type, prior content (vehicles), current content, percent difference.

FREQ Inputs

a. Run Control Data

Run options: simulation, optimization, short trip spatial response, longer trip spatial response, modal response.

Control strategy: maximize passenger input, maximize vehicle input to the freeway, maximize vehicle-miles of freeway travel, maximize passenger-miles of freeway travel.

Order of simulation: input data, simulation before control, simulation after control, simulation and optimization after short trip spatial response, simulation and optimization after longer trip spatial response, simulation and optimization after modal response.

O-D usage: equivalent hourly flow rates for the time slice or, time slice count.

Analysis options: perform weaving analysis, parallel route is provided, perform mainline delay calculations, user or program supplied V/C ratios, user supplied fuel rates or program supplied, emissions rates: (1980 California, 1980 49 state, user supplied), user supplied ramp limit or 1500 VPH default, user supplied metering plan or program optimization metering plan, user supplied or program supplied priority cutoff and/or ramp control, default metering rates of max =900 VPH & min = 180 VPH or user supplied, user supplied queue length limit or none, modal shift calculations: (automatic, on-vehicle travel time / 4.5 percent busses / 7.0 percent carpools, carpools of 3 or more passengers), modal shift sensitivity (low level bus availability, medium level bus availability, high level bus availability).

b. Parameters

Number of freeway subsections.

Number of time slices.

Number of time slices per hour and the factor by which each time slice O-D table will be multiplied.

Average arterial occupancy.

Desired speed for mainline delay calculations.

Average design speed on the freeway.

Percentage of all vehicles on the alternate route which are trucks.
Percentage of trucks on the alternate route which are diesel-powered.
Buffer factor for the maximum metering rate.
Maximum V/C ratio of all subsections in order for metering to occur.
Capacity buffer.
Minimum perceived travel time savings for spatial shift and modal shift demand responses.
Magnitude of the modal shift towards carpools.
Rounding factor for the destination time slice of the forward type of temporal response.
Time of day at the beginning of the first time slice.

c. Subsection Descriptions.

Number of the subsection.
Number of lanes.
Subsection capacity.
Length of the subsection.
Arterial capacity for the subsection.
Family of speed-flow curves to be used on this subsection, if different from the parameter value.
Progression: good, poor, no signal.
Ramp : on, off, none.
Special ramp: two lane on-ramp, left hand on or off-ramp, none
Mean freeway subsection gradient.
Mean alternate route gradient for the subsection.
Percent of all vehicles on the subsection which are trucks.
Percent of all trucks in the subsection that are diesel-powered.
Free-flow speed.

d. Ramp Limits Card.

User supplied general ramp limit for every ramp.
Up to six on-ramp and three off-ramps can be assigned different ramp limits.

e. Queue Limit Data

Up to 20 ramps can be specified.

Ramp number.
Maximum number of vehicles that can queue of this ramp.

f. Speed Flow Curves Data

For user specified speed flow curves Max of 24 points for each curve

X point for volume/capacity ratio.

Y point for speed.

g. Mainline Fuel Rate Data (User supplied fuel rate data)

For freeways for each vehicle class of (automobiles, single-unit gas trucks, combination trailer-diesel trucks) fuel rate at x miles per hour where x starts at 5 MPH and goes up to 70 MPH in 5 MPH increments, fuel rate at idle.

For arterials for each vehicle class of (automobiles, single-unit gas trucks, combination trailer-diesel trucks) fuel rate at x miles per hour where x starts at 5 MPH and goes up to 40 MPH in 5 MPH increments.

h. User Supplied Emission Rate Data

For each of the following categories emission data is entered: HC from automobiles, HC from single-unit gas trucks, HC from combination diesel trucks, CO from automobiles, CO from single-unit gas trucks, CO from combination diesel trucks, NO, from automobiles, NO, from single-unit gas trucks, NO, from combination diesel trucks. The data entered is as follows: emission rates for each average subsection for speed from 5 MPH to 70 MPH in 5 MPH increments, fuel rate at 70 MPH, emission rate at idle.

i. Occupancy Data by origin

Proportion of one passenger vehicles, Proportion of two passenger vehicles, Proportion of vehicles with three or more occupants, Proportion of buses, Average occupancy of vehicles with three or more occupants, average occupancy of buses.

j. Time Slice O-D Data

By time slice 1 to 4 0 - D tables can be entered for one-passenger autos, two passenger autos, three or more passenger autos, buses - these 0 - D tables override the passenger occupancy data.

k. Arterial Flow Data

Flow of the arterial of each subsection per time slice in hourly rates.

1. Ramp Count Data for use with Synthetic O-D Table Generator Utility

Location of each origin by subsection number, Location of each destination by subsection number, Total traffic demand of each origin for each time period in veh/hr, Total traffic demand of each destination for each time period in veh/hr, growth rates for individual ramps.

m. Ramp Control Features

Lower limit of the occupancy level of priority vehicles which are not metered for all ramps (if used), By ramp: lower limit for the occupancy of unmetered traffic at a ramp, no control option, priority vehicle use only option, ramp closed to all traffic option, automobile only option, buses only option.

n. Maximum Metering Rate Data

Maximum metering rate in vehicles per hour for each on-ramp for each time slice.

o. Minimum Metering Rate Data

Minimum metering rate in vehicles per hour for each on-ramp for each time slice.

FREQ Outputs

Summary input information: Times of run, functions used, number of time slices per hour, weaving analysis on/off, the arterial occupancy rate, internal or user supplied speed flow curves, internal or user supplied fuel data, type of emission rates, alternate route truck percentage, metering constraints, capacity buffer.

Freeway and arterial design feature report by subsection: subsection number, number of lanes, length, design speed, origin and/or destination, truck factor, gradient, percent trucks, percent diesel trucks, special ramp (yes/no), free flow speed on alternate route, capacity of alternate route, arterial type, grade of alternate route, subsection location.

Ramp delays by on-ramp and time slice: ramp number, queue length in vehicles, delay in veh-hrs, average metering delay in min for input point, merging point, and total.

Freeway performance table by time slice and subsection number: number of subsection, number of lanes, length, O-D data demands by volume(origin, destination, demand), Adjusted volumes(origin, destination, volume), freeway capacity, weave efficiency, queue length, storage rate, V./C, speed, fuel consumption in MPG, HC in GSIVM, CO in GS/VM, NO_x in GS/VM. Total length of sections, Max V/C, Avg Speed, Avg fuel consumption, Avg HC, avg CO, avg. NO,.

Arterial performance table by time slice and subsection number: number of subsection, length, original demand, modified demand, diverted demand (origin, destination), arterial capacity., V./C, speed, fuel consumption in MPG, HC in GS/VM, CO in GS/VM, NO_x in GS/VL., Max V/C, Avg Speed, Avg fuel consumption, Avg HC, avg CO, avg. NO,.

Distribution of vehicle occupancy by on-ramp number: on-ramp number, percent of 1 passenger autos, percent of 2 passenger autos, percent of 3 or more passenger autos, percent of buses, average carpool (3+) occupancy, average bus occupancy.

Freeway summary table by time slice: time slice number, freeway travel time(veh-hr, pas-hr.), ramp delay (veh-hr, pas-hr), total freeway travel time (veh-hr, pas-hr), total travel distance (veh-mi, pas-mi), average speed, gasoline consumed in gallons, HC emissions in KG, CO emissions in KG, NO, emissions in KG, begin time of time slice, Totals for all above categories.

Arterial summary table by time slice: time slice number, arterial travel time(veh-hr, pas-hr.), arterial travel distance (veh-mi, pas-mi), average speed, gasoline consumed in gallons, HC emissions in KG, CO emissions in KG, NO, emissions in KG, marginal demand in veh-hrs, begin time of time slice, Totals for all above categories.

Metering plan summary table by on-ramp number: number of on-ramp, original demand (veh, passengers) metering limits (min, max.) priority cut off level, freeway input rate (veh, pass) non-priority metering rate, preset control strategy, total original demand (veh, pass), total freeway input rate(veh, pass). Total demand (current time period (veh, pass), cumulative(veh, pass)), Total metered demand (current time period(veh, pass), cumulative(veh, pass)), Total transferred demand (current time period(veh, pass), cumulative(veh, pass)), Total diverted demand (current time period(veh, pass), cumulative (veh, pass).

Ramp control summary table by time slice: time slice number, metering rate, queued vehicles, diverted vehicles for each on-ramp.

Optimization summary table by time slice: time slice number, total demand (veh, pass), diverted demand (veh, pass), transferred demand (veh, pass), metered demand (veh, pass), percent diverted (veh, pass), percent transferred (veh, pass), percent metered (veh, pass), begin time of time slice, totals for all the above categories.

Plot of user supplied speed - flow curves.

Origin - Destination Table.

Freeway travel times in minutes in O-D table format.

Speed contour diagram.

Queue length contour diagram.

FRESIM Inputs:

a. Run Control

Time step.
Frequency at which lane change logic is implemented in time steps.
Seed for random number.
Max. length of initialization.
Simulation starting time on 24 hour clock.

b. Link Geometry data.

Upstream and downstream link.
Link length.
Link type: urban, ramps, freeway.
Mean desired free-flow speed.
Number of thru lanes.
Grade.
Downstream node at end of link receiving left turning traffic.
Downstream node at end of link receiving through traffic.
Downstream node at end of link receiving right turning traffic.
Location on this freeway link at which drivers begin to react to an upcoming exit or location where early waming sign becomes visible to the motorist.
Node locating off-ramp, freeway junction.

c. Link Names

Node at upstream and downstream ends of link.
Link name.

d. Link Operations

Node at upstream and downstream ends of link.
Radius of curvature.
Type of auxiliary lane for 1st aux. lane
Length of 1st aux. lane.
Type of auxiliary lane for 2nd aux. lane

Length of 2nd aux. lane.
Identification of lane entered in through receiving link by vehicles in lane 1 of this link: 2nd **Aux.** left lane, 1st Aux. left lane, lane 5, lane 4, lane 3, lane 2, lane 1.
Specification of lanes separated by physical barriers which prevent weaving.
Superelevation.
Pavement type: dry concrete, wet concrete, dry asphalt, wet asphalt.
Distance from upstream node of link for freeway data station.
Distance from upstream node of link for another freeway data station.

e. Ramp Link Operation.

Node at upstream and downstream ends of link.
"Type" of downstream intersection, used to select appropriate distribution about mean queue discharge headway.
Identification of lane entered in through receiving link by vehicles in lane 1 of this link: 2nd Aux. left lane, 1st Aux. left lane, lane 5, lane 4, lane 3, lane 2, lane 1.
Radius of curvature.
Superelevation.
Pavement type: dry concrete, wet concrete, dry asphalt, wet asphalt.

f. Surface Link Operation

Node at upstream and downstream ends of link.
"Type" of downstream intersection, used to select appropriate distribution about mean queue discharge headway.
Mean queue discharge headway, in tenths of a second.
Lost time for first vehicle in queue when signal becomes green.
Upstream node of link whose thru traffic opposes left turning traffic from this link.
Size of right turn pocket.
Size of left turn pocket.
Channelization code for lane 1: unrestricted, reserved for left turn vehicles, closed for this subinterval, reserved for right-turn vehicles.
Channelization code for lane 2: unrestricted, reserved for left turn vehicles, closed for this subinterval, reserved for right-turn vehicles.
Channelization code for lane 3: unrestricted, reserved for left turn vehicles, closed for this subinterval, reserved for right-turn vehicles.
Channelization code for lane 4: unrestricted, reserved for left turn vehicles, closed for this subinterval, reserved for right-turn vehicles.
Channelization code for lane 5: unrestricted, reserved for left turn vehicles, closed for this subinterval, reserved for right-turn vehicles.

g. Link Turning Movement

Node at upstream and downstream ends of link.
Percentage of vehicles turning left at downstream node.

Percentage of vehicles traveling through at downstream node.
Percentage of vehicles turning right at downstream node.

h. Sign and Signal Control

Node number.
Actuated signal index to a subroutine.

i. Sign and Fixed Time Control

Reference offset to interval 1
Upstream node number of approach link number 1.
Upstream node number of approach link number 2.
Upstream node number of approach link number 3.
Upstream node number of approach link number 4.
Control code for signal facing approach link number 1 during interval 1: yield sign or amber, green, red, red with green right arrow, red with green left arrow, stop or red with right turn permitted after stop, no turns - green thru arrow, red with left and right green arrows, no left turn - green thru and right.
Control code for signal facing approach link number 2 during interval 1.
Control code for signal facing approach link number 3 during interval 1.
Control code for signal facing approach link number 4 during interval 1.
Duration of control interval 1.
Control code for signal facing approach link number 1 during interval 2.
Control code for signal facing approach link number 2 during interval 2.
Control code for signal facing approach link number 3 during interval 2.
Control code for signal facing approach link number 4 during interval 2.
Duration of control interval 2.
Control code for signal facing approach link number 1 during interval 3.
Control code for signal facing approach link number 2 during interval 3.
Control code for signal facing approach link number 3 during interval 3.
Control code for signal facing approach link number 4 during interval 3.
Duration of control interval 3.
Control code for signal facing approach link number 1 during interval 4.
Control code for signal facing approach link number 2 during interval 4.
Control code for signal facing approach link number 3 during interval 4.
Control code for signal facing approach link number 4 during interval 4.
Duration of control interval 4.
Control code for signal facing approach link number 1 during interval 5.
Control code for signal facing approach link number 2 during interval 5.
Control code for signal facing approach link number 3 during interval 5.
Control code for signal facing approach link number 4 during interval 5.
Duration of control interval 5.
Control code for signal facing approach link number 1 during interval 6.
Control code for signal facing approach link number 2 during interval 6.
Control code for signal facing approach link number 3 during interval 6.
Control code for signal facing approach link number 4 during interval 6.

Duration of control interval 6.

j. Actuated Control Format

24 parameter values may be specified. A definition of these parameters for six ramp metering and freeway traffic diversion follows: The first four actuated control methods are reserved for on-ramp metering algorithms developed for FRESIM. For all four metering procedures, it is assumed that only one link approaches the node at which metering is applied. This node must be the upstream node of a ramp link.

k. Clock Tie Ramp Metering

Node number.
"Basic" or "metered" signal code.
Movement for which discharging vehicle triggers return to "Basic " signal code: left-turn, through, right-turn.
Time for onset of clock time metering.
Metering headway.

1. Demand/Capacity Ramp Metering

Upstream and downstream node of freeway link containing detectors to be used in measuring freeway performance.
Lane containing first detector to be used in measuring freeway volume.
Longitudinal position of detector(s) in lane.
Capacity of freeway.

m. Speed Control Metering

Lane containing detector to be used as indicator of freeway speed.
Longitudinal position of detector in lane.
Speed threshold.
Metering headway. Signal will be set to "Metered" code at this frequency if speed is below speed threshold.
Second and third speed criteria.

n. Gap Acceptance Merge Control

Lane containing coupled loop detector to be used to measure speed and size of gap in freeway traffic and speed.
Longitudinal position of coupled loop detector.
Minimum acceptable gap.

o. Clock Time Diversion

Node number at diversion point on freeway.

Time for onset of clock time diversion.
Percent of through traffic to be diverted to alternate path.
Nodes defining alternate paths of diverted traffic.

p. Least Time Path Diversion

Node number at diversion point on freeway.
Nodes defining alternate path of diverted traffic.

q. Intersection Actuated Traffic Control.

Node number where actuated controller is located.

r. Actuated Controller.

Node number of intersection controlled by an actuated signal controller.
Upstream and downstream node number of approach number 1 which is serviced by this actuated controller.
Upstream and downstream node number of approach number 2 which is serviced by this actuated controller.
Upstream and downstream node number of approach number 3 which is serviced by this actuated controller.
Upstream and downstream node number of approach number 4 which is serviced by this actuated controller.
Upstream and downstream node number of approach number 6 which is serviced by this actuated controller.
Upstream and downstream node number of approach number 7 which is serviced by this actuated controller.
Controller coordination code: yes, or no.
Red rest code: yes or no
Value of background cycle length (if controller is coordinated).
Entry code: single ring, dual ring and single entry, dual ring and dual entry.
Detector switching code: active or inactive.

s. Phase Data

Node number.
Phase number.
Phase actuation code.
Phase non-actuated: yield point, end of yield interval, offset.
Phase actuated: force-off point, minimum initial interval, initial interval code.
Initial interval code.
Initial actuation data.
Passage time.
Minimum gap.
Time to reduce to minimum gap.
The controller reduces the gap by this amount.

Time between reduction in gap.
The gap reduction amount.
Maximum extension.
Maximum green
Amber duration.
Red clearance.
Red revert
Recall switch code.
Inhibit maximum termination code.
Overlap code.

t. Phase Operations.

Node number at which actuated controller is located.
Phase number.
Signal code identifying the signal indication servicing approach numbers 1 - 4 during this phase.
Approach and lane containing detector(s) that when actuated issues call for its phase when inactive.
Approach and lane containing detector(s) that when actuated issues call for its phase when active.

u. Volume Card

Node at upstream and downstream end of link.
Flow rate.
Percent of high performance passenger car.
Percent of intercity bus
Percent of heavy single unit truck.
Percent of trailer truck.
Percent of vehicles assigned to lane 2.
Percent of vehicles assigned to lane **3.**
Percent of vehicles assigned to lane 4.
Percent of vehicles assigned to lane 5.

v. Surveillance Specification.

Node at upstream and downstream end of link.
Location of detector.
Detector type: doppler radar, short loop, coupled pair of loops.
Effective loop length.
Lane code of detector: 1, 2, 3, 4, 5, first aux. left lane of left turn pocket, second aux. left lane, first aux. right lane, second aux. right lane.
Distance separating coupled pairs of short loops.

u. Incident Specification

Node at upstream and downstream end of link.
Incident code by lane (l-5 and 1st and 2nd left and right aux. lanes): normal speed, traffic capacity reduced at point of incident by amount specified by "rubber neck" factor, blockage at point of incident.
Longitudinal location of incident.
Length of roadway affected by incident.
Time of onset of incident.
Duration of incident.
"Rubber neck" factor - the percent reduction in capacity at point of incident.

FRESIM Outputs:

Link Definition Report by link: number of lanes, length, aux. lane lengths, mean free-flow speed, grade, percent of volume/destination nodes: (left, thru, right), curvature (radius, pavement cond., superelevation), right lane of pair separated by a physical barrier, downlink through receiving lane.

Advance Warning Signs by link: distance from downstream node, node locating off-ramp, distance from off-ramp.

Ramp Link Report by link: number of lanes, length, mean free-flow speed, grade, percent of volume/destination nodes (left, thru, right), type of downstream intersection, mean queue discharge headway, lost time, curvature (radius, pavement cond, superelevation), on/off ramp, downlink through receiving lane.

Surface links report by link: number of lanes, length, capacity of left and right turn pockets, mean free-flow speed, grade, percent of volume/destination nodes (left, thru, right), type of downstream intersection, lost time, mean queue discharge headway, id of source traffic opposing left-turners, lane channelization for each lane.

Sign and signal control definition report by node: interval, duration, offset, signal codes facing approaches.

Entry link statistics by link: total flow rate, percent by vehicle type, percent vehicles by lane.

Specification of surveillance detectors by link: station number, detector number, lane, type, location, length of loop(s).

Incident Definition report by link: incident code by lane, upstream location, length affected, time of onset, duration, rubberneck factor.

Freeway Link Statistics by link: Vehicles entering link, vehicles exiting link, number of lane changes, Current number of vehicles on link, Average number of vehicles on link, vehicle-miles, vehicle-minutes, seconds/vehicle (total time, movement time, delay time), move time/total time, vehicle-minutes/vehicle-mile total, delay, volume vehicle/lane/hour, density vehicles/lane-mile, speed mile/hour; averages and totals of all.

Ramp and surface statistics by link: Vehicles entering link, vehicles exiting link, Current number of vehicles on link, Average number of vehicles on link, vehicle-miles, vehicle-minutes, speed, seconds/vehicle (total time, movement time, delay time), move time/total time, vehicle-minutes/vehicle-mile (total, delay), percent queue delay average saturation percent, cycle failure, link type.

Freeway station headway and speed report by link and lane: mean speed, mean headway, percent of traffic at or below indicated speed (approx. 24 - 50 by 2 mph steps) 9 percent of traffic at or below indicated headway (approx. from 1.0 to 6.2 seconds by 0.4 second steps)

Intermediate link report by link: type, number of vehicles on link, number of vehicles discharged, turn movement (left, thru, right), current number of vehicles in lane by lane, delay/veh, queue delay, cycle failures, surface link channelization, average speed, signal code, number of lane changes.

Cumulative values of fuel consumption and of emissions by link: type of link, fuel consumption (gallons by vehicle type, mpg by vehicle type), vehicle emissions(HC by vehicle type, CO by vehicle type, NO, by vehicle type).

Surveillance detector report by link and detector and time period: volume, time mean speed, mean headway, mean occupancy.

Surveillance detector report from station to station by time: volume in, volume out, space mean speed, density of vehicles per lane mile.

Measure of Effectiveness (MOE) reports: vehicles discharged for all links and network, delay time for all links and network, lane changes for freeway links, density for freeway links and network, average saturation percent for non-freeway links, vehicle-miles for all links and network, travel time for all links and network, volume for freeway links, time in queue for non-freeway links, average speed for all links and network.

INTEGRATION Inputs:

a. Run Control Data

Simulation time.
Frequency of outputs to listing file.
Frequency of outputs to numeric file.
Frequency of outputs to the screen.
Frequency of minimum path outputs to the screen.
Update frequency for minimum path trees for vehicle types 1 to 5.
Amount of error introduced into the real-time data prior to tree building. This will produce either a normally distributed error or a log-normal distributed error.

b. Node Coordinates for graphics purposes and Node Type Designation.

Number of nodes.
Node number.
X and y coordinated of the node location for display on screen and plots,
Node/Zone Identifier: both trip origin and destination, trip destination only, trip origin only, node only.
Information availability at node: no RGS beacon or Changeable Message Sign (CMS) installed, CMS installed

c. Link Structure and Characteristics Descriptor Data.

Number of links.
Link number.
Start and end node of link.
Length of link.
Free-flow speed.
Basic free flowing saturation flow per lane.
Number of lanes on link.
Platooning dispersion factor as per TRANSYT.
Rate of increase in travel time for increases in Volume/Capacity ratio. (1st derivative)
Rate of increase of rate of increase in travel time for increases in Volume/Capacity ratio. (2nd derivative)
Number of the traffic signal which control this link.
Number of the first phase of discharge of the above signal for this link.
Number of the second phase of discharge of the above signal for this link.
High Occupancy Vehicle (HOV) use indicator: all vehicle types, only HOV vehicles.
Surveillance indicator: yes or no.

d. Time Series of Signal Timings.

Number of traffic signals with the traffic network.
Number of traffic signal plans.
Signal plan duration in seconds in multiples of 60 seconds.
Plan number.
Traffic signal number.
Initial cycle length that will be utilized in the simulation.
Minimum cycle length that will be allowed in any subsequent optimization.
Maximum cycle length that will be allowed in any subsequent optimization.
Offset of the first phase of the traffic signal.
Number of phases at the signal.
For each phase: effective green of phase duration, effective lost time of phase, interval of how often signal participates in any optimization.

e. Vehicle Departure Rates by O-D Pair.

Number of origin destination (O-D) pairs.
O-D pair number.
Origin node.
Destination node.
Departure rate.
Fraction of the vehicle headway that is random.
Time at which the given O-D flow rate starts.
Time at which the given O-D flow rate ends
The probabilities of vehicle types 1 - 5.

f. Incident Descriptor Data.

Number of incidents in the simulation.
Number of the incident.
Number of the link impacted by the incident.
Number of lanes affected by the incident.
Time at which the incident starts.
Time at which the incident ends.

g. Summary of Average Link Flows/Travel Times on Link Data.

Number of time periods.
Duration of each time period.
Number of links in the network.
Maximum link number.
Time for period and period number.
Number of the link.
Hourly traffic flow on the link averaged over the entire simulation.
Net capacity of the link prior to incidents, signals or ramp meters.
Link free flow time on link, constant for entire simulation.

Link’s average user travel time over entire simulation.
Link’s average marginal system time over entire simulation.
Link’s standard deviation of user travel time over entire simulation.
Link’s average queue over entire simulation period.
Average hourly number of stops during simulation period.
Average maximum allowed number of vehicles per link.
Average number of vehicles on link during simulation.
Average link speed of vehicles during simulation.
Average occupancy during simulation based on vehicle detection length of 5m.

h. Time-Series of Anticipated Link Flows/Travel Times for Vehicle Type 1 and/or 3 Data.

Number of periods.
Duration of each time period.
Number of links in the network.
Maximum Sink number.
Time at the start of the time period.
Number of the time period.
Number of the link.
Hourly traffic flow rate on the link during given time period.
Net capacity of the link during the time period prior to incidents, signals, or ramp meters, constant value.
Link’s free flow time during the time period, constant value.
Link’s user travel time at the conclusion of the given time period.
Link’s marginal system time at the conclusion of the given time period.
Standard deviation of user link travel time.
Queue on link at conclusion of time period.
Total number of stops during the time period.
Maximum allowed density of vehicles on link at end of time period.
Actual current density of vehicles on link at end of time period.
Average speed of vehicles at the end of the time period.
Average occupancy of vehicles on link at the end of the time period.

i. Externally Specified Constant All-Or-Nothing Routings for HOV Vehicle Type 5.

Number of periods for which trees are provided.
Duration of each time period
Number of nodes in network
Maximum node number.
Maximum destination number.
Period number.
Number of trees in period.
Tree number within time period.
Percent weighting applied to tree.
Node vehicle is currently at.
Link to be taken at “node” in order to reach destination.

j. Time-series of Multipath Routings For Vehicle Type 1.

Number of periods for which trees are required.
Duration of each time period
Number of nodes in network
Maximum node number.
Maximum destination number.
Period number.
Number of trees in period.
Tree number within time period.
Percent weighting applied to tree.
Node vehicle is currently at.
Link to be taken at "node" in order to reach destination.

INTEGRATION Outputs:

Maximums: number of O-D pairs, number of vehicles , number of vehicle types, number of links, node number, links into/out of node, number of vehicles on network, zone number, number of future time steps, signal number, number of phases per signal, number of random number seeds, number of equilibrium paths, number of TravTek time factors, number of TravTek vehicles, number of TravTek tree links, number of forward tree nodes, number of forward minutes.

Input and Output data file names: file names and number, simulation time, data output rates, error checking level.

Open Node/Zone coordinates data: Graphic window coordinate rages: min. X & Y, Max. X & Y, number of origin and destinations, number of destinations only, number of origins only, number of nodes only, number of invalid nodes, number origins (total), number destinations (total), number nodes (total), min & max origin number, min & max destination number.

Open link characteristics: Number of links, number of signalized links, number of stop signs, number of yield signs, number of HOV links, number of links surveillance, maximum link number.

Open signal timing data: number of signals, number of plans, plan duration, current signal plan.

Open Origin-Destination demand data: number of O-D pairs, total number of vehicles.

Open Incident data: number of incidents.

Decomposing Macro O-D into micro departures data: total number of travtek vehicles, total number of vehicles.

Definition of link characteristics data: total network length, total network lane length, number of network vehicle spots needed, number of network vehicle spots present.

O-D trip table times at a point in time.

Link flow summaries by link at a point in time: start and end nodes, speed, saturation, lane number, length, link flow, green time, V/C ratio, travel time(total, free, average), average speed, average stops, vehicle on link (max. possible, max. observed, current observed), Summaries (total link travel times, total network travel, total network length, average network speed, average trip time, average trip length, number of invisible vehicles, total network stops, average network stops).

Timing optimization at point in time by signal number: phase, approach, link, approach flow, saturation flow for the approach, flow ratio for the given approach, critical flow ratio for the phase, the sum of all the critical flow ratios at the signal, cycle length, total lost time at the signal, total green time at the signal, green time for the given phase, intergreen time for the given phase, start value within the cycle of the green phase, end time of the green within the phase.

Average O-D trip times by vehicle type: origin zone, destination zone, number of vehicles (departing, arriving, entering), Departures (first, last), arrivals (first, last), trip times (total, minimum, average, maximum, standard deviation).

Total O-D trip times by zone: Origin zone, destination zone, number of vehicles (departing, arriving, entering), trip times (average, standard deviation, total), max park times.

O-D summaries: Sum of total trip times, average trip time, total demand to enter network, vehicles eligible to enter, vehicles in their driveways, vehicles left on network, vehicles that completed trip.

Summary of network incidents: incident number, start time, end time, lane reduction, duration.

ROADSIM Inputs:

a. Run Control Data

Traffic assignments enabled.
Initialization period time.
Whether fuel consumption and emission output is required.
How many time periods will be simulated and the duration of the time period.
Graphical data output enabled.'

b. Rural Road Parameters

These values are run specific on all links.

Value of mean desired free-flow speed.
Standard deviation of desired mean free-flow speed.
Percent of vehicle's maximum, zero grade speed which is attainable utilizing partial horsepower such as during car-following maneuvers. This fractional power restraint is applied to passenger cars and recreational vehicles.
Measure of the pass suppressing influence which exists upstream of a curve to the right.
Bias to be added algebraically to desired speed for trucks and buses, fpm * 10.
Bias to be added algebraically to desired speed for recreational vehicles, fpm * 10.
Nominal forward sight distance.
Random number seed to select interarrival headways and vehicle types for entering vehicles in direction one.
Random number seed to select interarrival headways and vehicle types for entering vehicles in direction two.
Random number seed to select desired speeds in direction one for entering vehicles.
Random number seed to select desired speeds in direction two for entering vehicles.
Random number seed for passing maneuver decisions.

c. Rural Road Lii Characteristics

Upstream and downstream link.
Link length.
Direction of travel along this link.
Desired attainable mean free-flow speed for a "standard" vehicle on link.
Distance from upstream node marking the beginning of the first no-passing region.
Distance from upstream node marking the end of the first no-passing region.
Distance from upstream node marking the beginning of the second no-passing region.
Distance from upstream node marking the end of the second no-passing region.
Distance from upstream node marking the beginning of the third no-passing region.
Distance from upstream node marking the end of the third no-passing region.

d. Rural Road Sight Distance Regions

Upstream and downstream link.
Distance from upstream node marking the beginning of the first passing sight distance region.
Passing sight distance at the beginning of the first region.
Distance from upstream node marking the end of the first passing sight distance region.
Passing sight distance at the end of the first region.
Distance from upstream node marking the beginning of the second passing sight distance region.
Passing sight distance at the beginning of the second region.
Distance from upstream node marking the end of the second passing sight distance region.
Passing sight distance at the end of the second region.
Distance from upstream node marking the beginning of the third passing sight distance region.
Passing sight distance at the beginning of the third region.
Distance from upstream node marking the end of the third passing sight distance region.
Passing sight distance at the end of the third region.

e. Rural Road Link Geometry

Upstream and downstream link.
Distance from upstream node marking the beginning of the steady crawl region.
Distance from upstream node marking the end of the steady crawl region.
Mean crawl speed in this region.
Standard deviation of crawl speeds in this region.
Distance from the upstream node to the point which marks the beginning of the first grade region.
Value of grade at the beginning of the first grade region.
Distance from the upstream node to the point which marks the end of the first grade region.
Value of grade at the end of the first grade region.
Distance from the upstream node to the point which marks the beginning of the second grade region.
Value of grade at the beginning of the second grade region.
Distance from the upstream node to the point which marks the end of the second grade region.
Value of grade at the end of the second grade region.
Distance from the upstream node to the point which marks the beginning of a horizontal curve.
Radius of curvature.
Superelevation.
Distance from the upstream node to the point which marks the end of the horizontal curve.

f. Rural Road Vehicle Characteristics

Vehicle type 1 through 16.
Vehicle length.
Values for autos and recreational vehicles only: maximum acceleration, maximum speed.
Values for trucks and buses only: weight per net horsepower ratio, weight per frontal area ratio, multiplicative factor correcting horsepower to local elevation, multiplicative factor correcting aerodynamic drag to local elevation, vehicle does/doesn't use downgrade crawl data and restricts multiple passing, vehicle fleet component code
Number of vehicles per hour by type entering the roadway in direction one, or if traffic in this direction enters from an adjacent subnetwork, the proportion of vehicles entering the roadway in direction one of this type.
Number of vehicles per hour by type entering the roadway in direction two, or if traffic in this direction enters from an adjacent subnetwork, the proportion of vehicles entering the roadway in direction two of this type.
Maximum entry speed for a vehicle by type in direction one.
Maximum entry speed for a vehicle by type in direction two.

ROADSIM Outputs:

Rural Road Parameters: mean free flow speed, standard deviation of mean speed, max. acceleration factor to account for horsepower restraint, max. speed factor to account for horsepower restraint, measure of pass suppressing influence upstream of a curve to the right, speed bias (RV's./trucks and buses), nominal forward sight distance, random number seed to select interarrival headways and vehicle types for entering vehicles (direction l/direction 2), random number seeds to select desired speeds for entering vehicles (direction l/ direction 2), random number seed for passing maneuver decisions.

Rural Road Link characteristics by link: length, mean, speed, direction, no passing regions (begin, end), sight distance regions (beginning location, sight distance, ending location, sight distance).

Rural Road Link Geometry by link: crawl region (begin, end, mean speed, standard deviation), grade regions (begin percent, end percent), curve regions (begin, end, radius of curve, Superelevation, curve direction).

Rural road vehicle characteristics by type: length, affected by crawl zone, fleet component, maximum entry speed for direction 1 & 2, light vehicle (max. acceleration, max. speed), heavy vehicle (wt/hp, wt/frontal area,, elevation corrections (HP, aero. drag).

Entry volumes by direction and vehicle type.

Cumulative statistics by link and category (auto, RV, truck/bus) vehicle-trips, vehicle-miles, mean speed, standard deviation of speed, speed extremes (min., max).

Link travel times by link and category (auto, RV, truck/bus) mean (ideal, zero-traffic, actual), standard deviation.

Link delay times by link and category (auto, RV, truck/bus) mean (geometric, traffic, total), standard deviation.

Passes attempted/ completed/ aborted by category (auto, RV, truck/bus) by link, number, per file per hour, totals.

Link-specific MOEs by direction: headways (sec, number, percent, cumulative), speeds (ft/sec, number, percent, cumulative), platoon sizes (number, percent, cumulative).

Vehicle type-specific output: number, mean speed, mean travel time (ideal, zero traffic, actual)

Speed distribution output: speed, autos (number, percent, cumulative), R.V.'s (number, percent, cumulative). trucks (number, percent, cumulative), all (number, percent, cumulative).

TRAF-NETSIM Inputs:

a. Run Control Data

Traffic assignments enabled.
Initialization period time.
Whether fuel consumption and emission output is required.
How many time periods will be simulated and the duration of the time period.
Graphical data output enabled.

b. LinkNameData

Link name.

c. Link Description Data

Number of lanes.
Length of lanes.
Channelization data (such as car pools).
Link specific traffic behavior (such as free flow speed).
Turning movement descriptions

d. Traffic Parameters Data

Response to gaps in traffic for turning vehicles.
Standard deviation of desired free flow speed.
Types of vehicles.
Turn calibration data.
Spillback and vehicle length.
Vehicle response to yellow signals.
Gaps in oncoming traffic which are acceptable for vehicles turning onto a side street across traffic.
Pedestrian flow interaction with traffic.
Variations around user specified free flow speed.
Short term event distribution.
Bus station dwell time distribution.

e. Bus Operations Data

Routes.
Frequency of service along the routes.
Type of bus stops.
Average dwell time at each bus stop.
Percent of buses not stopping at a stop.

f. Sign and Signal Control Data

Upstream node to intersection and intersection type: yield, stop, uncontrolled.
Upstream node to pretimed signal intersection and durations for each signal interval.
Signal transition from one timing plan to another.
Actuated controller data:
Approaches and referenced links.
Time when permissive periods begin and end and when force-offs occur.
Traffic movements permitted during each phase.
Detector location, type and characteristics.
Phase operations: max. green time, max. extension, vehicle extension, gap reduction times, extensions of phase for pedestrians.

g. Traffic and Vehicle Occupancy Data

Traffic volumes entering from outside the network including percent carpools and/or trucks.
Traffic volumes entering or leaving the network from within the network are called source/sink links and are used to represent the behavior of minor traffic sources such as parking lots.
Vehicle occupancy: autos, car pools, trucks, and buses.

h. Incidents, Events and Parking Maneuver Data

Time period of occurrence.
Short term events take place in curb lane.
Parking maneuver interruption.

i. Vehicle Characteristics Specifications Data

Length.
Acceleration.
Speed.
Discharge headway.
Percent of vehicle in the fleet.

j. Fuel and Pollution Specification Data

Fuel consumption rate for autos, trucks, and buses.
HC emission rate.
CO emission rate.
NO, emission rate.

k. Graphics Data

Location of each node relative to each other.

TRAF-NETSIM Outputs:

Initialization Statistics: time interval, prior content, current content, percent difference
Bus station properties.
Sequence of nodes defining bus route.
Sequence of stations along each bus route.

Network wide bus statistics by route: bus trips, total travel time, mean travel time person trips person travel time, avg. bus occupancy.

Characteristics of NETSIM links for 1st time period: Link from -> to, length, # of lanes full, pocket (left, right), gradient percent, link type, channelization, destination node (left,right, thru, diag), lost time, Queue discharge headway, free flow speed, right turn on red enabled/disabled, pedestrian flow, lane alignment, street name.

Characteristics of links for subsequent time periods: link, channelization, pedestrian flow speed

Turning movements and pocket data: link, tuning movement percent of (left, through, right, and diagonal turns), pocket length for left and right turns.

Traffic control data for fixed timed signals: node, offset, cycle length, interval, duration, approaches, signal state

Traffic control data for actuated signals: node, offset, cycle length, detector length, detector delay, interval timings and extensions

Entry Link volumes: flow rate, trucks, car pools
Source/Sink flow rate.

Short term events: mean freq., mean duration

Parking activity: link, duration frequency.
Vehicle type specifications.

Cumulative link statistics: link, vehicle miles, vehicle trips, vehicle minutes .(move, delay, total), ratio of move/total, minutes/mile (total, delay), seconds/ veh. (total, delay, queue, stop), avg. values (percent stops, volume VPH, Speed), avg. veh. occupancy, congestion (storage, phase failure), avg. queue by lane, max. queue by lane.

Cumulative link specific person measures of effectiveness: link, person mile person trips, delay person-min., travel time person-mm.

Movement specific statistics by link (left, thru, and right): vehicle-mile, vehicle-trips, speed, stops (percent).

Measures of effectiveness by link and turn movement (left, thru, right): veh - min. (moving time, delay time, total time, ratio move/total), sec./veh (total time, delay, queue, stop).

Cumulative values of fuel consumption and emissions by link: fuel in gallons and mpg for auto, truck, bus; veh emission rates (kg/mile.hour) HC, CO, NO,.