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An Evaluation of Traffic Simulation Models for its Applications

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AN EVALUATION OF TRAFFIC SIMULATION MODELS FOR ITS APPLICATIONS

THESIS

BY

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CHAPTER 1

INTRODUCTION

The growth of urban automobile traffic has led to serious traffic congestion in most cities. Since travel demand increases at a rate often greater than the addition of road capacity, the situation will continue to deteriorate unless better traffic management strategies are implemented. One of the most attractive remedial measures for addressing the congestion problem is the deployment of Intelligent Transportation Systems (ITS). ITS is the application of current and evolving technologies to transportation systems and the careful integration of system functions to provide more efficient and effective solutions to multimodal transportation problems. A wide range of technological developments fall under the ITS agenda.

The rapid growth of ITS applications in recent years is generating an increasing need for tools to help in system design and assessment. Traffic simulation models have proven to be one of the most cost-effective tools to reach these objectives. Evaluating traffic networks equipped with ITS technologies are a vital necessity in the overall design of ITS systems. The integration of traffic modeling studies into the framework of ITS and its potential benefits can be seen in Figure 1.

Tools are needed to improve the increasingly complex and rapidly deteriorating transportation systems of today. Comprehensive research tools for quantifying the

expected benefits from ITS are, however, still absent. Therefore, the ability of traffic simulation models to simulate ITS technologies and operations such as real-time control strategies, route guidance capabilities, real-time graphics displays, environmental and safety measures of effectiveness, effects of in-vehicle navigation systems, vehicle/path selection capabilities, and user interface must be evaluated.

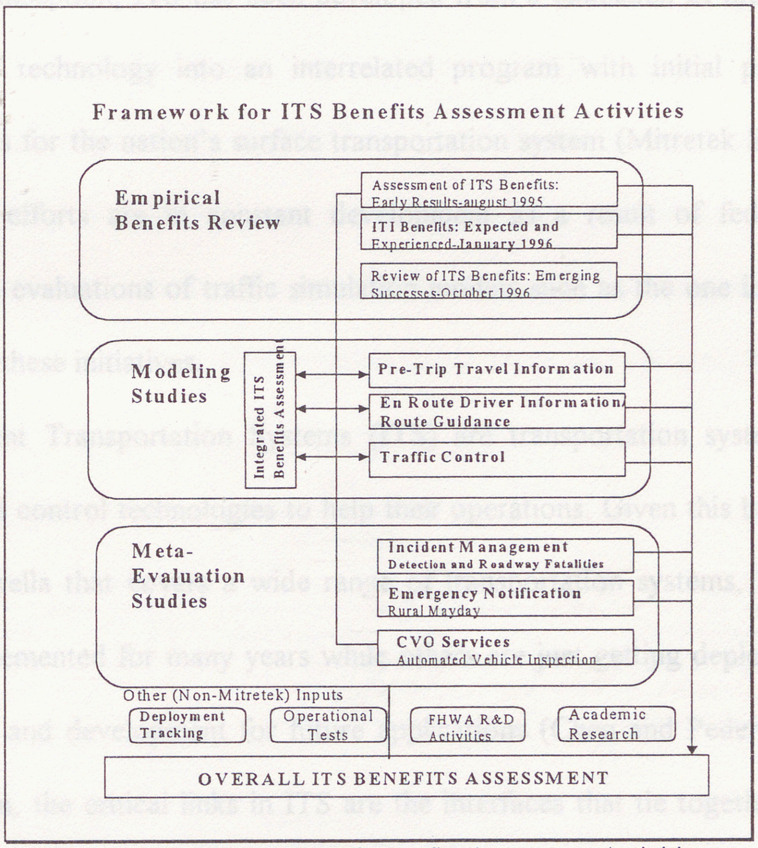


Figure 1. Framework for ITS Benefits Assessment Activities
Source: USDOT, 1996

Background of ITS Development

Congress established the Intelligent Transportation Systems with the passage of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) and its successor the Transportation Equity Act for the 21st Century (TEA-21) of 1998. ITS applies

advanced and emerging technologies in such fields as information processing, communications, control, and electronics to surface transportation needs. If these technologies are effectively integrated and deployed, there could be a number of benefits including more efficient use of our infrastructure and energy resources, and significant improvements in safety, mobility, accessibility, and productivity (US DOT, 1996). In the years since its inception, ITS has been developed from a collection of ideas and isolated applications of technology into an interrelated program with initial projects already yielding benefits for the nation's surface transportation system (Mitretek Systems, 1996). New research efforts are in constant development as a result of federal initiatives. Comprehensive evaluations of traffic simulation models such as the one in this thesis are a major part of these initiatives.

Intelligent Transportation Systems (ITS) are transportation systems that apply information and control technologies to help their operations. Given this broad definition, ITS is an umbrella that covers a wide range of transportation systems, some of which have been implemented for many years while others are just getting deployed or are still under research and development for future applications (Chen and Pedersen, 1997). As with any system, the critical links in ITS are the interfaces that tie together the different parts of the system. It was decided that an architecture was needed to achieve the vision Congress put forth for ITS in 1991: a vision of a seamless, multimodal, national intelligent transportation system that would have a consistent character across the country.

National Architecture of ITS

In the early stage of ITS development, a need for architecture to provide an overall framework was identified. The architecture lays out the boundaries, players, and strategies for the process of information management. It was needed to form a common vocabulary and common sets of design and interconnection standards to tie advanced transportation systems together and create new ones (USDOT, 1996). As a result the Federal Highway Administration (FHWA) sponsored the development of a National ITS Architecture. Figure 2 presents a very top level simplified Architecture Flow Diagram. The diagram represents the four classes of subsystems, the terminators associated with each of the classes and the type of information that is exchanged between the classes.

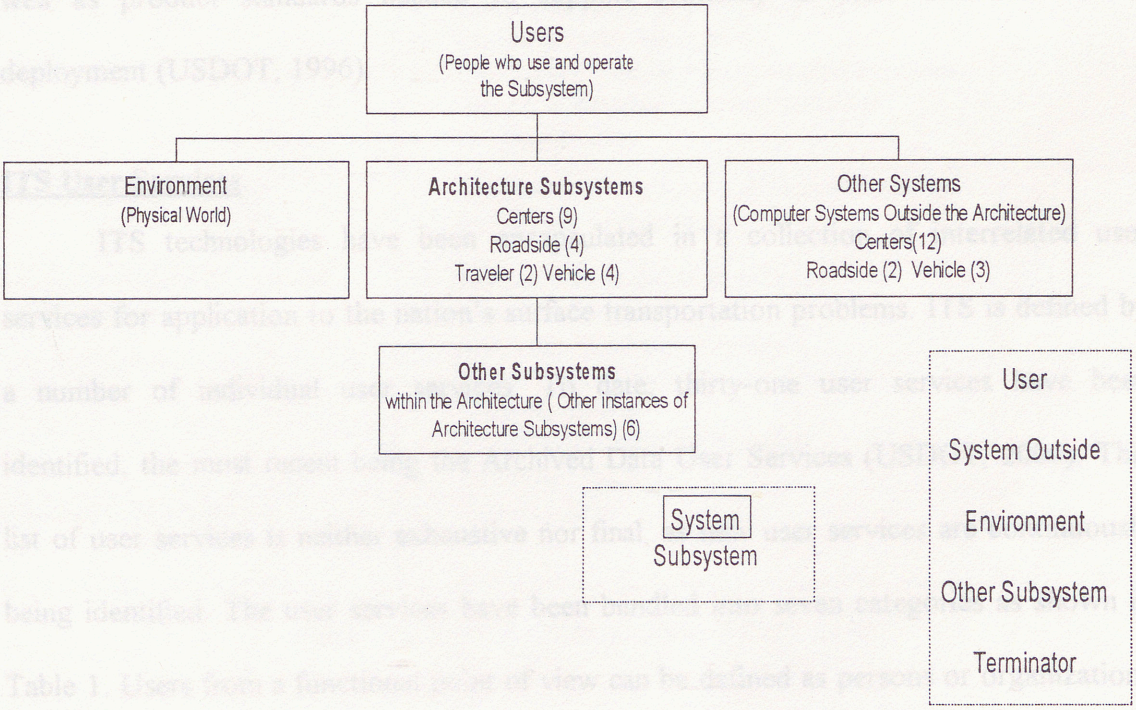


Figure 2. Simple View of ITS Architecture Structure.
Source: The National Architecture for ITS, USDOT, 2000

The National ITS Architecture provides a common structure for the design of intelligent transportation systems. It is not a system design nor is it a design concept. What it does is to define the framework around which multiple design approaches can be developed, each one specifically tailored to meet the individual needs of the user, while maintaining the benefits of a common architecture noted above. The architecture defines the functions (e.g., gather traffic information or request a route) that must be performed to implement a given user service, the physical entities or subsystems where these functions reside (e.g., the roadside or the vehicle), the interfaces/information flows between the physical subsystems, and the communication requirements for the information flows (e.g., wireline or wireless). In addition, it identifies and specifies the requirements for the standards needed to support national and regional interoperability, as well as product standards needed to support economy of scale considerations in deployment (USDOT, 1996).

ITS User Services

ITS technologies have been encapsulated in a collection of interrelated user services for application to the nation's surface transportation problems. ITS is defined by a number of individual user services. To date, thirty-one user services have been identified, the most recent being the Archived Data User Services (USDOT, 2000). This list of user services is neither exhaustive nor final, as new user services are continuously being identified. The user services have been bundled into seven categories as shown in Table 1. Users from a functional point of view can be defined as persons or organizations to which functions are provided. Users can be infrastructure operators and decision makers, government, traffic, local and/or highway authorities, private parking operators,

public transit operators, vehicle drivers, freight shippers and operators of goods, vehicles and other types of fleets.

Table 1. ITS Interrelated User Services.

User Services Bundle	User Services
Travel and Transportation Management	• En Route Driver Information • Route Guidance • Traveler Services Information • Traffic Control • Incident Management • Emissions Testing • Demand Management and Operations • Pre-trip Travel Information • Ride Matching and Reservation • Highway Rail Intersection
Public Transportation Operations	• Public Transportation Management • En Route Transit Information • Personalized Public Transit • Public Travel Security
Electronic Payment	• Electronic Payment Services
Commercial Vehicle Operations	• Commercial Vehicle Electronic Clearance • Automated Roadside Safety Inspection • On-board Safety Monitoring • Commercial Vehicle Administration Processes • Hazardous Materials Incident Response • Freight Mobility
Emergency Management	• Emergency Notification and Personal Security • Emergency Vehicle Management
Advanced Vehicle Control and Safety Systems	• Longitudinal Collision Avoidance • Lateral Collision Avoidance • Intersection Collision Avoidance • Vision Enhancement for Crash Avoidance • Safety Readiness • Pre-crash Restraint Deployment • Automated Highway
Information Management	• Archived Data

Source: The National ITS Architecture, USDOT, 2000

Needs for Traffic Simulation Models

As indicated earlier traffic simulation models are becoming an increasingly important tool for traffic control. Simulators are needed, not only to assess the benefits of ITS in a planning mode, but also to generate scenarios, optimize control, and predict network behavior at the operational level. They can give the traffic engineer an overall picture of the traffic and the ability to assess current problems and project possible solutions immediately. Experimental or new techniques can be tried and tested without any disruption to traffic in a real network. Traffic shows some characteristics of a complex system. There are stable and unstable states, deterministic, chaotic or even stochastic behavior with phase transitions, fractal dimensions and self-organized criticality. In handling such a complex system, simulation can be a good tool. In the global warming debate, political decisions reckon on computer simulations. Likewise, computer models can be used to simulate the influence of governmental measures like road pricing or building of new streets.

Since the technological advances and concepts underlying ITS in urban networks were not envisioned when many simulation models were developed, these models may not be directly applicable to networks with ITS components such as Advanced Traveler Information Systems (ATIS) and Advanced Traffic Management Systems (ATMS) especially at an operational level. Traffic simulation models can be classified as either microscopic, mesoscopic, or macroscopic. Microscopic models are models that continuously or discretely predict the state of individual vehicles. Microscopic measures are individual vehicle speeds and locations. Macroscopic models aggregate the description of traffic flow. Macroscopic measures of effectiveness are speed, flow and

density. Mesoscopic models are models that have aspects of both macro and microscopic models. In addition, simulation models are classified by functionality, i.e. signal, freeway, and integrated.

Functions of Traffic Simulation Models for ITS

The Actions de Préparation, d´accompagnement et du suivi (APAS, 1995) assessment of road transport models and system architectures has identified four main uses for simulation models in ITS:

1. **Simulating networks including interaction between vehicles and new responsive control and information systems**. One of the main purposes of simulation models is to assess a set of transportation control options off-line. On-street evaluation is notoriously difficult because the day-to-day variability of traffic means that it is difficult and expensive to collect enough data to produce statistically significant conclusions. Therefore simulation models have been developed to allow complete control over the network environment.
2. **Short term forecasting**. Simulation models are also used when analyses are needed for immediate results. Examples include use in real-time evaluation of a set of possible responses following an incident on a roadway, or to predict emissions so that plans, which restrict cars entering the city center, can be implemented if the predicted emissions rise above a certain level.
3. **Enhancing assignment models**. Assignment models are used to predict changes in traffic flows when changes are made to the road network. If responsive

control systems are used within the network then interactions with the changing flows can be difficult to model without using traffic simulation.

4. Providing inputs to car driving simulations. Sophisticated driving simulators are being developed to allow the assessment of many new in-car systems in a totally safe environment. Traffic simulation models can be used to provide realistic scenarios for the simulator.

Limitations of Traffic Simulation for ITS

With regard to traffic simulation within an ITS framework, some limitations have been identified by Smartest (1997) as follows:

1. *Modeling congestion*. Most simulation models use simple car following and lane changing algorithms to determine vehicle movements. During congested conditions these do not realistically reflect driver behavior. The way congestion is modeled is often critical to the results obtained.

2. *Environmental modeling*. Considerable effort is being directed at producing emission models for incorporation into simulation models. For some emissions this is straightforward but for others complex chemical reactions are taking place within car exhausts making predictions difficult. It is also proving difficult to get reliable emission data for a reasonable mix of traffic.

3. *Integrated environments and common data*. Simulation models are often used with other models such as assignment models. There are common inputs required by all these models, such as origin-destination data, network topology, and bus

route definitions. However, each model often requires the data in a different format so effort is not wasted in re-entering data or writing conversion programs.

4. *Safety evaluation*. Safety is a very complex issue. Most safety prediction models are very crude, being based on vehicle flows on given roadways or on lane changes in mean vehicle speeds. Simulation models completely ignore vulnerable road users such as cyclists or pedestrians.

5. *Standard procedures and indicators for evaluation*. The traffic simulation has to produce outputs, which will rank the alternatives realistically. Alternative rankings are a function of the chosen performance indicators and the weights used. Standard sets of performance indicators and procedures to apply need to be produced.

While there is clearly a need for traffic simulation models that support ITS development based on the above discussions, there is also a need to evaluate existing models in order to delineate their specific features and functions. This research attempts to contribute to the ongoing effort to establish standards and criteria for traffic simulation models in order to integrate them into the framework of ITS benefits assessments. Standards will provide the means by which compatibility between systems will be achieved.

Research Objective

The objectives of this thesis are to evaluate traffic simulation models to determine their suitability as an evaluation tool in the framework of ITS benefits assessments.

Techniques used in this study rely in part on previously published data relating to traffic simulation models. After compiling this data a comprehensive categorized list of traffic simulation models is documented. This information will then be used to create a series of evaluation criteria. The criteria focus is on what features of a simulation model are important to ITS applications. With this series of criteria, an initial screen of the model list will be conducted to create a shorter more specific list. Each model on the shorter specific list will be evaluated based on the common standard/criteria. Finally, in depth evaluation of the list will be conducted.

CHAPTER 2

REVIEW OF LITERATURE

Traffic simulation models have been studied extensively over the past 30 years. Various effective models such as CORSIM (CORridor microscopic SIMulation) TRANSYT 7F and AIMSUN2 have been developed to study conventional traffic networks and controls (Barcelo and Ferrer, 1994), (FHWA, 1996), (McTrans, 1996). With technological advances, new uses for simulation models are being promoted. There have been recent efforts to develop simulation models for studying networks under ITS. Models such as INTEGRATION DYNASMART and METROPOLIS are being developed specifically for studying the effectiveness of alternative information supplying strategies, as well as alternative information/control system configurations, for urban traffic networks with Advanced Traveler Information Systems (ATIS) and/or Advanced Traffic Management Systems (ATMS) (Jayakrishnan et al., 1994), (Mahmassani et al., 1994), (de Palma et al., 1996), (Van Aerde, 1999). Two such models in development at the same time were INTEGRATION and DYNASMART. INTEGRATION was developed in the late 1980's at Queens University. It is a mesoscopic routing-oriented simulation model of integrated freeway and surface street networks. In reference to ITS, it is the first simulation model which considers the ITS route guidance information in the vehicle/routing mechanism (Prevedourous and Wang, 1998). DYNASMART is primarily a descriptive analysis tool for the evaluation of information supply strategies, traffic

control measures, and route assignment rules at the network level. In other words it does not attempt to find optimal configurations of ITS systems but instead studies the effectiveness of given configurations (Jayakrishnan, et al., 1994). Another traffic simulation tool on the ITS forefront is PARAMICS. The aim of PARAMICS is to explore the possibilities of ITS, and ultimately to implement a system where features of PARAMICS, including comprehensive visualization and microscopic traffic simulation are key components in the simulation arm of the ITS architecture. At this time the potential areas of application for PARAMICS include, traffic management and control, traffic control center modeling, and personal access to predictive travel information. Several research projects have already been completed, using PARMICS as the base for studying dynamic route decision-making. PARAMICS has been used for the simulation of traffic management and control systems in a number of locations, including Interstate I-49 in Minneapolis (Quadstone Limited, 1999). Ongoing studies are still being conducted to ascertain the limitations of traffic simulation models for ITS applications. One such study is SMARTEST, being conducted at Leeds University in the United Kingdom (Algers, et al., 1998). The project is directed toward modeling and simulation of dynamic traffic management problems caused by incidents, heavy traffic, accidents, road works and events. It covers incident management, intersection control, motorway flow control, dynamic route guidance and regional traffic information (Algers, et al., 1998). Studies such as SMARTEST will add to the recent research aimed at the validation and accreditation of the outputs of simulation models with regards to ITS.

Numerous research papers have been written in order to help validate traffic simulation model output. However, traffic engineering literature search for

comprehensive comparisons of real world traffic software based simulations of networks under ITS information will yield little, particularly with respect to newer software. An extensive literature search was undertaken using the TRB TRIS database and the World Wide Web on the Internet. Over 80 traffic simulation models were identified as shown in Tables 3-5 in section 4. Most of these models have specific functions such as signal control at isolated intersections, signal control at coordinated intersections, freeway simulation, etc. These simulation models will be evaluated in this thesis to identify those that have special features to support a certain element of ITS application.

CHAPTER 3

DESIGN OF THE STUDY

The study in this thesis will primarily rely on the published literatures including scientific papers, technical reports and Internet WebPages about various traffic simulation models. The entire evaluation will be conducted through two-steps: initial screening and in-depth evaluation. The initial screening will generate a shorter but more specific list of traffic simulation models. The in-depth evaluation of each model on the shorter list will eventually identify which model is suitable for what part of ITS applications. The evaluation of traffic simulation models for ITS development needs a series of criteria to be based upon. Key points within the criteria identify user requirements (Table 2) that were included in the listed criteria. These requirements include functionality, relevance, and ITS modeling ability. The following provides the criteria that will be used in the 2-step process in this study.

Criteria for Initial Screening

General research of traffic simulation models yielded more than 80 models. In order to screen models with no potential for use with ITS applications, criteria for initial screening were developed. Models were judged based on their ability to meet or be modified to meet these standards. These criteria are listed as follows:

1. Credible theories used in the model.

2. The model has been tested for real-world applications.
3. The ability to output measures of performance such as travel times and speeds.
4. Documentation has indicated incorporation of at least one ITS feature.
5. Model is obtainable by the public.

Criteria for In-Depth Evaluation

In-depth evaluation attempts to identify more specific features and limitations of models selected from the initial screening process. The following criteria were established for in-depth evaluation:

1. Must be capable of incorporating in the model the corresponding traffic devices such as detectors, traffic lights, VMS, etc.
2. Must also be able to imitate the functions of traffic devices, which includes providing the specific traffic measurements at the required time intervals, increasing the phase timing in a given amount of time and implementing a traffic calming strategy.
3. Must realistically reflect driver behavior and vehicle interactions.
4. Must have the ability to model different traffic flow conditions at a higher level of detail (e.g. uncongested, congested, and incident).
5. Must simulate the variability in traffic demand in time and space, and model the growth/interaction and decay of traffic queues, as well as capacity reductions due to incidents and bottlenecks.
6. Must be capable of evaluating various control strategies (e.g. fixed/actuated/adaptive control, and ramp metering).

7. Must be capable of interfacing with other control algorithms of ITS applications.
8. Must make reliable estimates of network traffic conditions.
9. Must predict network flow patterns over the near and medium terms in response to various contemplated information dissemination strategies.
10. Must provide routing information to guide travelers through the network.
11. Must have the ability to model both freeway and surface street traffic.
12. Must be well documented.

In this evaluation study, the most desirable model would encompass all the above criteria. However, some of the features, although desirable, can be considered optional while others are strictly essential. In Table 2, the criteria are rated based on their relative importance.

Table 2. Ratings for In-Depth Evaluation Criteria

#	Criterion	Importance Rtg
1	Model Traffic Devices	**
2	Imitate Traffic Device Function	**
3	Realistic Reflection of Driver Behavior and Vehicle Interaction	****
4	High Level Modeling of Traffic Flow	****
5	Simulate Variability of Traffic Demand	****
6	Evaluation of Control Strategies	****
7	Interface With Other Control Algorithms of ITS Applications	****
8	Reliable Estimates of Network Traffic Conditions	***
9	Provide Routing Information to Travelers in Network	****
10	Model both Freeway and Surface Street Traffic	****
11	Obtainable by Public	****
12	Well Documented	**

CHAPTER 4

EVALUATION RESULTS AND DISCUSSION

Initial Screening Results

This section will first classify all simulation models identified. Then it briefly describes main characteristics of each simulation model followed by a summary of the models selected as a result of the initial screening.

Classification of Simulation Models

Traffic simulation models can be classified as either microscopic, macroscopic or mesocscopic models. They can also be classified according to the nature of the network that they can be applied to i.e. signalized networks, freeway networks, integrated networks or specific purposes (Electronic Toll Collection, etc.). An initial review of all traffic simulation models that were identified for this research has resulted in the following list of classifications (Tables 3-5).

Table 3. Microscopic Models

	Model	Developer	Classification
1	AIMSUN2	Universitat Politechnica de Catalunya, Barcelona, Spain	Integrated
2	ANATOLL	ISIS and Centre d'Etudes Techniques de l'Equipment, France	ETC
3	ARCADY2	Department of Transport, UK	Signal
4	AUTOBAHN	Benz Consult – GMBH, France	Freeway
5	AVENUE	Tokyo Metropolitan University, Japan	Signal
6	CARSIM	No available information	Signal

7	CASIMIR	Institut National de Recherche sur lis Transports et la Securite,France	Signal
8	CONTRAM	TRL and Mott McDonald	Integrated
9	CORSIM	Federal Highway Administration (FHWA), USA	Integrated
10	DRACULA	Institut for Transport Studies, University of Leeds, UK	Integrated
11	FLEXYT II	Ministry of Transport, Netherlands	Signal
12	FOSIM	No Available Data	Freeway
13	FREEVU	University of Waterloo, Dept. of Civil Engineering, Canada	Freeway
14	FRESIM	FHWA, USA	Freeway
15	HIPERTRANS	European Commission DGIV (In Development), UK	Signal
16	HUTSIM	Helsinki University of Technology, Finland	Signal
17	ICARUS	Elsevier Company, Amsterdam	Integrated
18	INTEGRATIO N	Queens University, Transport Research Group, Canada	Integrated
19	INTRAS	Federal Highway Administration, USA	Signal
20	JAM	No Available Data	
21	MELROSE	Mitsubishi Electric Corporation, Japan	Integrated
22	METROPOLI S	Universite de Cergy-Pontoise, France	Freeway
23	MICROSIM	Centre if Parallel Computing (ZPR), University of Cologne, Germany	Signal
24	MICSTRAN	National Research Institute of Police Science, Japan	Signal
25	MIMIC	Automotive Automation Limited, UK	Safety
26	MITSIM	Massachusetts Institute of Technology, USA	Integrated
27	MIXIC	Netherlands Organisation for Applied Scientific, Netherlands	Freeway
28	NEMIS	Mizar Automazione, Turin	Integrated
29	NETSIM	Federal Highway Administration, USA	Integrated
30	OLSIM	University of Duisberg, Germany	Freeway
31	PADSIM	Nottingham Trent University, UK	Freeway
32	PARAMICS	The Edinburgh Parallel Computing Centre and Quadstone Ltd., UK	Integrated
33	PELOPS	Institut fur Kraftfahwesen Aachen, Germany	Integrated
34	PHAROS	Institut for Simulation and Training, USA	Signal
35	PLANSIM-T	Centre of Parallel Computing (ZPR), University of Cologne, France	Freeway
36	ROADSIM	FHWA, USA	Rural
37	SATURN	Institute for Transport Studies, University of Leeds, UK	Integrated
38	SHIVA	Robotics Institute – CMU, USA	Other

39	SIGSIM	University of Newcastle, UK	Signal
40	SIMCO2	Technical University of Aachen, Germany	Freeway
41	SIMDAC	ONERA Centre d'Etudes et de Recherche de Toulouse, France	Freeway
42	SIMNET	Technical University of Berlin, Germany	Freeway
43	SIMTRAFFIC C1	Trafficware, The Traffic Signal Software Company, USA	Signal
44	SISTM	Transport Research Laboratory, Crowthorne, UK	Freeway
45	SITRA-B+	ONERA Centre d'Etudes et de Recherche de Toulouse, France	Integrated
46	SITRAS	University of New South Wales,, Wales	Integrated
47	SMARTAHS	University of California Berkley, USA	Unknown
48	SMARTPATH	University of California Berkley, USA	Freeway
49	SOUND	University of Tokyo, Japan	Integrated
50	SPEACS	Prometheus Program, UK	Freeway
51	STEER	Network Control Group at University of York, UK	Freeway
52	STREETSIM	Not Available	Signal
53	TEXAS	University Of Texas, USA	Signal
54	TEXSIM	Texas Transportation Institute, USA	Signal
55	TRAFFICQ	MVA, USA	Signal
56	TRANSIMS	Los Alamos National Laboratory, USA	Freeway
57	TRGMSM	J. Wu and M. McDonald, USA	LRT
58	TRITRAM	CSRIO and Roads and Traffic Authority of New South Wales, Wales	Freeway
59	THOREAU	MITRE Corporation, USA	Integrated
60	UTSS	Hong-Cha University, China	
61	VEDENS	AEA Technology, USA	Signal
63	VISSIM	PTV System Software and Consulting GMBH, France	Integrated
64	WATSIM	KLD Associates, USA	Integrated
65	WEAVSIM	FHWA, USA	Integrated

Table 4. Macroscopic Models

66	ARTWORK	No Available Data	Traffic Safety
67	AUTOS	Georgia Tech Research Institute, USA	Freeway
68	CORFLO	Federal Highway Administration, USA	Integrated
69	FREFLO	Federal Highway Administration, USA	Freeway
70	FREQ	No Available Data	Freeway
71	KRONOS	No Available Data	Unknown

72	METACOR	No Available Data	Unknown
73	METANET	Techical University of Munich, Germany	Freeway
74	NETFLO 1	FHWA, USA	Signal
75	NETFLO 2	FHWA, USA	Signal
76	NETVACI	No Available Data	Unknown
77	PASSER-II	Texas Transportation Institute (TTI), USA	Signal
78	PASSER-IV	TTI, USA	Signal
79	TRANSYT-7F	FHWA, USA	Signal
80	TRANSYT/10	MVA, USA	Signal
81	TEXAS	University of Texas, USA	Signal

Table 5. Mesocopic Models

82	DYNAMIT	Massachusetts Institute of Technology, USA	Integrated
83	DYNEMO	Innovative Concepts, USA	Integrated
84	DYNASMART	University of Texas at Austin, USA	Integrated

Descriptions of Simulation Models

The purpose of the brief descriptions of traffic simulation models in this section is to identify those models that should be held for in-depth evaluation based on the criteria established in chapter 3. These models will be the basis of the initial and in-depth evaluations upon which final recommendations will be made with regard to traffic simulation model functionality for ITS application in the industry.

Descriptions of Microscopic Simulation Models

AIMSUN2

AIMSUN2 (Advanced Interactive Microscopic Simulator for Urban and Non-urban Networks) developed by J. Barcelo and J.L. Ferrer at the Polytechnic University of Catalunya in Barcelona, is a software tool capable of reproducing real traffic conditions in an urban network which may contain both expressways and arterial routes The behavior of every single vehicle is continuously modeled throughout the simulation according to several driver behavior models (car following, lane changing, gap acceptance). AIMSUN2 provides detailed statistical output: flows, speeds, travel times, etc., which may be presented as printouts or plots. Due to the detailed modeling of each vehicle in the network AIMSUN2 can simulate any kind of measurable traffic detector: counts, occupancy and speed. It provides very detailed modeling of the traffic network by simulation of some elements of the transportation system such as vehicles, detectors, and other elements such as traffic lights and entrance points. AIMSUN2 distinguishes between different types of vehicles and drivers; it can deal with a wide range if network geometries; it can also model incidents, conflicting maneuvers, etc. Recently, as part of a

DGVII funded project, AIMSUN2 has been linked to the UK SCOOT UTC system. In this real-world application AIMSUN2 passed details of traffic flow to SCOOT and utilized the information that was returned to it from the analysis. AIMSUN2 started as a research product but recently became a commercial product (Algers, et al., 1997).

ANATOLL

A prototype (not yet commercial), developed by the ISIS Company in France, is a microscopic simulator used to predict traffic queues at tollbooths. Each vehicle is given an arrival time, a payment type, and service time-change from one queue to another is allowed (Algers, et al., 1997).

ARCADY2, PICADY and OSCADY

Developed by the MVA Group Ltd. ARCADY for roundabouts, PICADY for priority intersections and OSCADY for signalized intersections are all used in testing design options for new junctions and modifications to existing ones. All three programs enable estimates of capacities, queues and delays to be made and facilitate examination of the effects of changes in routing patterns, following highway improvements. Capacity formulas are based on UK traffic conditions. However, right-hand rule of road can be accommodated in the modeling. These models are available to the public (McTrans, 1996).

AUTOBAHN

Developed by Benz Consult GMBH in Germany, the objective of AUTOBAHN is to investigate the effects of ITS measures on traffic flow and to investigate the effects of traffic on intelligent vehicles. AUTOBAHN uses a psycho-physiological spacing model. Arbitrary behavior of drivers and systems can be included and assigned to variable

amounts of vehicles. At this time no limitations on the size of network have been discovered because a limit has never been reached. This model is only used for consulting purposes (Algers, et al., 1997).

AVENUE

AVENUE (Advanced & Visual Evaluator for road Networks in Urban arEas), incorporates a route choice model and a traffic flow model that can reproduce over-saturated conditions on road networks. The features of AVENUE have been developed based on the OOP (object-oriented programming), which affords flexible modifications to user's requirements and graphical environment for easy operations. The effectiveness of the simulation model "AVENUE" has been validated by comparing the traveling time computed with the value observed on the arterial streets. AVENUE is in development at the University of Tokyo (University of Tokyo, 1999).

CARSIM

A CAR-following SIMulation model, CARSIM, is used to simulate not only normal traffic flow but also stop-and-go conditions on freeways. It is microscopic in nature. The features of CARSIM include:

1. Marginally safe spacing are provided for all vehicles,
2. Start-up delays of vehicles are taken into account,
3. Reaction times of drivers are randomly generated,
4. Shorter reaction times are assigned at higher densities, and
5. Dual behavior of traffic in congested and non-congested conditions is taken into account in developing the car following logic of this model .

CASIMIR

This model is used to simulate on a personal computer the operation of a traffic signal at an isolated intersection to evaluate the energetic efficiency of several control algorithms. CASIMIR is derived from INRET's microscopic vehicle simulation model SIMIR. It has a simple human interface, enabling the user to choose the intersection geometry and set various parameters. CASIMIR has an object-oriented programming approach and is written in the MODULA 2 language. Simon Cohen of INRETS Corporation in France designed the model in 1991. At this time it is no longer maintained by INRETS (Algers, et al., 1999).

CONTRAM

CONTRAM (**CON**tinous **TR**affic **A**ssignment **M**odel) was originally developed by TRL in the late 1970's. Since then it has been continuously developed over the years culminating in version 5 being released in 1988. CONTRAM is ideally suited to addressing the needs of increasing congestion by modeling congestion over longer time periods, larger areas with more complex travel behavior as well as the effects of measures such as route guidance. It is capable of representing time varying network conditions. UC Irvine in the city of Anaheim has used it only as an assignment tool, and by UC Berkeley in exploratory simulation of the Los Angeles Santa Monica freeway. A new version 7 has recently been developed jointly by TRL and Mott MacDonald. This model retains the features of CONTRAM 5 while radically overhauling the program and geographical interface to provide much greater flexibility in using the model. CONTRAM 7 has been designed to run under Windows 95/98 and NT on a 32-bit platform (TRL, 1999).

CORSIM

CORSIM developed by the FHWA is the first windows based version of a traffic simulation model. It integrates the existing NETSIM and FRESIM models. CORSIM is a microscopic stochasttic traffic simulation model that can realistically represent the real world dynamic traffic environment. It models four different types of on-ramp freeway metering (clock-time, demand/capacity, speed control and gap acceptance merge control). CORSIM has the most sophisticated car-following and lane-changing logic to simulate vehicle movements on a second-by-second basic. CORSIM has recently been released as a commercial product by the FHWA (FHWA, 1999).

DRACULA

DRACULA is an urban traffic assignment model. The major difference from conventional approaches is that DRACULA models the day-to-day evolution of traffic conditions, as a discrete time stochastic process rather than the abstract long-term equilibrium state. This stochastic process approach possesses a sound theoretical basis. Drivers respond to congestion through a learning sub-model, and daily select routes and departure times using a behavioral choice sub-model. A demand sub-model represents day-to-day variability in the network capacities (e.g. due to accidents). Finally, a traffic sub-model is used to move vehicles through the network each day. At its most detailed level, DRACULA represents the choices and experiences of individual drivers, and the movement of individual vehicles through the network (microsimulation) as these evolve in real-time and from day-to-day. DRACULA was developed at the Institute for Transport Studies at the University of Leeds (Algers, et al., 1999).

FLEXYT II

FLEXSYT-II is an event-based, microscopic simulation tool for traffic management studies. It is the successor of FLEXSYT-I, developed in the seventies and eighties by Frans Middelham. On a stochastic base vehicles move through the network, interacting with each other and the network (e.g., stop-lines and detectors). It has a no build-in control philosophy and is therefore suitable to study a range of problems. FLEXSYT-II uses a special traffic control language, called FLEXCOL-76. FLEXCOL-76 is based on the rules of Boolean algebra and the clear differentiation between the 'change of state of an element' (event) and the 'state of an element' (condition). The control part also has special structure. Output can consist of an event-by-event trace of the controller and tables containing an output on delays, queue lengths, network indicators and environmental aspects (fuel consumption and emission of toxic gasses). With FLEXSYT-II it is possible to do research on the structure of the network, such as the layout of intersections, length and number of lanes, effects of bus lanes, etc. However, due to its own traffic control programming language, it can also be used to study all kinds of traffic control strategies, such as the fixed-time control strategy, vehicle-actuated control strategies, traffic-depended control strategies and even fuzzy control. Furthermore, it can be and is applied to study traffic management measures, such as roundabouts, arterials, toll-plazas, ramp metering, main-line metering, HOV lanes, tidal flow lanes, etc. FLEXYT II is used to analyze the effect of several dynamic traffic management strategies, including traffic signal settings for networks, ramp metering, structure of the network, toll plazas and lanes for special road users. FLEXYT was developed at the Transport Research Center in the Netherlands in 1994 (McTrans, 1996).

FOSIM

FOSIM (Freeway Operations SIMulation) was developed in the USA for simulation of traffic flow on multi-lane freeways. No available data.

FREEVU

FREEVU (Freeway Evluation with Visual Understanding) is a personal computer simulation model intended for freeway design and analysis. It is an extension and enhancement of a PC based version of the FHWA INTRAS model, which is also a predecessor of the current FHWA FRESIM/CORSIM models. It allows the user to specify a freeway section, including lanes, grades, exits and entrances, posted speed limits, and detector locations. Vehicle movement is based on classic car-following theory and collision avoidance restrictions. However, FREEVU also incorporates behavioral lane changing algorithms and vehicle performance constraints. Dr. Bruce Hellinga and Dr. John Shortreed developed this model at the University of Waterloo, Ontario, Canada (Algers, et al., 1999).

FRESIM

FRESIM is a component model of the TRAF simulation system designed for microscopic freeway simulation. The FRESIM model is an enhancement to the INTRAS model and includes improvements to the geometric and operational capabilities and employs car-following and lane-changing models. FRESIM can simulate geometric conditions that include 1-5 thru lanes, 1-3 lane ramps, grades, curves, superelevation, lane additions, lane drops, incidents, work zones and auxiliary lanes. The operational features include lane changing; ramp metering; surveillance system; different vehicle types of 2-passenger and 4-truck; heavy vehicle lane bias or restriction, different driver

habits, and warning signs for lane drops, incidents and off ramps. FRESIM will not directly model HOV's or reduced lane width. FREeway micro-SIMulator (FRESIM) simulates most of the prevailing freeway geometries and provides realistic simulation of operations features. The behavior of each vehicle is represented through interaction with its surrounding environment, which includes the freeway geometry and other vehicles. FRESIM was developed by the Federal Highway Administration (McTrans, 1996).

HIPERTRANS

HIPERTRANS is a collaborative project within the European Commission Research and Development Framework Programme IV, DG VII Transport. HIPERTRANS will develop an accurate, high speed, and visually interactive, simulator of urban transport networks within a high-performance computing environment. Traffic systems suppliers to test urban traffic control systems will use HIPERTRANS simulator. Network operators will use the simulator to test traffic management strategies and train operators. HIPERTRANS predictor will be used by network operators to forecast the change to traffic flows on a real road network much faster than a real life system (Algers, et al., 1999).

HUTSIM

Helsinki University of Technology, Laboratory of Transportation Engineering, has developed this traffic simulator in Finland in 1989. HUTSIM uses standard car-following, gap acceptance theories. The simulation is one approach to analyze modern traffic actuated signal controllers, complicated intersections and changing traffic conditions. The basic method in HUTSIM is that a real signal controller is taken into the laboratory and the simulator is connected to the system. This means that only intersection

and traffic are programmed into the computer. HUTSIM also gives many opportunities to analyze non-signalized intersections and roundabouts. Output files include time/space curves, vehicle/signal details and fixed format reports. HUTSIM is a commercial product used by Road Administrators, City Planning Offices and Traffic Consulting companies (Smartest, 1999).

ICARUS

This microscopic model describes traffic flow under conditions of driving without real-time information and the introduction of several degrees of interaction between advanced driver information systems and human reactions to them. Developed by Elsevier Company in Amsterdam.

INTEGRATION

INTEGRATION is a fully microscopic simulation model that tracks the lateral as well as longitudinal movements of individual vehicles to the resolution of a deci-second. The car following algorithm is a kinematics model that calculates the individual vehicle speeds based on the macroscopic parameters of free-flow speed, speed at capacity and jam density. Gap acceptance logic was developed for modeling stop/yield sign control and unprotected left-turns at traffic signals. INTEGRATION also permits the density of traffic to vary continuously along a link and, thus demonstrating the dispersion of a platoon as it traverses the link. Up to five different driver/vehicle types are used to represent different routing behavior or access privileges to real-time traffic conditions. The model features and capabilities include assessment of the effectiveness of route guidance systems, impacts of ramp metering and signal control strategies, and the modeling of incidents. This model is available to the public (Van Aerde, 1999).

INTRAS

The INTRAS traffic simulation model, developed by KLD Associates, is a microscopic, stochastic simulation model that simulates the behavior of individual vehicles and includes the capability of counting the total number of lane changes. It uses a vehicle specific, time-stepping, highly detailed lane-changing and car-following logic to realistically represent traffic flow in a freeway corridor. INTRAS was reprogrammed by the FHWA and is now available as FRESIM (KLD, 2000).

JAM

Model used to predict the traffic flows on a network to find the arrangement of traffic flows to minimize total travel time or distance. No other information available.

MELROSE

MELROSE (**M**itsubishi **EL**ectric **RO**ad traffic **S**imulation **E**nvironment) is a microscopic simulator being developed in order to evaluate the overall performance of traffic systems. The purpose of the simulator is as an enhanced planning tool in ITS. MELROSE is able to simulate traffic flow in both urban streets and freeways. Discrete time simulation is performed on each car using the developer's original vehicle movement model. The simulation models of MELROSE are built in an object oriented programming style that allows them to be easily extended in order to apply them to various types of intelligent transportation systems. MELROSE can output statistics data such as average travel time, average stop time, average delay etc. Yukio Goto for Mitsubishi Electric Corporation developed this model in 1993 and it is not available to the public at this time (Smartest, 1999).

MICROSIM

The objective of MICROSIM is the high-speed simulation of microscopic traffic alternatives. It is based on a cellular automaton traffic model. Vehicles are generated according to a Poisson distribution and/or at uniform arrivals. Its features include the ability to model network details such as signalized intersections; unsignalised intersections with stop and yield signs. Other features include: route plan, maximum velocity, acceleration and vehicle assignment, cloning of template vehicle, statistical variation of maximum velocity and/or acceleration. This model has been verified in detail for replication of vehicle behavior at intersections and replication of vehicle behavior within a link, however it is still in the development stages. Developed by Kai Nagel, Michael Schrekenberg and Marcus Rickert at the Center of Parallel Computing (ZPR) at the University of Cologne (Smartest, 1999).

MICSTRAN/ TRAS-TSC

MICSTRAN (MICroscopic Simulator model for TRA Networks), MACSTRAN (MACroscopic Simulation of TRAffic Network), DYTAM (Dynamic Traffic Assignment Model), and MICTRAD (MICroscopic TRAffic Demand Model) are four traffic simulation models used in the governmental institute NRIPS (National Research Institute of Police Science) in Japan. The MICSTRAN package was designed as a tool for pre-evaluating traffic management strategies such as traffic regulation and traffic signal control prior to on-street operation. MICSTRAN is used for microsimulation of urban traffic (public or private) in large-scale networks. The model was developed in 1975 by Dr. Takeshi Saito et. al. of NRIPS as a research oriented model. It has formed the basis for a new simulator developed in 1997-called TRAS-TSC (TRAffic flow Simulator for

evaluating Traffic Signal Control). This new model is for evaluating traffic signal control algorithms. Features of MICSTRAN include:

- Representation of network details such as intersections;
- Vehicle representation;
- And vehicle assignment (Algers, et al., 1999).

MIMIC

MIMIC is a periodic-scanned microscopic traffic simulation model in which each vehicle and driver has individual characteristics, and with which the influence of other vehicles, road design, and physical environment can be calculated. The road user effects considered in this system are traffic safety, travel time, vehicle costs and community severance. The environment impacts considered are air pollution, noise, and vibration. University of Chalmers' School of Technology proposed this model (University of Chalmers, 1996).

MITSIM

A MIcroscopic Traffic SIMulator (MITSIM) has been developed at the Massachusetts Institute for Technology for modeling traffic flows in networks involving advanced traffic control and route guidance systems (Yang and Koutsopoulos, 1996). MITSIM represents networks at the lane level and simulates movements of individual vehicles using car following, lane changing, and traffic signal response logic. Probabilistic route choice models are used to capture drivers' route choice decisions in the presence of real time traffic information provided by route guidance systems. MITSIM is designed as a testbed for evaluating traffic management systems with the following characteristics:

1. it provides real-time sensor data that mimics the surveillance capacities of the traffic management systems in an ITS environment;
2. it accepts traffic controls and routing information as input from traffic management systems and maintains the state of traffic signals and signs in the simulated network; and
3. it calculates a set of measures of effectiveness (MOE) that represent the performance of the systems to be evaluated (Smartest, 1999).

<u>**MIXIC**</u>

The TNO project was aiming at the development of an instrument for the assessment of the impacts of modern ITS technologies in traffic. It uses microsimulation on a time incremental basis 0,1 second. By means of computer simulation, the consequences for safety, exhaust-gas emission, noise emission, and traffic performance will be weighed in an integrated manner. This instrument should ultimately be suitable for a wide range of Dynamic Traffic Management (DTM) applications. The general framework envisaged a structure with both a microscopic and a macroscopic simulation model. Both models are linked in such a manner that processes can be modeled on an individual driver and vehicle level, but also that an efficient assessment can be provided on a network level. The MICroscopic model for Simulation of Intelligent Cruise control 1.1. (MIXIC 1.1.) was built as a result. The driver and vehicle model has been integrated into MIXIC 1.1. Further, MIXIC 1.1 is equipped with a method for measuring shockwaves. Developed at the Center for Regional Transportation Infrastructure Delft, it is used as a research tool (Algers, et al., 1999).

NEMIS

NEMIS was designed as a specific solution to the problem of on-street testing. Its ability to model urban networks in microscopic detail (individual vehicles, single intersections or road sections) makes it a valuable tool for testing traffic control strategies or techniques at local and area levels. NEMIS is a scientific software package and, since its creation, it has been used principally for research and development work and for the technical assessment of traffic control strategies. It cannot be considered a commercial product. It has been developed for the micro-simulation of urban traffic (private and public) in large-scale networks. It is capable of modeling urban networks and vehicle behavior in considerable detail, and is well structured to meet a variety of application needs. Its usefulness has been demonstrated for the following tasks:

1. Analysis of the effects of regulation and network modification on traffic mobility,
2. Evaluation of different traffic light control strategies ,
3. Testing of traffic assignment techniques, and
4. Simulation and evaluation of route guidance strategies and variable message systems (Algers, et al., 1999).

NETSIM

NETSIM, part of the FHWA TRAF family of simulation models, is used for microscopic simulation and analysis of urban traffic and arterial corridors. Simulation abilities include: different vehicle types (e.g., buses, trucks, carpool), pedestrian interaction, traffic signs (e.g., yield signs and right turn on red), different signal types (e.g., actuated or fixed time), on-street parking, HOV, and graphic animation. NETSIM

simulation results include delay per vehicle, average speed, number of stops, queue lengths, vehicle origin-destination information, bus routes and animation (Algers, et al., 1999).

OLSIM

An urban micro-simulator based on Cellular Automata, developed by the University of Duisburg (www.traffic.comphys.uni-duisberg.de), 1999. There is limited data on this model.

PADSIM

PADSIM, a parallel micro-simulator developed at Nottingham Trent University Computing Department, is used to combine the realism of microsimulations with the efficiency of macrosimulations without incurring the disadvantages of the respective approaches. The PADSIM simulator achieves high computational performance by means of macroscopic modeling and it retains realism through calibrating the macrosimulations using concurrent microsimulation in selected network nodes (this can be considered to be logically equivalent to taking measurements). PADSIM uses a simple linear car-following model with probalistic traffic flow generation and using turning movements coefficients to perform dynamic assignments. It has been calibrated and validated using SCOOT data for Mansfield, Nottinghamshire. PADSIM is a research prototype (Smartest, 1999).

PARAMICS

PARAMICS is a microscopic simulator originally developed at the Edinburgh Parallel Computing Center in Scotland. Paramics is a software system for the simulation of congested traffic networks at the level of individual vehicles. It provides a scalable

solution, operational across a wide range of hardware, from desktop workstations to the Cray T3D supercomputer. It includes a sophisticated microscopic car-following and lane changing model for roads up to 32 lanes in width. Depending on the nature of the application and computer platform, simulation of the behavior of many thousands of vehicles may be at undertaken several times faster than real time. Each vehicle in the simulation represents a driver/vehicle type with associated characteristics, and as a consequence, ATT systems, route guidance, route choice and pollution monitoring can be modeled at a microscopic level. Paramics is suitable for traffic management planning and policy evaluation at a strategic and local level, VMS strategy evaluation, the modeling of congestion and incidents, and other areas where a rapid reactive and proactive planning tool has application. The model has been designed as fully scalable software operating on a UNIX workstation. PARAMICS was released for commercial application as a development system in 1996, it is now available in the US and worldwide. PARAMICS provides the user with the ability to make a large number of measurements of the simulation as it progresses, for subsequent output and analysis. In addition, Paramics enables the modeling of the interface between drivers and Intelligent Transportation Systems (ITS). Further modifications to PARAMICS have made it operable on a PC workstation (Quadstone Limited, 1999).

PELOPS

PELOPS (Program for the dEvelopment of Longitudinal micrOscopic traffic Processes in a System relevant environment) was developed at the Institute of Automotive Engineering, Technical University Aachen, Germany in co-operation with the BMW AG. The idea of PELOPS is a combination of high detailed sub-microscopic

vehicle- and microscopic traffic technical models that permit investigations concerning the longitudinal dynamic of vehicles as well as an analysis of the course of traffic. The advantage of this combination is the opportunity to take all interactions into consideration that occur between driver, vehicle and traffic. An important basis for the realization of this idea is the fact, that the computer capacity was significantly optimized during the last years. Without this capacity the required degree of detail with a simultaneous consideration of all influencing factors would be unthinkable. PELOPS is orientated towards the fundamental elements of traffic, namely route and environment, driver and vehicle. The route model is based on the presentation of the altitude profile with gradients, further on the presentation of the curves with straight stretches of road, arcs of a circle and transitions from a straight route to a curve, as well as of the number of lanes with the respective lane widths. The focal point of the latest research with PELOPS was the investigation of optimizing measures through the application of new vehicle- and traffic-technologies (Aachen Technical University, Germany, 1999).

PHAROS

PHAROS is a microscopic traffic simulator being created as a tool for mobile robot research. It is used to develop a driving program to control a robot van, which has been constructed at Carnegie-Mellon University. PHAROS encodes detailed information about the topography of the street network, the geometry of the streets, the nature of all surface markings, the locations of signs, and the indications of traffic signals. In addition PHAROS simulates a fleet of vehicles moving realistically through a network. PHAROS currently is primarily useful for researchers interested in having or developing a traffic environment for intelligent agent research (Smartest, 1999).

PLANSIM-T

The traffic simulation software was developed and programmed at the Center for Parallel Computing at the University of Cologne to simulate traffic flows on road networks on a very high level of detail. The simulation program is written in C++ and allows the simulation of arbitrary road networks. PLANSIM-T is still a research product. The main features of PLANSIM-T are:

1. the ability to study different traffic flow models,
2. the individual routing of every single car,
3. the ability to build any given network topology from user supplied data files and to import huge highway networks (via suitable converters) from databanks,
4. easy modification of car following rules, and collection of statistical data (fundamental diagrams, time headways, and lane usage distributions),
5. model traffic with all its additional features (crossings, elaborate right of way rules),
6. dynamic emission calculation
7. simulate traffic as fast as possible (Algers, et al., 1999).

ROADSIM

ROADSIM provides microscopic simulation of 2 lanes, 2 way rural roads and is part of the TRAF family of simulation models developed by the Federal Highway Administration. Information on this model is limited (FHWA, 1997).

SATURN

SATURN (Simulation and Assignment of Traffic to Urban Road Networks) is a suite of flexible network analysis programs developed at the Institute for Transport

Studies, University of Leeds and distributed by WS Atkins of Epsom since 1981. It consists of an equilibrium assignment algorithm and macroscopic flow relationships. It has been widely used to evaluate changes in circulation (one-way streets, pedestrian schemes) and other traffic management schemes. Regarding ITS applications, the model has been used to evaluate effectiveness of route guidance systems and road pricing studies. Work is underway to replace SATURN with a microscopic model (Skabardonis, 1997).

SHIVA

SHIVA (Simulated Highways for Intelligent Vehicle Algorithms), developed by the Robotics Institute at Carnegie Mellon University, is designed to model the tactical level of driving, and to make it easy to design and test vehicle algorithms that operate at this level. It is primarily aimed at the intelligent vehicle research community. SHIVA is used to design intelligent vehicles that do not, as yet exist. SHIVA's modular, object-oriented structure allows easy extension. Currently SHIVA provides both a rule based monolithic architecture, as a distributed multi agent architecture incorporating learning. No validation has been performed (Algers, et al., 1999).

SIGSIM

SIGSIM was created at the Center for Transport Studies in the University of London and is used to simulate traffic behavior within a network of signal-controlled junctions for the evaluation of signal control policies. Individual vehicles are simulated using a car-following model, which calculates the speed and position of each vehicle on a lane according to each vehicle's individual characteristics and the characteristics of the

vehicle in front, it provides statistical output data. SIGSIMS state of development is research with on-going development (Algers, et al., 1999).

SIMCO2/GANTRY

This simulation program was developed at the Technical University of Aachen in Germany. The Simulation of Intelligent Maneuvering and Communications (SIMCO2) is a microscopic simulation program for road traffic. The most important application of SIMCO2 is freeway traffic (Aachen Technical University, 1999).

SIMDAC

SIMDAC is a microscopic traffic simulation tool with detailed driver behavior modeling, meant to reproduce the evolution of a line of cars on a single lane, and to evaluate the safety and comfort condition (in terms of headway, time-to-collision, and acceleration) for various disturbing maneuvers of the leading car. It includes a driver model, and two separate car-following laws, in order to better represent the dissymmetrical behavior between acceleration and braking phases. The more relevant features of this model include detailed simulation of driver behavior (foot placement, vigilance level), possibility to simulate realistic reaction time dispersion among drivers, and detailed dynamic display of vehicles and driver behavior. It has been validated and calibrated with real life experiments involving two equipped cars enabled to calibrate maximum deceleration and mean values of driver's reaction times with respect to test bed devices. Jean-Françoise Gabard designed SIMDAC for ONERA-CERT in France and it is used as a research product (Algers, et al., 1999).

SIMNET

SIMNET was developed at the Technical University in Berlin. The objective of the simulation model is to evaluate traffic control measures based on individual vehicle simulation. The main purpose is to evaluate traffic control strategies. SIMNET was developed as an internal research tool within the TU Berlin and is unavailable to the public. It is mainly a discrete event simulation, where the traffic model is a queuing model (Smartest, 1999).

SIMTRAFFIC

Developed by Trafficware, The Traffic Signal Software Company, SimTraffic makes animation and simulation accessible to all traffic engineers. SimTraffic models:

- Actuated and Pretimed Signals,
- Two-way Stop and All-way Stop Intersections,
- Models Cars and Trucks,
- Detailed Pedestrian Modeling,
- Multiple Vehicle Types, and
- Multiple Driver Types (Trafficware Company, 1999).

SISTM

SISTM (Simulation of Strategies for Traffic on Motorways) has been designed to study freeway traffic in congested conditions with the aim of developing and evaluating different strategies for reducing congestion. It is a microscopic freeway simulation with car-following algorithms that use a modified Gipps equation. It is not sold commercially and is only available for TRL or Highway Agency. SISTM has been validated against

average speeds and flows at specific points, using detector loops, on a ¾ lane freeway. Developed at the Transport Research Laboratory in London (Algers, et al., 1999).

<u>SITRA-B+</u>

SITRA-B+, developed by CERT, is able to model medium sized urban networks including complex intersection topology and is particularly suited to the assessment of real time UTC strategies including bus priority and route guidance strategies. SITRA-B+ is an urban traffic simulation tool for the assessment of traffic control and route guidance strategies (vehicles are equipped with on-board devices and receive either dynamic impedance or optimal recommended routes towards their destination). SITRA-B+ can also be used to assess off-line assignment techniques, building of infrastructure, public transport policy etc. The simulation is microscopic; i.e. each vehicle is an individual entity. The change in the simulation states occurs in discrete moments, the car following law is a linear combination of relative velocity and headway between the considered and preceding vehicles. SITRA B+ IS a research product only distributed to some patrons involved in the DRIVE project. The car-following law was partially validated (travel times were checked on an 8 intersection axis) and has been calibrated on a Lyon sub-network (LLAMD project) (Algers, et al., 1999).

<u>SITRAS</u>

Designed by Peter Hidas at the University of New South Wales in Australia SITRAS aims to faithfully simulate the details of traffic flow on urban road networks with emphasis on simulating congested conditions for the purpose of analysis and evaluation of various intelligent transportation systems, such as congestion and incident management systems and route guidance. It is a microscopic time-interval update

simulation program implemented in object-oriented structure. The main modules of the model are vehicle progression based on car following and lane changing theory. SITRAS features the ability to simulate actual vehicle movements through intersections, allowance of vehicles to move between specific origin-destination points and extensive output on network wide, link wise, and origin-destination wise measures of effectiveness. The model has been developed as a purely research product and is currently not validated or calibrated (Algers, et al., 1999).

SMARTPATH/ SMARTAHS

SmartPath is one of the projects of the PATH program at the University of California, Berkeley. It was started in the spring of 1991 to address questions of feasibility, safety and performance of Automated Highway Systems. SmartPath provides a simulation environment for testing various controller designs, evaluating performance and observing the interaction between the vehicle controllers and the highway. To run the simulation, the highway configuration and various simulation parameters need to be specified. SmartPath output is a comprehensive state description of each vehicle on the highway. SmartPath is also a visual simulation package. It provides a graphical interface for viewing the simulated data (highway and vehicles) in a natural way. SmartAHS is a specification, simulation and evaluation framework for modeling, control and evaluation of Automated Highway Systems (AHS) (University of Berkeley, n.d.).

SOUND

SOUND (a Simulation model On Urban Networks with Dynamic route choice), developed at the University of Tokyo, incorporates users' route choice behaviors and is able to reproduce traffic condition in advance when some traffic regulation and/or control

strategies change. The model can also handle several user groups depending on their choice behaviors. SOUND is applied to a network consisting of several hundreds to thousands of nodes and links. Traffic flow is described discretely using a packet (a group of a few vehicles with same characteristics). SOUND does not have lanes but every packet moves sequentially along a link, but it can reproduce the physical queue evolution since traffic density on a link is carefully controlled in relation to its flow. The model has been validated through several applications to the Metropolitan Expressway network and the surface street network of the Southwest Tokyo (University of Tokyo, 1999).

SPEACS

SPEACS is a discrete time, single car micro-simulator of motorway corridor conditions. It was first developed under the PROMETHEUS Program and has since been extended and enhanced so that the current version provides car movement in a 3-lane corridor, simulation of ICC functions and the effects of information provided through external ATT infrastructures. Each vehicle-driver pair is assigned parameters, such as maximum speed, acceleration, desired speed, driver attitude etc. The vehicle is moved according to an empirical car following law based on a model proposed by Gibbs, but improved to provide closer similarity to actual traffic density-flow characteristics. Behavioral and decisional rules are used to simulate maneuvers such as overtaking, lane changing, etc. These rules take account of vehicle-driver characteristics and preferences and the behavior of surrounding vehicles. The model is also able to simulate traffic sensor functions. The evolution of traffic conditions can be followed by means of an interactive graphics interface that allows immediate information to be obtained on any single vehicle or stretch of the motorway. The information is output in the form of tables,

histograms or the visual representation of single equipped stretches. The interface also permits incidents or hazards to be introduced in the course of the simulation. Despite the absence of a specific user manual, the program is very easy to use and training requirements are therefore minimal. It has been interfaced with a car simulator model to assess the effects of longitudinal control. The model has been calibrated using data from the peri-urban freeway around Bari and the Padova-Mestre freeway corridor (Algers, et al., 1999).

STEER

STEER (Signals/Traffic Emulator with Event-based Responsiveness) is a program intended to simulate traffic on an urban network. The program is intended for simulation of real networks and is therefore capable of dealing with large numbers of vehicles (a typical simulation involves tens of thousands) in city-sized networks. STEER is part of the RONETS suite of software being developed at the University of York. The capabilities of the program include:

- Dynamic microsimulation,
- Day-to-day model,
- Multi-modal travel,
- Road pricing simulation,
- Modeling of a variety of signal control policies,
- Accounts for rerouting behavior of drivers to avoid congestion and pricing, and
- Can simulate park and ride schemes (Algers, et al., 1999).

StreetSIM

StreetSIM is a microscopic, time step and behavior based simulation model developed to model urban traffic operations, providing the user with simulation results consisting of on-screen animation of: vehicular movements, traffic signal operation, detector actuation's and travel time summary. The program can analyze traffic operations under constraints such as lane configuration, traffic composition, traffic signals, etc., thus making it a useful tool for the evaluation of various alternatives based on transportation engineering and planning measures of effectiveness.

Besides its animation capabilities, StreetSIM generates numerous user-customizable output files. This information includes:

- detailed travel time statistics,
- detailed delay statistics,
- queue length statistics,
- detailed signal timing information (green time, cycle length, etc.),
- protocol of detector actuations,
- graphical output such as time space diagrams and speed profiles, and
- environmental indicators (FHWA, 2000).

THOREAU

An object oriented traffic simulation tool for traffic engineers. It emphasizes the simulation of advanced traveler information systems (ATIS) and advanced traffic management systems (ATMS) as components of intelligent transportation systems (ITS).

It does this by generating thousands of vehicles, simulating them on trips through complex networks, and recording travel times. THOREAU (Traffic and Highway Objects for Research, Analysis, and Understanding) has primarily been used for evaluation of various adaptive traffic signal algorithms, from corridor synchronization to real-time actuation to a combination of both. THOREAU was originally developed by Dr. William Niederinghaus at the MITRE Corporation and enhanced by Dr. Paul Wang also at MITRE. Further enhancement and maintenance is being done by the Richard Glassco of Mitretek Systems (Algers, et al., 1999).

TRAFFICQ

TRAFFICQ is used for the detailed study of relatively small road networks, but which may contain complex traffic and pedestrian management schemes. Each vehicle and pedestrian is modeled as a single entity, and the time varying and random characteristics of traffic flow are integral to the modeling. Simulation of both upstream and downstream interactions between different junctions is an important feature of TRAFFICQ, developed by the MVA Group Ltd (MVA Group Ltd., 2000).

TRGMSM

A microscopic simulation model, TRGMSM (road Traffic and Rail vehicles General Microscopic Simulation Model), which is developed by J. Wu, and M. McDonald. as a design tool to investigate the interactions between Light Rail Transit (LRT) and road vehicles at intersections (Smartest, 1999).

TRANSIMS

TRANSIMS models create a virtual metropolitan region with a complete representation of the region's individuals, their activities, and the transportation

infrastructure. Trips are planned to satisfy the individuals' activity patterns. TRANSIMS then simulates the movement of individuals across the transportation network, including their use of vehicles such as cars or buses, on a second-by-second basis. This virtual world of travelers mimics the traveling and driving behavior of real people in the region. The interactions of individual vehicles produce realistic traffic dynamics from which analysts using TRANSIMS can estimate vehicle emissions and judge the overall performance of the transportation system. The models simple car-following and lane changing logic are based on cellular automaton technique. TRANSIMS tries to capture every important interaction between travel subsystems, such as an individual's activity plans and congestion on the transportation system. Also, because TRANSIMS tracks individual travelers — locations, routes, modes taken, and how well their travel plans are executed — it can evaluate transportation alternatives and reliability to determine who might benefit and who might be adversely affected by transportation changes. The Transportation Analysis and SIMulation System (TRANSIMS) employs advanced computational and analytical techniques to create an integrated regional transportation systems environment. The simulation environment includes a regional population of individual travelers and freight loads with travel activities and plans, whose individual interactions are simulated on the transportation system, and whose environmental impact is determined. Validation of traffic in a regional context has been completed. TRANSIMS was developed at the Los Alamos National Laboratory, in Los Alamos, New Mexico.

VEDENS

The VEDENS (VEhicle DENsity Simulation) model offers greater flexibility and a more realistic approach to understanding motorway-type traffic flows than has been available previously. In particular it allows driver behavior and vehicle types to be integrated into a detailed model of the road layout at the level of individual vehicles. It also offers an understanding of the type of decision-making algorithm which would be necessary for any on-board "auto pilot" for vehicle control. It is easy to set up a simulation, without the need for large volumes of origin-destination (OD) data. It also breaks away from the stereotyped models of different regimes, such as car following, emergency braking, etc., by using a single driver decision algorithm which is linked to the characteristics assigned to the drivers. VEDENS models the freeway as discrete sections, each of which is assigned a number of lanes. Currently up to six lanes can be modeled. Each section is also assigned a speed limit, a physical length and a gradient. Entry and exit slip roads, known as on- and off-ramps, can be assigned to any road section, offering a flexible facility for modeling a wide variety of motorway-type road configurations where there is unidirectional flow. All of these features can be viewed via an on-screen, visual display. Vehicles entering the model are selected at random from user-defined data, so that the effects of different proportions of vehicles can be investigated. Vehicles are created at the beginning of the model and on the on-ramps, according to flow rates specified for a particular simulation. The flow rates are variable in time. AEA Technology offers this model.

VISSIM

VISSIM is a microscopic, time step and behavior based simulation model developed to model urban traffic and public transit operations, providing the user with simulation results consisting of on-screen animation of:

- vehicular movements,
- traffic signal operation,
- detector actuations, and
- travel time summary.

The program can analyze traffic and transit operations under constraints such as lane configuration, traffic composition, traffic signals, block signals, transit stops, variable message signs, etc., thus making it a useful tool for the evaluation of various alternatives based on transportation engineering and planning measures of effectiveness. Besides its animation capabilities, VISSIM generates numerous user-customizable output files. This information includes:

- detailed travel time and delay statistics ,
- queue length statistics,
- detailed signal timing information (green time, cycle length, etc.),
- protocol of detector actuations and transit priority calls,
- graphical output such as time space diagrams and speed profiles, and
- environmental indicators.

WATSim

WATSim (Wide Area Traffic Simulation) is a microscopic model developed by KLD Associates. It is based on the well tested TRAF-NETSIM simulation model, extended to simulate traffic operations on freeways and other roadways. The freeway model logic has been calibrated using the latest data for the 1994 Highway Capacity Manual and field data. This model can be interfaced with DTA algorithms to simulate ITS systems. It is not marketed as a stand alone software but it is offered as part of a contract with it's developer. WATSIM has been tested and is currently in use in real world applications (KLD Associates, Inc., 1999).

WEAVSIM

Intense lane-changing maneuvers at weaving sections create turbulence that often led to congestion. WEAVSIM was developed for such studies. Freeway Data Collection for Studying Vehicle Interaction, a project of the FHWA, produced data sets at weaving sections and other problem areas to facilitate the study of freeway operations and the enhancement of freeway simulation models. Some of these data sets have been used in testing WEAVSIM (FHWA, 1999).

Descriptions of Macroscopic Traffic Models

ARTWORK

ARTWORK is a simulation of urban arterial work zones. This model evaluates traffic control systems at arterial street lane closures in the vicinity of signalized intersections. Specifically the objectives of this model are to simulate traffic flow at arterial street closures, to derive a series of system measures of performance as an output

of the model, and to validate the model's logic by using field data. No development data available.

AUTOS

AUTOS (ATMS Universal Traffic Operation Simulation) is a macroscopic traffic model developed at Georgia Tech Research Institute that is capable of validating many ITS components. This model is in the process of being tested. (Smartest, 1999).

CORFLO

CORFLO is a component model of the TRAF simulation system designed for the integrated urban network or corridor analysis at a macroscopic level with traffic assignment capabilities. It is the only available traffic model, which explicitly handles automobiles, trucks, buses, and carpools on freeways and surface streets in a single, integrated environment. CORFLO consists of three distinct submodels: FREFLO, NETFLO1, and NETFLO2. FREFLO, a macroscopic freeway simulation model, is based on the conservation equation and a dynamic speed density equation. It represents traffic in terms of aggregate measures on each section of freeway. It can simulate geometric improvements, HOV lanes, bus operations, lane closures and incidents. NETFLO1 and NETFLO2 simulate urban streets at different levels of detail. NETLFO1 treats each vehicle as an identifiable entity. NETFLO2 is an adaptation of the TRANSYT simulation model. Each CORFLO sub model can be run independently as a stand-alone model, or be applied to a specific sub network. Developed by the FHWA, it is available to the public (McTrans, 1996).

FRECON 2

FRECON 2 is a dynamic macroscopic freeway simulation model that can simulate freeway performance under normal and incident conditions. The model can generate point detector information for calibration and validation. It can generate a traffic responsive priority entry control strategy and evaluate its effectiveness. The traffic performance measures include travel times, queue characteristics, delay, fuel consumption and emissions (Yu, 1998).

FREFLO

FREFLO is a macroscopic freeway simulation model developed by the FHWA as part of the TRAF family of simulation models. This model has undergone extensive remodeling (Payne, 1978).

FREQ

FREQ is a macroscopic deterministic freeway simulation model, which calculates freeway and ramp capacities using the Highway Capacity Manual, and bottleneck capacities checked in the field. The FREQ model uses the standard shockwave theory to model the sudden drop of lane capacities that may be caused by traffic incidents. The macroscopic and deterministic mature of the FREQ model significantly simplifies the estimation of parameters (Yu, 1998).

KRONOS

An interactive, menu-driven microcomputer-based freeway simulation program, KRONOS-5, developed to make freeway simulation more accessible. This tool will be used to: compare alternative geometric configurations, estimate the effects of improvements, determine the adequacy of traffic management schemes, assess the

impacts of control strategies, study the formation and dissipation of congestion on the freeway and its ramps, and estimate the effects of lane blockages during construction. .

METANET/METACOR

META (modèle d'écoulement du traffic sur autoroutes) is a macroscopic freeway traffic model. METACOR is an extension of METANET to include modeling of parallel arterials. METACOR has been applied in a number of sites (Paris, Glasgow) only by the model developers. METANET is an implementation of META developed by the Dynamic Systems and Simulation Laboratory at the Technical University of Crete. The simulation of traffic flow is based on the flow conservation equation and a dynamic speed-density relationship. METANET can model multi-origin, multi-destination freeway networks with arbitrary topology and geometric characteristics. METANET aims to model free, dense and congested flow, and take account of capacity reducing events (such as accidents). It takes the form of a software package available for UNIX and IBM-compatible PC computers. The package is written in the `C' programming language. Program execution requires several text files that describe the roadway in question. The program then uses this information to generate an output file. This output file can then be processed using either the METANET data viewer (METAGRAF) or a MATLAB program developed to achieve a similar aim (Skabardonis, 1997).

NETFLO 1, NETFLO 2

NETFLO1 and 2 give macroscopic simulations of urban traffic. These models were developed as part of the TRAF family of simulation models for the FHWA. There is little information published on the development and application of the NETFLO models (Skabardonis, 1997).

NETVACI

No available data (Sheffi et al., 1982).

PASSER II, PASSER IV

Researchers at the Texas Transportation Institute (TTI) have developed PASSER© (Progression Analysis and Signal System Evaluation Routine) model, which consists of three optimization software programs that optimize traffic signal timings on single roadways or entire networks of roadways. PASSER outputs measures of performance such as stops/hr and fuel consumption. PASSER is designed to choose the best signal timings given certain traffic data. The three programs work with three different traffic signal scenarios--PASSER II with single signalized roadways, PASSER III with diamond interchanges, and PASSER IV with single or multiple roadways and diamond interchanges. PASSER can analyze numerous variables that affect progression. PASSER II and III have a simulation feature good for evaluating new developments—such as the construction of a new shopping center--and the impact they'll have on intersections. For instance, by simulating the intersection, PASSER can determine that the increased traffic at the intersection near the new shopping center might require an additional left turn lane (McTrans, 1996).

TRANSYT-7F

Developed by the FHWA as part of the TRAF family of simulation models, TRANSYT-7F is a traffic simulation and signal timing optimization program. It is one of the most comprehensive tools for traffic signal timing and analysis for two-dimensional networks. TRANSYT is macroscopic in nature. However, TRANSYT simulates traffic

flow in small time increments, so that its representation of traffic is more advanced than other macroscopic models (McTrans, 1996).

TEXAS

TEXAS Model for Intersection Traffic can be used in evaluating the operational effects of various traffic demands, types of traffic control and/or geometric configurations at individual intersections. It may be applied in evaluating existing or proposed intersection designs and for assessing the effects of changes in roadway geometry, driver and vehicle characteristics, flow conditions, intersection control, lane control and signal timing plans upon traffic operations. This new version is also capable of analyzing diamond interchanges and actuated control. TEXAS operates in a user-friendly, interactive environment. Special features include animated graphics that show drawn-to-scale, color-coded vehicle types moving through the geometry of the intersection. TEXAS was written by the University of Texas at Austin and is offered by the Texas DOT (McTrans, 1996).

TRANSYT/10

TRANSYT/10 is designed to model traffic behavior and produce fixed-time signal plans that minimize vehicle delay and stops in an urban network of co-ordinated traffic signals. The packaged is widely accepted as the standard off-line method for setting fixed time signals. Signal offsets and the allocation of green times can be optimized to reduce delays and stops, different classes of vehicle modeled and bus given priority. In TRANSYT/10, a new facility has been introduced to permit the accurate modeling of flared approaches. Developed by MVA (MVA Group, 1999).

Descriptions of Mesoscopic Traffic Models

DYNAMIT

DynaMIT is a real-time Dynamic Traffic Assignment system that provides traffic predictions and travel guidance. Travel guidance refers to information provided to a tripmaker in an attempt to facilitate his/her decisions relative to departure time, travel mode and route. Clearly, departure time and (to some extent) travel mode recommendations are only effective prior to trip departure, whereas route guidance information may be useful both before and during a trip. In order to guarantee the credibility of the information system, the guidance provided by DynaMIT is consistent, meaning that it corresponds to the predicted traffic conditions that will be experienced by the drivers. Moreover, DynaMIT provides a user-optimal guidance, with the objective that no user can find a path that she/he would prefer to the one that would be chosen following the provided guidance information. DynaMIT is designed to operate in real time, accept real-time surveillance data, and estimate and predict time-dependent OD flows. The system also incorporates different driver classes and their behavior, provides self-calibration capabilities, estimates current network conditions, predicts future traffic conditions, interfaces with the traffic control system, and generates route guidance consistent with the predicted traffic conditions. It is designed to make departure time, mode and route recommendations for a variety of information systems and information dissemination strategies. DYNAMIT was developed by Moshe Ben Akiva et.al. at the Massachusetts Institute for Technology (MIT, 1996).

DYNEMO

Unlike static models, DYNEMO's traffic assignment routine is dynamic in the sense that it assigns traffic based on real-time traffic conditions, e.g. queue formations at signalized intersections or congested freeway sections. Dynamic traffic assignment leads to more realistic traffic assignment results over a specified study period. In addition to DYNEMO's (dynamic traffic) assignment ability, its on-screen animation capabilities makes it an ideal tool for illustrating the impact of various design alternatives to both technical and non-technical audiences. Unique features of DYNEMO include:

- Dynamic traffic assignment based on traffic control such as
- Traffic signal timing,
- Stop sign locations,
- Ramp metering,
- Real-time traveler information systems;
- On-screen animation;
- Directly importing Origin/Destination (O/D) matrices from EMME/2; and
- Directly exporting assigned traffic routes to VISSIM, a microscopic traffic and transit simulation software package.

DYNEMO's capability to import and export files from other transportation planning software packages minimizes time needed for manually coding this information. This feature not only reduces time and cost, but also reduces the possibility of errors resulting from manual data entry. In regard to its traffic flow modeling logic, DYNEMO uses a mesoscopic model. The mesoscopic model applies both microscopic and macroscopic modeling logic to control the behavior of vehicles within the network. The macroscopic

component governs vehicle behavior on links according to link-specific speed distributions and speed-density relationships. The microscopic component controls the interaction of vehicles at nodes where priority rules control vehicle behavior. Traffic control is modeled in the form of signalized intersections (ramp meters) using cycle length, offset, green splits and discharge rates as input parameters or priority ruled intersections (stop controlled) with major turning movements, minimum headway's and storage on the intersection as input. Furthermore, decision points are placed anywhere within the road network. These decision points provide information required by the vehicles for particular route choice. Various criteria (e.g. time, distance, generalized cost, and external traveler information) are considered for route choice.

DYNASMART

DYNASMART (Dynamic Network Assignment simulation Model for Advanced Road Telematics) designed by Hani Mahmassani and others at the Center for Transportation Research at the University of Texas was designed as both an assignment and simulation model for ITS. Traffic flow is simulated macroscopically based on the continuity equation and modified Greenshields speed-density relationships. The model can simulate traffic signals, ramp meters and incidents. DYNASMART calculates optimal travel paths based on the simulated travel times and simulates the movements and routing decisions by individual drivers equipped with in-vehicle information systems. DYNASMART has been used to study the core network of Austin, Texas and the network of Anaheim, California. Further development of this model has led to the development of DYNASMART-X a traffic assignment and optimization tool. This enhancement combines advanced network algorithms and models of tripmaker behavior

in response to information in a simulation based framework to provide reliable estimates of network traffic conditions, predictions of network flow patterns over the near and medium terms in response to various contemplated traffic control measures and information, dissemination strategies, and routing information to guide travelers through the network. This model is not available to the public (Mahmassani and Peeta, 1999).

METROPOLIS

METROPOLIS is an interactive environment, which simulates automobile traffic in large urban areas. The core of the system is a dynamic simulator, which integrates commuters' departure time and route choice behavior over large networks. METROPOLIS is a mesoscopic simulator based on a behavioral driver information process. It allows real-time and off- line simulations. It has been tested for real-world applications on the network of Geneva. Developed by Andre' de Palma et. al. (de Palma et al., 1996).

Summary of Selected Models

A brief description of all identified traffic simulation models has revealed that many of them were not developed for the purpose of supporting ITS applications. The following table (Table 6) summarizes all models based on the five criteria developed in chapter 3. The unchecked box represents that either the model does not meet this criterion or available documentation did not show this feature. Table 6 shows that the following models have passed the initial screening process and deserve an in-depth evaluation: AIMSUN 2, CONTRAM, CORFLO, CORSIM, FLEXYT II, HUTSIM, INTEGRATION, PARAMICS and VISSIM.

Table 6. Summary of Models Based on Initial Criteria

Model	Criteria					Model	Criteria					Model	Criteria				
	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
AIMSUN2	X	X	X	X	X	MICSTRAN				X		TRAFFICQ	X				
ANATOLL				X		MIMIC	X			X		TRANSIMS	x	x	x	x	
ARCADY2	X				X	MITSIM	X		X	X		TRANSYT-7F	x	x			x
AUTOBAHN	X			X		MIXIC	X			X		TRANSYT 10	x				x
AUTOS				X		NEMIS				X		VEDENS				x	
AVENUE	X		X			NETSIM				X		VISSIM	x		x	x	
CARSIM	X	X				NETFLO	X				X	WATSIM	x		x	x	x
CASIMIR	X					NETVACI						WEAVSIM	x	x			
CONTRAM	X	X		X	X	OLSIM	X										
CORFLO	X	X	X	X	X	PADSIM	X	X									
CORSIM	X		X	X	X	PARAMICS	X	X	X	X	X						
DRACULA	X			X		PASSERII	X		X		X						
DYNAMIT	X			X		PASSERIV	X		X		X						
DYNASMART	X	X		X		PELOPS	X			X							
DYNEMO	X			X		PHAROS				X							
FLEXYT II	X		X	X	X	PLANSIM-T	X			X							
FOSIM						ROADSIM											
FRECON 2			X	X	X	SATURN	X	X			X						
FREFLO	X					SHIVA	X			X							
FREEVU	X				X	SIGSIM	X		X	X							
FRESIM	X			X	X	SIMCO2											
FREQ	X			X		SIMDAC	X		X								
HIPERTRANS				X		SIMNET	X			X							
HUTSIM	X		X	X	X	SIMTRAFFIC	X										
ICARUS						SITRA B+	X			X							
INTEGRATION	X	X	X	X	X	SITRAS	X		X	X							
INTRAS	X					SMARTAHS			X	X							
JAM			X			SMARTPATH			X	X							
KRONOS						SOUND		X		X							
MELROSE	X			X		SPEACS	X	X	X								
METACOR	X	X	X	X		STEER				X							
METANET	X	X	X	X		STREETSIM	X		X								
METROPOLIS	X	X				TEXAS	X			X	X						
MICROSIM	X	X		X		THOREAU	X	X		X							

In-Depth Evaluation Results

The in-depth evaluation of the nine selected models in chapter 4 consisted of a review of the models documentation with emphasis on the model strengths, weaknesses and suitable areas for applications with respect to ITS. Table 7 lists the selected models and their evaluations based on specific ITS application areas.

Table 7. Summary of Models Based of In-Depth Criteria

	AIMSUN 2	CONTRAM	CORFLO	CORSIM	FLEXYT II	HUTSIM	INTEGRATION	PARAMICS	VISSIM
ITS Features Modeled									
Traffic devices (1)	X						X	X	
Traffic device functions (2)	X						X	X	
Traffic calming (2)					X	X	X	X	X
Driver behavior (3)	X			X	X		X	X	
Vehicle interaction (3)	X			X	X		X	X	
Congestion pricing (4)						X		X	
Incident (4) (5)	X		X	X	X	X	X	X	X
Queue spillback (5)	X			X	X	X	X	X	X
Ramp metering (6)	X			X	X	X	X	X	X
Coordinated traffic signals (6)	X	X		X	X	X	X	X	X
Adaptive traffic signals (6)	X	X		X	X	X	X	X	X
Interface w/other ITS algorithms (7)	X								
Network conditions (8)	X					X		X	
Network flow pattern predictions (9)					X	X	X	X	X
Route guidance (10)									
Integrated simulation (11)	X	X		X		X	X	X	X
Other Properties									
Runs on a PC	X	X		X	X	X	X	X	X

	AIMSUN 2	CONTRAM	CORFLO	CORSIM	FLEXYT II	HUTSIM	INTEGRATION	PARAMICS	VISSIM
Graphical Network Builder	X	X			X	X			X
Graphical Presentation of Results	X	X		X	X	X	X	X	X

*( ) Corresponds to in-depth criteria.

Strengths and Weaknesses of Selected Models

Traditional traffic simulation models often treat traffic as homogeneous platoons that obey simple speed/flow relationships. Such models find it difficult to assess the effectiveness of ITS which often requires, among other things, interaction between individual vehicles and the new systems (systems under information) to be modeled. The selected models are evaluated in this section according to their strengths (ability to assess the effectiveness of ITS) based on the in-depth criteria specified in chapter 3.

AIMSUN 2

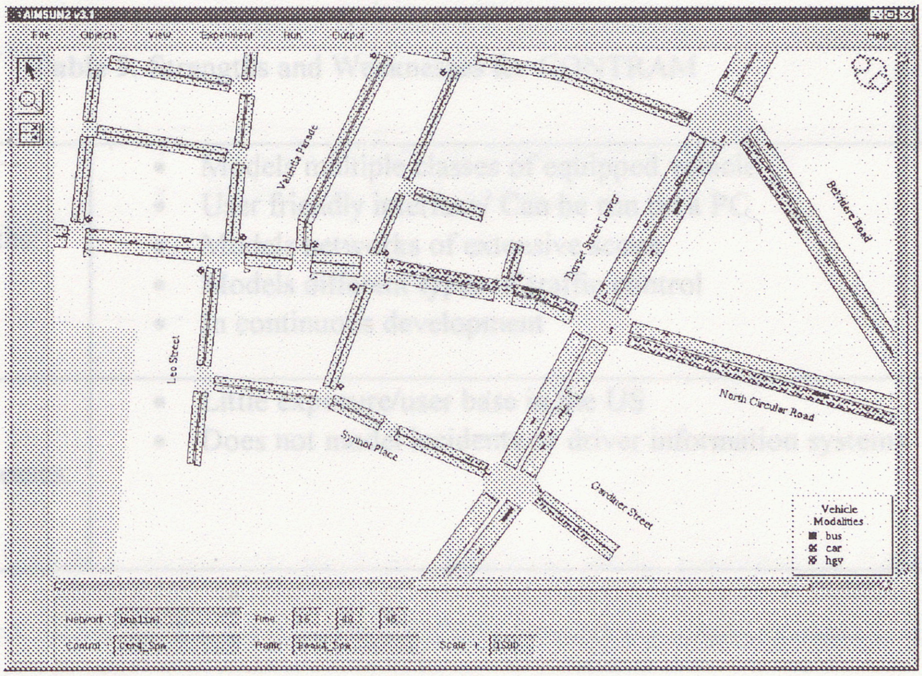
The objective of AIMSUN 2 is to simulate urban and interurban traffic networks containing a wide range of ITS applications, providing the user with a user friendly interface to facilitate both the model building and the use of simulation as an assessment tool (see Figure 3). The strengths of this model lie in its innovations, which include graphical editing capabilities, animation and simulation outputs, and simulator server: easy to communicate with external applications, i.e. adaptive control systems, two modeling approaches: flow and turning modifications based and route based (OD

matrices, paths). The strengths and weaknesses of employing AIMSUN 2 for ITS applications are listed in Table 8.

Table 8. Strengths and Weaknesses for AIMSUN 2

Strengths:	• Detailed statistical output: flows, speeds, travel times, etc. • User friendly interface/ Can be run on a PC • Can deal with different traffic networks • Models different types of traffic control
Weaknesses:	• Not widely used in the US • Route guidance and VMS are taken into account but the information or signalization to implement them must come from an external system

Figure 3. Screenshot of AIMSUN 2 Simulation



Source: Smartest, 1999

CONTRAM 5/7

CONTRAM is well documented. It provides a single integrated model and graphics package. Background traffic may be calibrated and modeled using dynamic multi-path assignment generated from an induced user equilibrium based on perceived travel time. Model strengths for ITS applications lie with its ability to model signalized intersections. The features available for more detailed modeling of signalized intersections include, phase delays, opposed turns, and multiple signal plans. At the heart of CONTRAM is a dynamic assignment model that predicts traffic routes, link flows and queues and delays at intersections as they evolve over time. Thus it is capable of accurately representing time varying network conditions. The strengths and weaknesses of CONTRAM can be seen in Table 9.

Table 9. Strengths and Weaknesses for CONTRAM

Strengths:	• Models multiple classes of equipped vehicle • User friendly interface/ Can be run on a PC • Models networks of extensive scope • Models different types of traffic control • In continuous development
Weaknesses:	• Little exposure/user base in the US • Does not model incidents or driver information systems

CORFLO

CORFLO is a set of macroscopic simulation models which consist of: FREFLO, NETFLO1, and NETFLO2. The components of CORFLO enjoy a wide usage and run on inexpensive computers. Outputs from CORFLO include a fairly extensive set of performance measures (travel time, delay, speeds, fuel consumption, and emissions). A graphics post-processor (GCOR) provides graphical displays of model results. It is the only available traffic model that handles automobiles, trucks, buses, and carpools on freeways and surface streets in a single, integrated environment. It can simulate geometric improvements, HOV lanes, bus operations, lane closures and incidents. Strengths and weaknesses are listed in Table 10.

Table 10. Strengths and Weaknesses for CORFLO

Strengths:	• Runs on inexpensive computer • Component models are well established
Weaknesses:	• Not built for dynamic route guidance modeling • Background model implicit, nonmodular

CORSIM

CORSIM is a microscopic stochastic simulation model consisting of the widely used FRESIM model for freeways and the NETSIM model for adjoining surface streets. It realistically represents the real world dynamic traffic environment. CORSIM produces a variety of measures of effectiveness to quantify traffic network performance. In

addition CORSIM produces animated graphics allowing the user to look and feel the simulation results and perform many more reviews of outputs in much less time. In 1997, an enhanced version of CORSIM was released that interfaces with various traffic assignment and control algorithms. This modeling system called TrEPGS (Traffic Estimation, Prediction, and Guidance System) is specifically designed for ITS applications. Major strengths include the explicit modeling of freeway, arterial and intersection designs, several vehicle types (cars, buses, and trucks), and control options. Explicit modeling of control includes fixed-time; vehicle actuated, plus isolated or coordinated controllers. The major limitations are the lack of assignment algorithms, which make it difficult to evaluate traffic diversion strategies due to ramp metering, incidents, and traveler information systems. Currently the model is limited to 600 links on both freeways and surface streets (i.e. the practical limit of the model is a 10 mile freeway section with an adjoining surface street network with about 75 signalized intersections). Given the level of detail needed to code the network and the lack of interfaces with other tools and databases, the model cannot be effectively used to simulate large networks. A summary of the strengths and weaknesses of this model are listed in Table 11. The software is available from the McTrans Center at $500/single license. The costs for multiple licenses range from $3000 to $7000 depending on the number of licenses.

Table 11. Strengths and Weaknesses for CORSIM

Strengths:	• Explicit modeling of freeway, arterial intersection designs • Comprehensive set of outputs • Comprehensive set of performance measures
Weaknesses:	• Current version not well tested • No ramp metering control

<u>FLEXYT II</u>

The strength of the simulator FLEXYT II is the possibility to use a special traffic control programming language (FLEXCOL-76) to simulate any type of control and the fact that the simulation is event based. It has user specified parameters, and the network can contain features such as stops for public transit, and priority intersections and routes. FLEXYT II can output measures of effectiveness such as delays, queue lengths, network indicators and environmental aspects. Because it is event based only changes of state of vehicles, detectors and signals are calculated. One of the weaknesses of FLEXYT II is the fact that there is no graphical user interface, however one is now in development but has yet to be widely tested. There is no vehicle assignment, other than specified by the user via a time-dependant OD-matrix for every intersection. The strengths and weaknesses are summarized in Table 12.

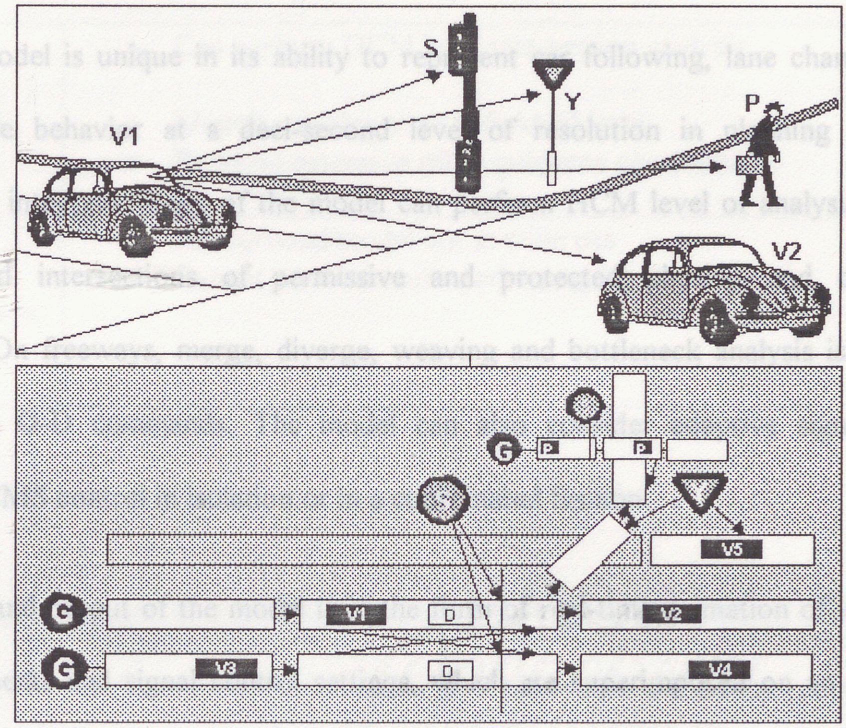
Table 12. Strengths and Weaknesses for FLEXYT II

Strengths:	• Any type of control strategy can be simulated • Can make comparisons on different control strategies
Weaknesses:	• No assignment • Small networks

HUTSIM

HUTSIM is a micro-simulation tool developed especially for traffic signal simulation. HUTSIM can be connected with real signal controllers, which makes it possible to test and evaluate real control strategies. Recently the scope of HUTSIM has been enlarged towards general urban traffic simulation. The advantages of HUTSIM are its flexible and versatile object oriented approach (as seen in Figure 4), utilization of real controller control systems, and graphical user interface. It outputs measures of effectiveness such as time/space curves, and vehicle/signal details. Drawbacks of this model is that it requires a large level of network detail to operate, constructing a large network can be very time consuming, and a powerful PC is required with large models and heavy traffic. A summary of strengths and weaknesses can be found in Table 13.

Figure 4. Example of Object Interactions in HUTSIM



Source: Helsinki University of Technology, 2000

Table 13. Strengths and Weaknesses for HUTSIM

Strengths:	• Flexible object oriented approach • Very detailed level of modeling • On-line animation and screen output
Weaknesses:	• No dynamic route guidance • Time consuming to use

INTEGRATION

This model is unique in its ability to represent car following, lane changing and gap acceptance behavior at a deci-second level of resolution in planning types of networks. The integrated logic of the model can perform HCM level of analysis of stop sign controlled intersections of permissive and protected phasing and of signal coordination. On freeways, merge, diverge, weaving and bottleneck analysis is possible using dynamic O-D commands. The model can also consider adaptive signal, ramp metering and CMS control in isolation or in a coordinated fashion.

The visual output of the model is in the form of real-time animation of individual vehicle movements and signal control settings, which are superimposed on an idealized graphical representation of the network. This graphical interface permits the status of individual vehicles or links to be queried. A time series of statistics on travel time, distance, number of stops, queue sizes, fuel consumption and vehicle emissions are logged during each run to permit extensive post-processing of selective model results. The model provides the detailed modeling of driver/vehicle characteristics through a number of other traffic simulation models. Thus, a number of design and control options are handled approximately. Software costs range from $400/single license for a small version (250 links), to about $10,000/single license for the largest version. Costs for multiple licenses are arranged through the model developer. Table 14 summarizes strengths and weaknesses.

Table 14. Strengths and Weaknesses for INTEGRATION

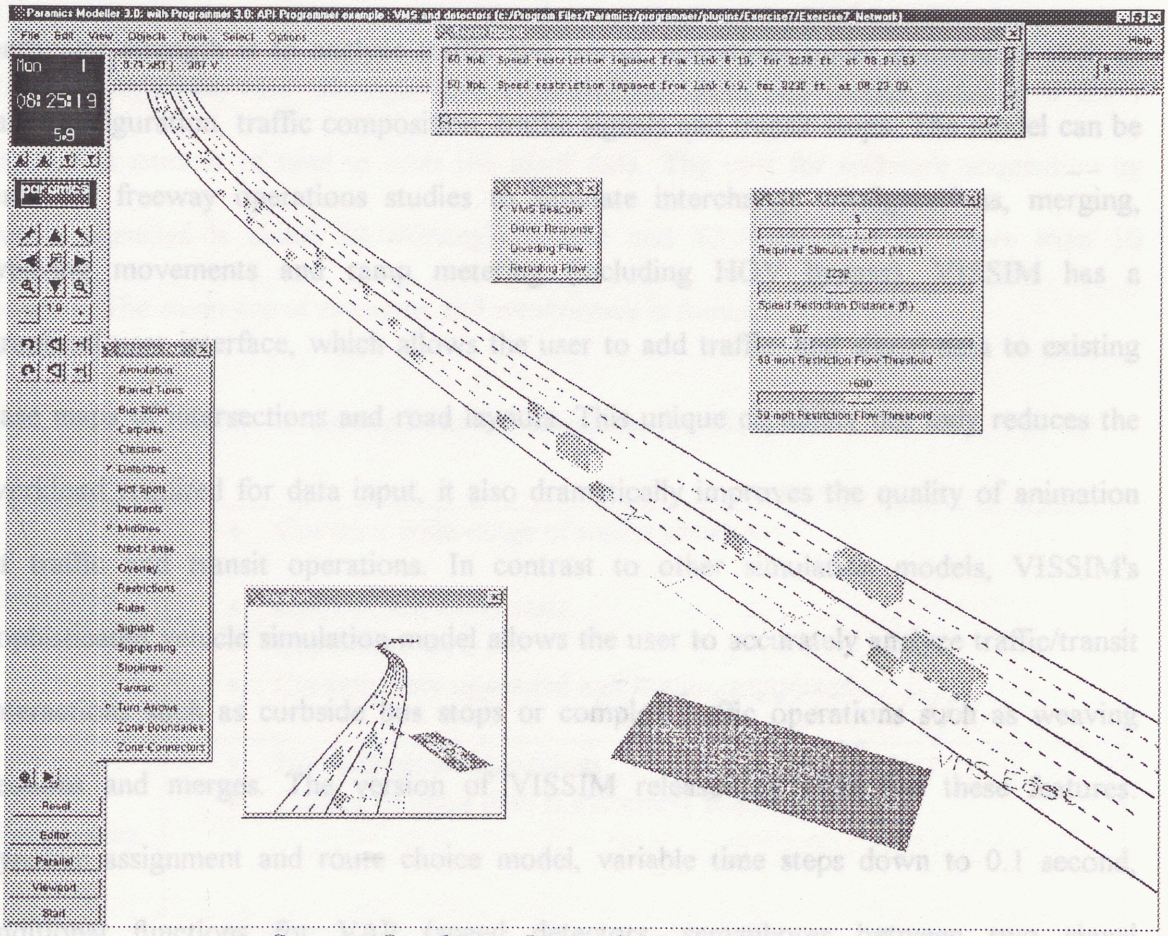
Strengths:	• Can perform HCM level intersection analysis • Models vehicles at an individual level • Provides extensive route guidance capabilities
Weaknesses:	• Background model not in wide use • Cannot perform multi-path assignment

PARAMICS

The major strength of PARAMICS is its software design for high performance and scalability. It provides integrated modeling of networks consisting of freeways, arterials, and minor roads, various intersection types (signals, stop signs, roundabouts) and parking garages with no limit on the network size, and the number of vehicles that can be simulated. The user interface with multiple graphical windows for data input and output provides an excellent visualization tool. The program includes an Application Programming Interface (API) to externally specify algorithms and control options (see Figure 5). PARAMICS limitations include a lack of equilibrium traffic assignment, and limited options in modeling traveler information/guidance, which means that the model updates the routing instructions at each intersection instead of being path based, which may result in myopic travel paths with extensive twists and turns. Other weaknesses include not being able to explicitly model a number of control options such as bus signal preemption from mixed-lanes, and limited user options in modeling incidents and work zones. An evaluation of PARAMICS at UC Irvine indicated that the model accurately

replicated traffic flow on a single freeway link, but fairly high discrepancies were found between observed and predicted flows during the simulation on the entire Irvine network. Software costs include $22,000/single license with an annual license renewal fee of $3,500 plus the cost of $7,000 for a basic cost. PARAMICS strengths and weaknesses are summarized in Table 15.

Figure 5. PARAMICS Programmer API using VMS Beacons



Source: Quadstone Limited, 2000

Table 15. Strengths and Weaknesses for PARAMICS

Strengths:	• Real time simulation of hundreds of vehicles • Comprehensive visualization system • Provides intelligent route guidance capabilities
Weaknesses:	• Not extensively used in the US

VISSIM

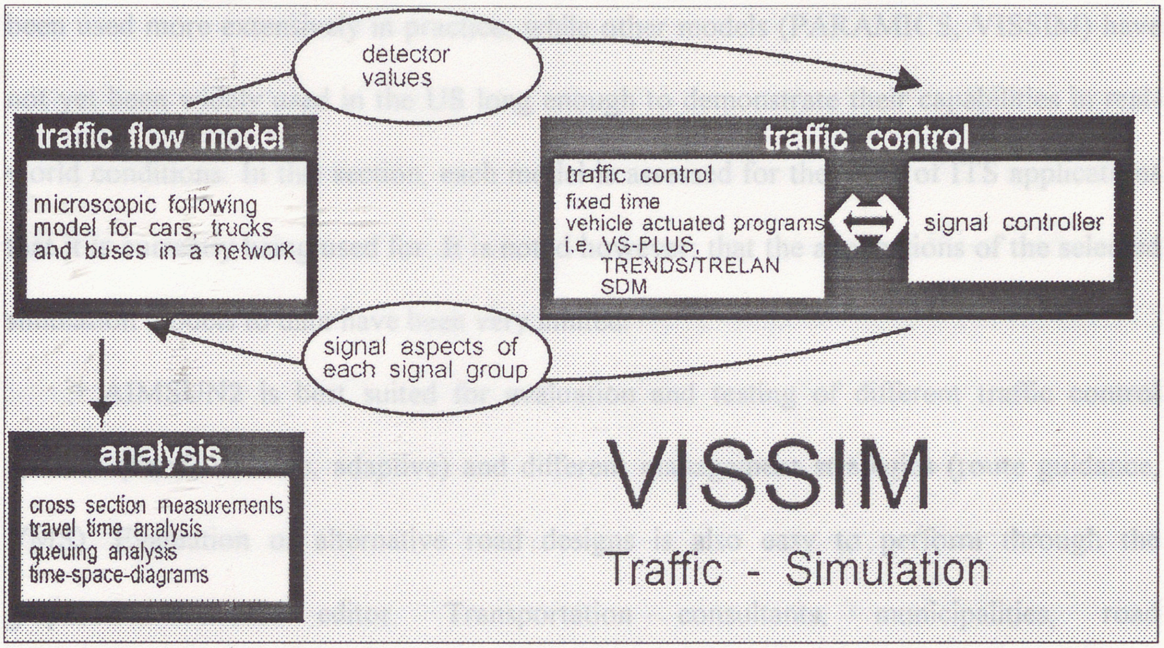
VISSIM is a microscopic traffic and transit simulation model. The programs particular strength is to analyze traffic and transit operations under constraints such as lane configuration, traffic composition, traffic signals and transit stops. The model can be used for freeway operations studies to simulate interchange configurations, merging, weaving movements and ramp metering (including HOV bypass). VISSIM has a graphical user interface, which allows the user to add traffic, and signal data to existing base maps of intersections and road layouts. This unique capability not only reduces the workload required for data input, it also dramatically improves the quality of animation of traffic and transit operations. In contrast to other simulation models, VISSIM's sophisticated vehicle simulation model allows the user to accurately analyze traffic/transit interactions such as curbside bus stops or complex traffic operations such as weaving sections and merges. The version of VISSIM released in 1999 has these features: dynamic assignment and route choice model, variable time steps down to 0.1 second, additional functions for VAP (speed detectors, semaphores between two signal controllers, frame plans, check of intergreen violation), graphical flow charter VISVAP

generates automatically VAP-code, enhancements to model transit vehicles to cope with stop times dependent on passenger boarding, Interface to the signal control software suite TEAPAC from Strong Concepts (USA), graphical enhancements (color for vehicle types, articulated vehicles, 3-D animation), true 32-bit helps to run VISSIM 3.0 about 4-times faster than 2.x releases, and detailed emission model including vehicle fleet compositions. The limitations of this model are no traffic assignment thus, it is not suitable for corridor capacity improvements at the regional level, or to evaluate network wide effects of traveler information/guidance systems in combined freeway and arterial networks. It uses a time step of 1's, which is too slow for Automatic Cruise Control. There are no software limits on the size of the network to be modeled, but the practical limit is networks with 60 signalized intersections. Also the model requires a fairly significant amount of time to code the input data. The cost for software acquisition by public agencies is about $9,000/single license and $2,550/license for more than 10 licenses. The summary of strengths and weaknesses is found in Table 16.

Table 16. Strengths and Weaknesses for VISSIM

Strengths:	• Covers a wide range of traffic situations • Can run feasibility tests • Can be run on a PC • Continuously upgraded and hotline supported
Weaknesses:	• No assignment algorithms • Coding of input data is extremely time consuming

Figure 6. Flow Chart of VISSIM Traffic Simulation



Source: www.ptv.de/system, 2000

From the listing of the selected models' strengths and weaknesses, it is obvious that some models are more suitable than others for integration into the ITS framework. Therefore, the areas where simulation models can be useful are important to consider as a part of this evaluation.

<u>**A Summary of Suitable Areas of Application**</u>

There are several important areas of applications for traffic simulation models within the ITS framework. Evaluation of transportation networks involving traveler information systems and responsive control systems requires that traffic is modeled in great detail and that their interactions with the systems are captured. All the selected simulation models are operational, well documented, and being used by non-model

developers in real-world applications. All of these models are expected to be supported and continually enhanced in the future. Some models (CORSIM, INTEGRATION) have been used more extensively in practice, while other models (PARAMICS, VISSIM) have not yet been widely used in the US long enough to demonstrate their capabilities in real-world conditions. In this section, each model is assessed for the areas of ITS applications that it is currently being used for. It is noted however; that the applications of the selected simulation models to date have been very limited.

AIMSUN2 is best suited for evaluation and testing of different traffic control systems (fixed, variable, adaptive) and different management strategies (route guidance, VMS). Evaluation of alternative road designs is also easy to perform through the graphical network editor. Transportation consultants, municipalities, road administrations, universities, and public transport companies are using it. INTEGRATION has been used in several studies in research and practice. Most of the earlier studies involved the assessment of benefits from real time route information and guidance (the Travtek experiment in Florida, the National ITS System Architecture Study). INTEGRATION also appears to be the model best suited for corridor improvement strategies such as corridor capacity improvements, and various HOV treatments (exclusive lanes, special interchange designs, occupancy rules). CORSIM is aimed at assessing advanced traffic control scenarios in which the route choice is fixed (adaptive traffic signal control on arterials, and traffic responsive ramp metering without diversion). There have been numerous applications of CORSIM both in research and practice. It is continually enhanced by the FHWA, and it is used as the standard simulation test bed in several major research studies, including the NCHRP Weaving

Study for HCM2000. FLEXYT II can predict the effects of a certain control strategy or compare different strategies. Road authorities, consultants, universities and manufacturers of traffic control equipment use the model. HUTSIM can be used for: evaluation and testing of signal control strategies, evaluation of different traffic arrangements, development of new control systems, and evaluation of ITS applications. HUTSIM users consist of road administrations, city planning offices and traffic consultant companies. PARAMICS excels in modeling congested road networks and ITS infrastructures. PARAMICS can currently simulate the traffic impact of signals, ramp meters, loop detectors linked to variable speed signs, VMS and CMS signing strategies, in-vehicle network state display devices, and in-vehicle messages advising of network problems and re-routing suggestions. Vehicle re-routing in the face of ITS is controlled through a user-definable behavioral rule language for maximum flexibility and adaptability. The PARAMICS software continues to undergo further development, driven by contract work and the continued incorporation of new technology in real-world transport systems. Currently, development is underway in the following areas: detailed modeling of noise and exhaust pollution; multi-modal transportation simulation; traffic state determination from on-line vehicle counts; and provision of predictive traffic information for in-vehicle services. PARAMICS is currently in use on a wide range of projects in the UK and US, on a service/consultancy basis. Results of VISSIM are used to define optimal vehicle actuated signal control strategies, test various layouts and lane allocations of complex intersections, test the location of bus bays, test the feasibility of complex transit stops, test the feasibility of toll plazas, find appropriate lane allocations of weaving sections on freeways etc. There are several applications of VISSIM in Europe

primarily on traffic signal control and transit priority. It has also been used in Germany to study the effects of speed limits and incidents on freeways. King Metro County is currently using VISSIM on transit signal priority studies in Seattle. Several studies in the US applied VISSIM on intersection/interchange design and operations. The results of these studies are still unavailable. CONTRAM models time-varying traffic demands on roadway networks that are restrained by limited capacity and transient overload, and predicts the variation through time of the resulting routes, queues, and delays. It can be used to predict the effects of signal timings and coordination, fuel consumption, and numbers of stops. It can also be used for designing urban traffic management options. From the summary of suitable applications and the assessment of strengths and weaknesses several assumptions can be made about the future use of traffic simulation models for ITS applications and the enhancements that need to take place to answer the interoperability issues.

CHAPTER 5

STUDY FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

This study identified, selected and evaluated traffic simulation models for ITS applications. The models represented a range of off-the-shelf simulation tools and approaches under development. The following constitute the study findings and recommendations regarding traffic simulation models and their ability to be used in their current state in the interim before needed enhancements can be made. The recommendations for selecting the most promising models to address the various ITS applications needs are based on the evaluation criteria using the most current information at the time of the study. It is also recognized that this model evaluation needs to be repeated at frequent intervals in the future to assure that the best candidate models are brought to the forefront.

Traffic Simulation Model Findings

It is obvious from the previous evaluation that at present no one model fully meets the needs of ITS applications. None of the models is capable of totally simulating the effects of some of the ITS applications such as real time control, traffic management operations and interactions on control and traveler information systems. The findings of this evaluation are summarized below for each model from the final selection:

AIMSUN 2: This model appears to be one of the newer simulation models on the forefront of the ITS movement. It meets a large number of the ITS related criteria. However, because of its limited validation and calibration in the US makes it cannot be given further consideration within the context of this study.

CONTRAM 7: Despite this models complete redesign of its data structure to improve user interaction, enough information could not be found to confirm that CONTRAM models enough ITS functions to be considered further for the purposes of this study.

CORFLO: Macroscopic modeling allows for fast simulation times and analysis of design control scenarios. Consists of three distinct submodels that have been well calibrated and documented, and can run alone as stand alone models. Lacks capability to simulate most ITS applications.

CORSIM: Appears to be the leading model for testing most of the scenarios involving alternative geometric configurations (weaving, merging, diverging), incident and work zone impacts, and various ramp metering options. It also appears to be the leading model for testing scenarios involving intersection design, signal coordination options, and transit modeling for exclusive lanes or mixed in traffic. CORSIM can assess advanced traffic control scenarios in which the route is fixed (adaptive traffic signal control on arterials, and traffic responsive ramp metering without diversion).

FLEXYT II: This model has been validated for three different situations: a signal intersection, a roundabout, and a freeway with congestion. FLEXYT II has at last counted only 38 users and no known applications in the US.

__HUTSIM__: Meets a good portion of the evaluation criteria but no documented use in the US.

__INTEGRATION__: Appears to be the leading model for evaluating ITS scenarios along corridors that involve effects of real time route guidance systems, or changes in traffic patterns as a result of freeway ramp metering options. Several studies have been documented that demonstrate most of the model features.

__PARAMICS:__ Provides the most comprehensive visual displays for viewing the results through multiple windows, and animation of vehicle movements including 3-D displays during the simulation run. Applications in Britain seem promising. Only recently released for use in the US. However, there is a lack of applications in the US.

__VISSIM:__ Used in several US studies for transit signal priority, intersection/interchange design and operations. The results from these studies are as yet unpublished so information on real world applications cannot be assessed.

Conclusions

The findings from the evaluation indicate that presently CORSIM and INTEGRATION appear to have the highest probability of success in real world applications. Both models have continued development and enhancements are on going, and more applications by non-model users. It is prudent to add that with more calibration and validation in the US the AIMSUN 2 and PARAMICS models will be brought to the forefront in the near term for use with ITS applications.

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