Synopsis of Traffic Simulation Models

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Abstract

Computer simulation modeling is an established tool for assessing traffic operations. Over the past three decades, a variety of traffic simulation models have been developed, and many experiments and applications of these traffic simulation models to imaginary and real traffic operations have been conducted. This paper is intended to review widely used and newly developed models, in terms of modeling mechanisms, characteristics, and applications. Traffic simulation theories and approaches are briefly described. Simulation models developed for different traffic systems are then reviewed, including those for urban networks, freeways and integrated urban street/freeway systems. Important issues on model application are discussed.
I. Introduction

Computer simulation is playing an increasingly important role in the analysis and assessment of freeway and urban street systems, due to its capability and flexibility in modeling traffic conditions, control strategies, and driver behavior. Over the past three decades, a considerable variety of sophisticated computer models capable of simulating various traffic operations have been developed. Simulation models have different characteristics: static or dynamic, deterministic or stochastic, microscopic or macroscopic. Each simulation model has its own logic and use limitations, and is applicable to specific components of a transportation system.

Many experiments and applications of traffic simulation models to synthetic and real traffic operations have been conducted. By using simulation techniques, transportation specialists can study the formation and dissipation of congestion on roadways, assess the impacts of control strategies, and compare alternative geometric configurations. Most traffic simulation models used today are under continuous improvement. The lack of extensive model calibration and validation, the inappropriate or over-simplified assumptions inherent in model logic, the considerable input requirements and time consuming program execution may yield simulation results which are of limited use, misleading, or difficult to obtain. Many simulation-related issues should be considered carefully before a simulation model is applied to a specific traffic problem.

This paper is a literature review of traffic simulation models. Traffic simulation model classification, microscopic and macroscopic methodologies, and traffic flow assignment techniques embedded within simulation models are presented. Then, widely used and newly developed traffic simulation models are reviewed. Several important issues related to simulation model applications such as model selection, data needs, variability and reliability of results, and output analysis are discussed. A future paper will discuss our assessments of TSIS/CORSIM, WATSIM and INTEGRATION 2.
II. Overview of Simulation Model Characteristics

Traffic simulation models take into account the fundamental traffic flow, speed, density characteristics and integrate them with analytical techniques such as demand-supply analysis, capacity analysis, shock-wave analysis, and queuing analysis. Models logic varies across models and different approaches to represent traffic operations are employed. Traffic assignment is embedded in several simulation models, thus, it is discussed in this section.

2.1 Classification

A variety of traffic simulation models have been developed since the 1960s. The simplest model classification may be based on the classification of facilities that the model can analyze. Gibson (1) classified simulation models as those for intersections, arterials, urban networks, freeways, and freeway corridors. May (2) further identified a rural highway model type. The need for integrated control strategies has resulted in recent developments of simulation models for integrated freeway/signalized intersection networks (3). Each of these traffic subsystems, isolated, coordinated, or integrated, has unique problems and objectives. Each, therefore, has generated its own simulation models.

A common classification method for simulation models is based on the uncertainty content which represents the deterministic or stochastic nature of simulation, and the time horizon which represents the static or dynamic properties of simulation (4). A simulation model could be dynamic and stochastic, or dynamic and deterministic in nature. Given the traffic characteristics in the real world, simulation models which fall into the static classification do not exist, though simulation based on time-slice static traffic flows is not rare.

In terms of how often the status of the traffic network is updated and the statistics on traffic performance is collected, traffic simulation models can also be classified into types of interval scanning (or
time stepping) and event scanning (5). When time scanning is used, the state of the traffic system is
examined and performance statistics is collected at regular intervals of time. In the event based models, the
traffic situation is updated when events of importance to traffic operations occur (e.g., meter turns red).

Perhaps the most frequently used classification method is based on the details a model intends to
simulate, namely, microscopic or macroscopic modeling. Microscopic models consider the characteristics
of each individual vehicle, and its interactions with other vehicles in the traffic stream. Therefore, they can
simulate traffic operations in great detail but usually require extensive inputs, and computer execution time
for their application. Macroscopic models are characterized by continuum fluid representations of traffic
flow in terms of aggregate measures such as flow rate, speed, and traffic density. This category of model
loses a great deal of detail but gains an ability to deal with large problems within short execution times.
Analytical procedures are incorporated into both microscopic and macroscopic models to evaluate existing
conditions and predict performance under different design and control scenarios.

A limited number of simulation models fall into the third category of mesoscopic models (6). In
these models, vehicle packets or platoons are simulated. A packet is seen as a single vehicle, and its
turning movement and departure/arrival time is uniquely determined by the simulating mechanism. There
also exist some simulation models in which some of the modeled phenomena are not normally taken into
account in most of their similar models. For example, macroscopic models usually do not simulate lane-
changing, merging, and diverging behaviors. However, KRONOS, often classified as a macroscopic
model, does simulate these behaviors and therefore it could also be a mesoscopic model (7). On the other
hand, INTEGRATION, a microscopic model in the sense that individual vehicle movements are traced
through the network, does not explicitly consider the details of vehicle lane-changing and car-following
behavior (8), which is the core attribute of most microscopic simulation models. Conversely,
INTEGRATION considers the aggregate speed-volume interaction of traffic, which is the typical
treatment in macroscopic models. Similar to INTEGRATION, the AVENUE simulation model (9)
employs the hybrid representation of traffic flow, which treats traffic as continuum flow, but at the same
time it moves discrete vehicle images for the convenience of the route choice calculation and for handling conflicts of vehicles at intersections and lane changing. Therefore, there are some models such as INTEGRATION and AVENUE which could be classified as quasi-microscopic models.

2.2 Microscopic Methodology

Typical microscopic simulation modeling methods are based on car-following and lane-changing theories which can represent the traffic operations and vehicle/driver behaviors in detail. The car-following theory describes the longitudinal movement of vehicles. The classical car-following approach is quite straightforward, i.e., each vehicle attempts to advance at its desired speed while maintaining a safe following distance from the vehicle ahead (10). The lane-changing theory describes the lateral traffic behavior. This may be considered in term of a number of perception thresholds governing the consideration of the risk of accepting a gap in a neighboring lane (11). A set of decision rules are used to calculate whether a speed advantage may be obtained if a vehicle were to change lane.

Microscopic simulation modeling incorporates queuing analysis, shock-wave analysis, and other analytical techniques. In addition, most microscopic simulation models are stochastic in nature, employing Monte Carlo procedures to generate random numbers for representing the driver/vehicle behavior in real traffic conditions.

2.3 Macroscopic Methodology

Macroscopic models do not consider car-following behavior in detail, but instead model traffic as an aggregate fluid flow. To better understand the collective behavior of traffic and analyze flow conditions in a dynamic fashion, continuum models, either simple or high-order, are usually employed in macroscopic simulation modeling (12, 13). The simple continuum model consists of a continuity equation representing the relationship between the speed, density, and flow generation rate. This type of continuum model is
employed in KRONOS. The simple continuum model does not consider acceleration and inertia effects and cannot describe nonequilibrium traffic flow dynamics with precision (14).

The high-order continuum modeling takes into account acceleration and inertia effects by using a momentum equation in addition to the continuity equation characterizing the simple continuum model. This momentum equation accounts for the dynamic speed-density relationships observed in real traffic flow. Payne’s equation (6), a well known momentum equation, is employed in the FREFLO macroscopic model. Although the existing high-order models look promising, they have not as yet proved truly superior to the simple continuum models at least in medium-to-congested flow conditions (7).

2.5 Traffic Assignment

The addition of traffic assignment to traffic models expands the applicability of simulation models to traffic planners. For example, an early version of CORFLO integrated a static assignment model which assumed a time invariant O-D flow matrix (5). The static assignment technique is not suitable for dynamic traffic effects, which are critical in network simulation during both recurring and nonrecurring congestion.

In order to deal with simultaneous changes in both routing and traffic signal timings, a series of hybrid traffic/planning models were developed (3). These hybrid methods combined a detailed operational evaluation of traffic signal timings with a modified planning-oriented traffic assignment technique. Traffic demands are expressed as time-slice O-Ds for the entire network, which are assigned consecutively to represent the transient demand effects. This assignment technique was used in some freeway corridor simulation models such as CORQ (15, 16).

The limitation of time-slice O-D assignment is that the assignment model is not capable of employing the refined travel time and queue size from the evaluation phase to update the initial traffic assumptions. A queuing-based assignment technique was developed which does not need time-slice O-Ds and is capable of emulating the dynamic equilibrium conditions in view of continuously variable traffic demands and
controls (17). It also has a routing procedure that reflects the fact that many drivers may have some prior knowledge (based on experience or information from Intelligent Transportation Systems) (18).

III. Traffic Simulation Models

The earliest computer simulation work in highway transportation was the intersection simulation undertaken by the Transport Road Research Laboratory in the United Kingdom in 1951, and the first simulation work in the United States was on the intersection and freeway models developed at UCLA in 1953 (2). The development of simulation models has grown rapidly since then. Gibson (2), Van Aerde et al. (16), May (19), and Sabra and Stockfisch (20) review simulation models for intersections, arterial networks, freeways, and freeway corridors up to mid-1995. Just one year later, the menu has been increased by the introduction of TSIS/CORSIM, WATSIM and INTEGRATION 2.0. The presentation of models below is structured on the basis of type of facility(ies) they are capable of simulation.

3.1 Urban Street Networks

Urban street traffic systems comprise intersections, grid-based networks, and a variety of complex traffic activities and control strategies such as parking adjacent to traffic streams, bus blockage, one-way streets, reversible lane operations, etc. Both microscopic and macroscopic models are currently available for simulating these environments.

3.1.1 Microscopic: TRAF-NETSIM
NETSIM: NETSIM (NETwork SIMulation) is the only microscopic model available for urban street networks (2). NETSIM, formerly called UTCS-1, was initially released in 1971 and integrated within the TRAF (an integrated traffic simulation system) in the early 1980s (TRAF-NETSIM). Most operational conditions experienced in an urban street network environment can be simulated. This model provides a high level of detail and accuracy and it probably is the most widely-used traffic simulation model (21).

The TRAF-NETSIM model uses an interval-scanning simulation approach to move vehicles each second according to car-following logic and in response to traffic control and other conditions (22). TRAF-NETSIM uses Monte Carlo procedures to represent real-world behavior. Therefore, individual vehicle/driver combinations, vehicle turning movements on new links, and many other behavioral and operational decisions are all represented as random processes. The latest version of TRAF-NETSIM uses an identical seed number technique to represent identical traffic streams and reduce output variability (23).

3.1.2 Macroscopic: TRANSYT and NETFLO

TRANSYT: TRANSYT (TRAffic Network StudY Tool) is a deterministic, single-time period simulation and optimization model developed at the Transport and Road Research Laboratory (TRRL, now TRL) in the UK. There have been nine British versions of TRANSYT, and the model has been applied worldwide. In the early 1980s, TRANSYT-7F (F stands for Florida) was developed at the University of Florida. The data and outputs of TRANSYT-7 were modified to create a North American version, which is now the most commonly used version in the US (15).

TRANSYT-7F models traffic behavior in signal-controlled urban areas. During an optimization, it searches for a set of fixed-time signal timings that minimize vehicle delay. This is achieved by coordinating adjacent signals so that platoons of traffic can pass without stopping. TRANSYT-7F consists of a traffic model and an optimization process (24). The former calculates a performance-index (PI) for the network
using a particular set of signal timings, and the latter adjusts these timings and checks whether the adjustments improve the PI. In TRANSYT, there is no representation of individual vehicles, and all calculations are made on the basis of the average flow rates, turning movements and queues.

**NETFLO:** NETFLO (NETwork traffic FLOw simulation model) can simulate the traffic flows at two levels. NETFLO I (LEVEL I) is a stochastic, event-based model. It moves each vehicle intermittently according to events and moves each vehicle as far downstream as possible in a single move (5). Although NETFLO I treats each vehicle on the network as an identifiable entity, car-following and lane-changing behaviors are not modeled explicitly. Therefore, NETFLO I models traffic at a lower level of detail than NETSIM. NETFLO II (LEVEL II) is a deterministic, interval-based model. It is essentially a modified TRANSYT, but NETFLO II has no optimization capability. In NETFLO II, the traffic stream is represented in the form of movement-specific statistical histograms. Currently NETFLO and FREFLO, a macro freeway model, have been combined as an integrated simulation system CORFLO (25).

### 3.1.3 Mesoscopic: CONTRAM and SATURN

CONTRAM and SATURN were developed primarily for traffic assignment purposes. They can be used for simulating vehicle routing in a complex traffic system, and their modeling mechanisms have been modified and incorporated into integrated network simulation models such as INTEGRATION (3, 16).

**CONTRAM:** CONTRAM (CONtinuous TRaffic Assignment Model) is a traffic assignment and evaluation package that models traffic flows in urban networks. This model treats a group of vehicles, (packet), as a single entity, thus, vehicles which belong to a packet travel along the same minimum cost route and arrive at the same time. CONTRAM determines time-varying link flows and route costs, in terms of given time-varying route inflows, in a dynamic setting, and so is entirely different from TRANSYT and
NETSIM (26). In CONTRAM, traffic demands are expressed as O-D rates for each given time interval. These O-D rates are converted into an equivalent number of packets, which are assigned to the network at a uniform rate for each time interval. A traffic assignment equilibrium is achieved through iterations in which each packet is removed from the network and reassigned to a new minimum path.

**SATURN:** SATURN (Simulation and Assignment of Traffic in Urban Road Networks) is a traffic assignment model based on the incorporation of two phases: a detailed simulation phase of intersection delays coupled with an assignment phase which determines the routes taken by O-D trips (27). The complete model is based on an iterative loop between the assignment and simulation phases. Thus, the simulation determines flow-delay curves based on a given set of turning movements and feeds them to the assignment. The assignment in turn uses these curves to determine route choice and hence updates turning movements. These iterations continue until the turning movements reach reasonably stable values.

### 3.2 Freeways and Freeway Corridors

A corridor is a roadway system consisting of a few primary longitudinal roadways (freeways or major arterials) carrying a major traffic movement with interconnecting roads which offer the drivers alternative paths to their destinations (28). Freeway models usually simulate traffic flow on the integrated system of a mainline freeway and its ramps, whereas freeway corridor models may simulate the traffic on a mainline freeway and its ramps as well as limited parallel arterials.

#### 3.2.1 Microscopic: INTRAS, FRESIM and Others

**INTRAS:** INTRAS (INtegrated TRAffic Simulation) is a stochastic simulation model. It was developed by KLD Associates in the late 1970s and was enhanced continuously through the 1980s (19). It
uses a vehicle-specific, time-stepping, highly detailed lane-changing and car-following logic to realistically represent traffic flow and traffic control in a freeway corridor and surrounding surface street environment.

The INTRAS model requires fairly detailed geometric and traffic information, including link length, lane numbers, location, free-flow speeds, vehicle composition, traffic volumes, O-D data, etc. This model has been used to evaluate the freeway reconstruction alternatives (29) and weaving area capacity analysis (30, 31). Research results showed that INTRAS is not fully applicable to freeway weaving areas.

**FRESIM:** The INTRAS model was reprogrammed by JFT and Associates according to structure design techniques and made more user-friendly. The revised model was called FRESIM and has been incorporated into the TRAF family (16, 19). FRESIM can simulate complex freeway geometrics, such as lane add/drop, inclusion of auxiliary lanes, and variation in slopes, superelevation, and radius of curvature. The model can handle freeway operational features such as lane-changing, on-ramp metering, and representation of a variety of traffic behaviors in freeway facilities (5). FRESIM has become the most complete and updated microscopic freeway simulation model. However, no recent published articles on FRESIM applications were found in the literature.

**CARSIM, WEAVSIM, and FREESIM:** CARSIM and WEAVSIM emphasize specific application purposes; both were based on INTRAS. The INTRAS model, as a general purpose analysis model, had certain limitations, i.e., the car-following logic of INTRAS was not capable of realistically simulating the behavior of traffic under stop-and-go conditions on freeways. Therefore, a new car-following model named CARSIM (CAR-following SIMulation), was developed (32) to offer additional realistic features and capabilities for simulation of car-following behavior on freeways. Similarly, because the INTRAS lane-changing logic could not represent the intensive lane-changing maneuvers at the weaving sections of freeways adequately, WEAVSIM was developed specifically for the study of the dynamics of traffic flow at weaving sections (33).
FREESIM (10) is a stochastic model whose logic is based on a rational description of the behavior of the drivers in a freeway lane-closure situation. A set of algorithms were established to simulate driver car-following/lane-changing behavior in response to advance MUTCD warning signs.

3.2.2 Macroscopic: FREQ, FREFLO, KRONOS, and CORQ

**FREQ:**  
FREQ is a deterministic simulation model for a directional freeway corridor, developed at UC-Berkeley. Since 1968 the FREQ model has been under continuous development and a new version, FREQ10, is presently available (34). The FREQ10 system contains an entry control model (FREQ10PE) for analyzing ramp metering and an on-freeway priority model (FREQ10PL) for analyzing HOV facilities. The simulation module consists of two parts: the first for simulating freeway conditions and the second for parallel arterial conditions. The parallel arterial routes are aggregated and modeled as one, after several simplifying assumptions are incorporated into the analysis. Alparn and Gersten (35) applied and evaluated FREQ to bus-HOV lane. FREQ is one of the most traditional types of freeway corridor models. The primary weakness of FREQ is the over-simplification of arterial alternatives and lack of full diverting/rerouting techniques (16).

**FREFLO:**  
FREFLO, developed by Payne (6), simulates traffic flow on freeways using a formulation of aggregate variables based on suitably modified analogies of fluid flow. Initial work with the FREFLO revealed that the model was limited in its ability to realistically simulate congested flow conditions (36). Many efforts were made to address this problem, including the development of another freeway model, FRECON (37), which adopted the heuristic scheme in FREFLO. FREFLO itself was modified to resolve the difficulties in representing congested conditions and was incorporated into TRAF (5, 36). TRAF allows FREFLO to interface with other simulation models that can simulate the neighboring urban surface.
street systems. Within TRAF, an equilibrium traffic assignment model exists that may be used to provide volume and routing information to FREFLO.

**KRONOS:** KRONOS, developed by Michalopoulos (38), is a freeway simulation model which uses a simple continuum model to represent traffic flow. KRONOS has been continuously enhanced since the inception and several versions are described in the literature (7, 39, 40). Unlike other macroscopic simulation programs, KRONOS explicitly models interrupted flow behaviors such as lane changing, merging, diverging, weaving, and spillback, which were not taken into account by other macroscopic freeway programs. The recent version, KRONOS 8, can be applied for evaluating the effectiveness of different freeway design/operational alternatives. Currently, new traffic models to handle HOV/Diamond lanes and traffic responsive ramp metering are being developed (40).

**CORQ:** CORQ (CORridor Queuing), developed by Yagar (41), is a freeway corridor simulation/assignment model. The corridor consists of a directional freeway, its ramps, major cross streets, and any competing alternative surface streets. Traffic flows are approximated as fluids, and travel times are calculated as simple step functions for both free-flowing and congested conditions. A key element of CORQ is the dynamic assignment technique for allocating time-slice O-D demands to a time-dependent traffic network. However, the travel time relationship is expressed as a static step function of link flows and intersection delays: this is a drawback of CORQ (16). The time relationship is insensitive to changes in signal timings on parallel arterials. Because CORQ was perhaps the most detailed corridor-level model throughout the 1980s, parts of its modeling approach were modified and incorporated into the design of the *area-level* integrated network simulation models INTEGRATION.

### 3.3 Integrated Networks
Earlier methods simply combined existing subnetwork models through a traffic assignment subroutine to simulate an integrated system which encompasses several subsystems. One such attempt was made by Klijnhout (42) and existing TRANSYT and FREQ models were used to evaluate integrated control strategies for a combined network of freeways and traffic signals. The need to synthesize the state of the art and to model virtually all traffic situations within a single software system led to the idea of integrated traffic simulation system in the late 1970s, and some simulation models in composite, synthetic, or fully integrated fashions have been developed since the 1980s (3, 43).

3.3.1 Microscopic: SCOT, CORSIM, INTEGRATION, and WATSIM

**SCOT:** SCOT (Simulation of COrridor Traffic) may be the earliest model for integrated networks (44). The model is the synthesis of two models, UTCS-1 and DAFT. UTCS-1 is the precursor of NETSIM and DAFT is a mesoscopic simulation model for freeways, ramps, and arterials, in which vehicles are grouped into platoons. Therefore, SCOT may also be classified as a mesoscopic model (6). The key design element of the SCOT model is the interface features between the mesoscopic and microscopic characteristics of the two submodels (45). Because the integrated network nature and the dynamic assignment capability, the SCOT model was employed to assess the benefits of an integrated motorist information system in conjunction with dynamic traffic control in a freeway corridor including freeways, frontage roads, and signalized arterials (46). Although SCOT appears suitable for simulating area-level traffic networks, the model is no longer supported (16).

**CORSIM:** CORSIM is virtually a combination of two microscopic models, NETSIM and FRESIM. The model is capable of simultaneously simulating traffic operations on surface streets as well as freeways in an integrated fashion. However, within the earlier integrated traffic simulation system (TRAF), the total freeway/urban street systems simulated by the combination of NETSIM and FRESIM could only be called
composite networks rather than integrated networks, in terms of the TRAF system characteristics of distinct separation of the assignment and simulation phases of the analysis, independent control strategies in each subnetwork, data transfers between models/modules, and the lack of rerouting capability (3). A traffic assignment model can be run to enter O-D trip information, and two assignment options, system optimal or user equilibrium, can be selected. The assignment results then interface the components of the CORSIM model.

A Windows version of TSIS (Traffic Software Integrated System) (25) is being developed to provide an integrated, user-friendly, graphical user interface and environment for executing the CORSIM. TSIS/CORSIM was in beta-testing and refinement (Spring 1996), thus, there is no literature on the applications, capabilities, and problems.

INTEGRATION: INTEGRATION was developed in the late 1980s by Van Aerde and Associates (3, 17). INTEGRATION is a routing-oriented model of integrated freeway and surface street networks. In the model, individual vehicle movements through the network are traced to monitor and control the unique behavior of vehicles that belong to a certain subpopulation. The model differs from most other microscopic models in that only the aggregate speed-volume interactions of traffic and not the details of a vehicle's lane-changing and car-following behavior are explicitly considered (8). The model is routing-based, that is, a vehicle's trip origin, destination, and departure times are specified external to the model. The actual trip path and the arrival times at each link along the path to be derived within the simulation are based on the modeled interactions with other vehicles. Another distinctive feature of INTEGRATION is that it may be the first model which considers the ITS route guidance information in the vehicle routing/rerouting mechanism (46, 47). INTEGRATION has been applied to several projects (8, 48, 49). While INTEGRATION provides a graphical capability to view vehicles as they move through the network, it provides no Graphical User Interface for viewing and editing network data. This is a drawback (49),
because the ability to view/edit data is extremely useful for model setup, calibration, and scenario testing. Version 2 was released in late 1995. There is no literature on the capabilities of this version.

**WATSIM:** WATSIM (Wide Area Traffic SIMulation), developed by KLD Associates, was presented at the 1996 annual meeting of the Transportation Research Board, but has not been offered for sale. WATSIM is a stochastic, integrated network simulation model. It extends the functionality of TRAF-NETSIM to incorporate both freeway and ramp operations with surface street traffic. Basically, the internal processing of TRAF-NETSIM has been modified to create WATSIM. The WATSIM operational features include those in TRAF-NETSIM plus HOV configurations, light rail vehicles, toll plazas, path tracing, ramp metering, and real time simulation and animation (50). The WATSIM simulation model also includes an interface with a traffic assignment model.

3.3.2 Macroscopic: CORFLO

**CORFLO:** CORFLO is a combination of NETFLO I, NETFLO II, and FREFLO models, integrated within the TRAF or TSIS operation environment. The FREFLO submodel is used to simulate the traffic on the freeway subnetwork and the NETFLO components are used for the surface street network. The traffic assignment component of the earlier CORFLO model is a static model (5). Two important enhancements to CORFLO are the addition of new logic for user-optimal traffic assignment based on simulated link travel time and the introduction of capacity for en-route diversion modeling (51). Therefore, within the TRAF or TSIS system, the equilibrium traffic assignment model may be used to provide volume and routing information to FREFLO and NETFLO. The effectiveness of CORFLO to a navigation system application for alleviating non-recurring congestion was evaluated by Halati and Boyce (51).

3.4 Other Models
Simulation models such as TOWPAS and TRARR were developed for rural highways. Many traffic models have also been developed which employ signal-timing optimization processes to determine the cycle length, green time, phase sequence, and coordination offsets for signalized intersections and coordinated arterials. These optimization models were not reviewed in this paper.

IV. Discussion on Model Applications

The objective of simulation model development is to apply the model in real traffic problem solving. In this section, several important aspects related to the successful model application are examined. They include model selection, validation, input needs, and statistical analysis of output.

Simulation methods have long been recognized as a powerful tool for transportation specialists. In fact, transportation specialists have many analytical tools, and the simulation model is one among several techniques. Although the literature often emphasizes the positive aspect of the simulation approach, computer simulation modeling is not a panacea. In some cases it can be a controversial subject because of unsuccessful applications. May has outlined the strengths and weaknesses of the simulation modeling (2, p. 378). In view of the weaknesses, model users should be cautious in the application of simulation models. The successful model application largely depends on understanding the characteristics of a particular model, selecting the correct model for the problem at hand, and employing proper analysis methods in the model output interpretation.

Many computer simulation models are available today for analyzing a wide variety of traffic systems. Because most of these models were developed for different purposes, they usually have characteristics that may or may not fit a specific application. Thus, selecting the model is an important step toward traffic problem resolution.
Many examples of model evaluation and selection exist. For instance, to evaluate the effect of reconstruction alternatives on traffic operations, Cohen and Clark (29) had three freeway simulation models at their disposal, FREQ, FREFLO, and INTRAS. A preliminary analysis was done to determine the applicability of the three models, based on the application purpose. It was determined that the two macroscopic models (FREQ and FREFLO) were inadequate to simulate detailed cross-weaving phenomena in the test area, so the INTRAS model was selected. Another example is the use of simulation models to develop incident response plans and test a proposed control system design. Seven candidate simulation models were appraised by Marcus and Krechmer (49): DYNASMART, THOREAU, MID DYNAMIC TRAFFIC MODEL, CONTRAM, SATURN, INTEGRATION, and TRAF. Based on several evaluation criteria, the list was narrowed down to INTEGRATION and TRAF. INTEGRATION was determined to be the best suited to research of incident response. TRAF was not chosen primarily due to its inability to dynamically assign traffic.

Model evaluation and selection depend heavily on the establishment of a set of criteria. These criteria are usually based on the purposes of model application considered. Van Aerde et al. (16) proposed a general list of criteria for guiding model evaluation: 1) Quality of model in terms of traffic engineering theory; 2) Quality of program code; 3) User friendliness and documentation; 4) Field validation and verification; and 5) Availability, implementation, cost, and support. For each of these criteria, detailed subcriteria and corresponding weights can be listed depending on the objectives. A list of 16 criteria with their associated priority levels were also identified by Marcus and Krechmer (49) as a basis for selecting a candidate set of simulation models. After defining the list of criteria, a literature review and limited testing could be conducted to assist in the model selection process.

A large number of input data, including road geometrics, traffic demands and traffic flows, and control strategies, are needed for either microscopic and macroscopic simulation models. Usually microscopic models require more detailed geometric and traffic information than macroscopic models. Many data collection processes are described in (7), (30), and elsewhere. Recent advances in ITS
technologies have resulted in new technologies for wide area vehicle detection and traffic parameter derivations (14).

Model validation for a macroscopic simulation model is usually undertaken at a macroscopic scale only. For a microscopic model, however, validation should be conducted at both a microscopic level and a macroscopic level (11, 31, 52). At the microscopic level, the attributes of individual vehicles such as location, time, headway, and speed computed from the simulation model are compared with those obtained from the field data. At the macroscopic level, the aggregate parameters such as the average speed, density, and volume of vehicles are compared between simulated results and fields data to ensure the overall behavior is also modeled correctly. Statistical techniques such as regression analysis, analysis of variance, or time series analysis may be used for such comparisons.

Validation data at a macroscopic level can be had with little effort. They usually consist of minute by minute records of flows, average speeds and headways all of which can be had from loop data or video recordings of traffic flows. On the other hand, data for microscopic validation are nearly impossible to have and microscopic properties which may be easy to measure may not relate well to a model’s behavioral parameters. Therefore, the microscopic level validation is probably the most difficult validation task. This often produces a microscopic validation at a mesoscopic level that is restricted to a small number of easily observable properties (11).

The widespread use of simulation models raises serious questions about the analysis of model variability and reliability. These problems are more critical in the case of microscopic, stochastic models. Most microscopic, stochastic models employ Monte Carlo procedures to generate random numbers for representing the stochastic behavior of individual driver-vehicle combinations. As a result, the simulation output of stochastic simulation models may contain a great deal of variability from one run to the next. The variability in model output can lead to concern about the model’s reliability, and the user may have difficulties in analyzing the simulation results under different control strategies (4, 43).
One method frequently used for reducing the variability of model outputs is the method of independent replications (4). Theoretically, this method is very simple because it mainly uses an adequate number of independent runs to get the means and variances for model parameters. For example, Rathi and Nemeth (10) used the FREESIM model and conducted five replications to obtain the average volume values for each speed zone. Skabardonis et al. (30) used the INTRAS model and repeated simulation runs several times with different input random seeds to reduce the variation in the predicted speeds of vehicles. Simulation results from stochastic models like INTRAS may also vary with the length of simulation time, especially for congested conditions. Hence simulation time should be long enough to get stable simulation results. The replication method for reducing model variability, in practice, could be very inefficient when many runs with long stabilization period are needed to generate adequate observations for analyses.

Another method is the *batch means* method which works on a single simulation run (4). The total observations generated from a single long simulation are divided into subsequences or batches, and the observations in a given batch are essentially similar to those generated by a short replication. The batch means method was employed in the WEAVSIM simulation experiment (33). For each 45 minutes simulation run, three results could be obtained with batch sizes of fifteen minutes. This concept of batch means-based variance reduction is appealing, but batch size determination is not straightforward (43).

Two other variance techniques, common random numbers and antithetical varieties, have been used for the TRAF-NETSIM model for the first time (43, 53). Both techniques reduce the variability of stochastic models by controlling the random number seeds used to drive the simulation model. The antithetical varieties technique reduces the variance of estimated parameter values by creating negative correlation between observations in paired replications of a single system. The common random numbers technique just matches the random number seeds in simulation experiments and therefore represents a very intuitive yet simple-to-implement variance reduction procedure. These variance reduction techniques can easily be applied by using the "identical traffic stream" feature of the TRAF-NETSIM, one of the recent
enhancements of the model which is intended to assure that the variance in the performance measures is primarily due to the control variables and not to random variation.

The statistical aspects of simulation experiments are also important. Consider the example of an INTRAS model application to weaving area capacity analysis undertaken by Fazio and Rouphail (31). In order to ascertain the basic relationships between conflict rates and speeds on the one hand and weaving section parameters on the other, parameter analyses on the latter variables were conducted. A total of 360 runs, one hundred twenty experiments with three replications of each, were performed. Without proper statistical inference techniques, reliable experiment conclusions could not be obtained.

In conclusion, different simulation models have different features and application limitations, not to mention that the simulation modeling itself has a limited ability to represent the real world traffic environment. To be successful in the model application, a variety of knowledge is required including traffic flow theory, computer operations, statistical analysis, and decision making. The selection of the proper simulation model for a given traffic problem is the most important step, followed by the quality of input data, and the attention output data analysis and interpretation. It is expected that models which can treat the integrated arterial/freeway networks will receive much attention, particularly with the development of ITS and congestion management systems.

References


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