The University of Michigan

IVHS

Intelligent Vehicle-Highway Systems

Review of Traffic Simulations for Intelligent Vehicle-Highway System Evaluation

Steven E. Underwood

University of Michigan
College of Engineering/Transportation Research Institute
Ann Arbor, Michigan

January 31, 1990

IVHS Technical Report-90-10

UNIVERSITY OF MICHIGAN
TRANSPORTATION RESEARCH INSTITUTE • (313) 936-1066
2901 Baxter Road, Ann Arbor, MI 48109-2150, and

COLLEGE OF ENGINEERING • (313) 764-4333
4112 EECS, Ann Arbor, MI 48109-2122

Review of Traffic Simulations for Intelligent Vehicle-Highway System Evaluation

Steven E. Underwood

University of Michigan
College of Engineering/Transportation Research Institute
Ann Arbor, Michigan

January 31, 1990

IVHS Technical Report-90-10

Introduction

This report compares and evaluates eight traffic simulation models for their potential application for designing intelligent vehicle-highway systems (IVHS) implementations. The evaluation focuses on those models that are relatively well known and/or that have particular characteristics that may be useful for IVHS applications. The models are:

Name	**General Use**
TRANSYT	Optimization of signalized network
NETSIM	Microscopic (vehicle level) simulation of traffic operations used to evaluate sophisticated signal control and transportation systems management improvements
FREQ8PE	Freeway corridor simulation with ramp metering optimization
CORFLO (FREFLO)	Freeway corridor simulation that is part of the FREFLO package of models
NETFLO	Simulation of urban arterials used to evaluate traffic control and geometric improvements
CONTRAM	Simulation of signalized urban arterials used to design traffic management schemes
SATURN	Simulation of signalized urban arterials used to design traffic management schemes
INTEGRATION	Simulation of integrated freeway corridor and signalized arterial network used to evaluate traffic control and in-vehicle guidance strategies

The review is based on descriptions of the models from technical reports and the published literature. The comparison did not involve testing of the models or review of the program code.

Of all the models reviewed the INTEGRATION simulation model appears to be the most suitable for evaluating the impacts of advanced driver information system (ADIS) and advanced traffic management systems (ATMS). The model was designed specifically for these purposes and incorporates both traffic flow and traffic assignment capabilities. It is also one of the few models that integrates both freeway and arterial simulation in a single package. The primary limitations of the model are (1) it does not account for platoon behavior in the signalized network, (2) it does not route our assign the vehicles on the basis of predicted traffic flows, (3) it is relatively computationally intensive, and (4) it is still in the early application stage of development.

Table 1. Overview of Traffic Simulation Packages

Characteristics	TRANSYT-7F	TRAF-NETSIM	FREQ8PE	CORFLO (FREFLO)	CORFLO (NETFLO)	CONTRAM	SATURN	INTEGRATION
Network scope	Urban arterial	Urban arterial	Directional freeway	Freeway	Urban arterial	Urban arterial	Urban arterial	Freeway corridor and arterial networks
Level of detail	macroscopic	microscopic	macroscopic	macroscopic	macroscopic	quasi-microscopic (mesoscopic) vehicles in packets	quasi-microscopic (mesoscopic) Cyclic flow profile	microscopic
Package structure	atomic	atomic	molecular	atomic	molecular	atomic	atomic	atomic
Model type(s)	optimization of signalized network	simulation of traffic operations	Freeway corridor simulation, ramp metering optimization.	simulation	Three arterial simulations with different levels of detail: 1. Individual vehicles 2. Platoons 3. Major arterial aggregate time lags	optimiation of signalized network, simulation of assigned traffic in the network, no signal coordination	signalized network operation, optimizes traffic signals, simulation of assigned traffic in network, both isolated and coordinated control	Simulation of dynamic integrated freeway/traffic signal network
Traffic behavior	deterministic	stochastic, time-varying	deterministic	deterministic, traffic varying over time	1. stochastic, event-based 2. deterministic 3. deterministic	deterministic	deterministic	stochastic
Traffic flow algorithms	Platoon dispersion (i.e., minimize stops and delays for system); Represents the traffic stream in terms of movement-specific statistical histograms.	Deterministic car following logic.	Merging, weaving and speed-volume in accordance with HCM; compressible fluid theory for queueing	This aggregate variable model of freeway traffic uses a fluid-flow analogy to traffic operations. An equilibrium speed-density relationship is incorporated into a dynamic speed equasion. The model consists of a set of conservation equasions for vehicles. Flow is represented by flow past boundaries, density, and space-mean-speed in section.	Different traffic flow algorithms are used in each of the three models: 1. Microscopic (NETSIM-like) event-based movement without car following. 2. Platoons use movement-specific histograms (TRANSYT) 3. Webster's vehicle delay. All link-segment-specific values of volume are time-dependent.	Three types of links: signal controlled, give-way, and uncontroled. Specify lengths, free-running times, saturation fow, and turning movements. Demands as O-D flow rates. Capacity restrained equlibrium.	Traffic flow is represented as a cyclic flow profile as in TRANSYT. Junction delays are estimated on the basis of 4 profiles which represent the upstream inflow pattern, the platoon dispersion downstream arrival pattern, the pattern during which vehicles are allowed movement, and the pattern leaving the intersection. The model accounts for delays caused by opposing flows, platoons, signal phases, and lane capacities.	Link flow characteristics are represented by inflow rate, outflow rate, and vehicle concentration. Travel times are based on the level of saturation. When undersaturated uniform delay is a function of traffic volume. When oversaturated queueing effects are factored in. Dynamic signal timing and ramp metering can be included. Platoon dispersion is not included in model.
Traffic assignment algorithms	no	no	Diversion of ramp queue	Interfaces with TRAFIC equilibrium assignment model	Interfaces with TRAFIC equilibrium assignment model (Nguyen, 1974).	Equilibrium assignment; capacity-restrained equilibrium model. Assignment of all vehicles without explicitly considering "current" time slice.	Equilibrium assignment; succession of all-or-nothing assignments (Dow & Van Vliet, 1979) Intersection simulation finds delays for: zero flow, current flow, capacity. Iteration between assignment and simulation.	Equilibrium assignment; all-or-nothing, Dial-like, assignment. See Dial (1971). Individual vehicles are assigned to updated shortest path at intersections.
Incidents and diversion	no	no	yes	yes	Three different models: 1. As blockage, diversion policy 2. As blockage 3. No diversion	no	no	Effective reduction in the number of lanes for specified duration. This can be introduced during the simulation.
Traffic signals and signal optimization	Time scan optimization "hill climbing." Hill climbing is accomplished by varying offsets and splits in steps and calculating the resulting effects.	no	no	no	no	Cycle length, phasing, split are represented. Signal coordination is allowed.Lost time, stage number, cycle times, stage duration are specified. Traffic signal timings are optimized.	Cycle length, phasing, split are represented. Signal coordination is allowed. Traffic signal timings are optimized.	Signals control the departure priveleges on any link. Signal timing routine is internal to the model or dynamic timing can be introduced through SCOOT. Traffic signal timings are optimized.
Queueing	no	yes	yes	no	Three different models: 1. Queue discharge distrib. 2. Queue histogram. 3. No queue effects	Dynamic growth and decay of queues within time slice. Also queue spillback.	Dynamic growth and decay of queues within time slice. Two types of queueing: (1) transient queues, and (2) permanent queues. No queue spillback.	Queue works backword from the first vehicle adding prevailing saturation flow headway. Also queue spillback.
Ramp metering	no	no	Linear programming for ramp metering, time scan	yes	no	Ramp metering rate is not simulated.	Ramp metering rate is not simulated.	Traffic signal with appropriate metering rate

Table 2. History and Support for Traffic Simulation Packages

Characteristics	TRANSYT-7F	TRAF-NETSIM	FREQ8PE	CORFLO (FREFLO)	CORFLO (NETFLO)	CONTRAM	SATURN	INTEGRATION
Model origins	(original)	UTCS-1, TRANS, DYNET	(original)	MACK	1. SDC, TRANS, NETSIM, SCOT-Q 2. TRANSYT, SIGOP-II 3. WEBSTER	(original)	(original)	(original)
Original year	1967	1969 (DYNET)	1970	1971	1980	1978	1978	1986
Developers	TRRL, Robertson	KLD, Lieberman, Wicks, Bruggeman, Worral	May, Blankenhorn, et al.	KLD, Nguyen, James, Lieberman, Andrews; also Payne & Associates (FREFLO)	KLD, Nguyen, James, Lieberman, Andrews	Leonard, Tough, Baguley	Bolland, Willumsen, Hall, Van Vliet	Van Aerde, Yagar
Current developer	TRRL & FHWA	FHWA	ITS	FHWA (KLD)	FHWA (KLD)	TRRL	Institute for Transport Studies at Leeds	MTO, Queens University
Selected publications	Skabardonis, et al (1988), Al-Deek, et al. (1988)	Lieberman (1969),	Blankenhorn & May (1972), Al-Deek, et al. (1988)	Payne (1972), Payne, et al. (1973). Lieberman, et al. (1980), JFT Assoc. (1989)	Lieberman, et al. (1980),	Leonard, Tough, & Baguley (1978); Tough (1978)	Bolland, Van Vliet & Willumsen (1978); Hall, Van Vliet, & Willumsen (1980)	Van Aerde (1985) Van Arede & Yagar (1988), Rakha, et al. (1989), Van Aerde, Voss, et al. (89), Van Aerde & Rakha (1989)
Distribution	McTrans, PC Trans	FHWA (TRAF)	ITS	FHWA (TRAF)	FHWA (TRAF)	TRRL	Institute for Transport Studies at Leeds	MTO
User Guide	Wallace, et al (1988)	Yedlin, et al. (1988)	Imada & May (1985)	Yedlin, et al (1988)	Yedlin, et al (1988)	Leonard & Gower (1982)	Van Vliet & Hall (1987)	Van Aerde & Voss (1988)
Support	McTrans	FHWA	ITS	FHWA for Beta test	FHWA for Beta test	TRRL under license	not known	MTO for Beta tests
Microcomputer	yes	yes	yes	Under development	Under development	yes	yes	yes

Table 3. Description of Simulation Functions

Characteristics	TRANSYT-7F	TRAF-NETSIM	FREQ8PE	CORFLO (FREFLO)	CORFLO (NETFLO)	CONTRAM	SATURN	INTEGRATION
Primary purpose	Develop signal timing plans for arterials and grid networks. The objective is to minimize stops and delays for the system as a whole rather than maximizing the arterial bandwidth.	Evaluation of alternative urban intersection, arterial, or arterial network control strategies, with particular emphasis on sophisticated signal control and TSM improvements.	Evaluate priority lanes (PL) or priority entry (PE) strategies on directional freeways.	Evaluate the effect of adding freeway lanes, using fixed-time ramp metering strategies, and the effects of incidents. Traffic assignment makes it useful for planning. It is used with NETFLO for corridor analysis.	Evaluate traffic control strategies and geometric improvements on surface streets. It is useful as a planning tool with its traffic assignment component. It is used with FREFLO for corridor analysis.	To evaluate network of signalized junctions. It was developed to design traffic management schemes in urban areas.	To evaluate network of signalized junctions. It was developed to design traffic management schemes in urban areas.	Evaluate traffic control strategies and in-vehicle guidance strategies on integrated freeway/traffic signal networks. It may also be useful as the basis for a real-time route guidance system.
Use and application	Optimize signal timing, sign controled intersections, bottlenecks, and impacts of major TSM strategies.	TSM (signal installation and timing, changes in intersection control, real-time surveillance and control syrtems, left-turn restrictions,reversible lanes), impacts, Also bus lanes, geometric design (road widening, remove parking), etc.	Estimate operating conditions (e.g., speeds), fuel consumption, vehicle emissions on corridor during period; Estimate impacts of various traffic stratetgies (lane closeures, ramp closures, ramp metering, entry, etc.); Optimize ramp metering, evaluate diversion strategies	Estimate operating conditions (e.g., speeds), vehicle emissions on corridor during period; Estimate impacts of various traffic stratetgies (lane closeures, ramp closures, ramp metering, entry,HOV, surveillance and control, etc.), traffic reassignment (diversion)	Three models: 1. Install signals at inersections, pretimed signals, left-turn restrictions, bus service, reversible lanes. 2. Pretimed signals, left-turn restrictions, bus service, reversible lanes.	Signalized network operations: Predicts the flows, delays and queues throughout a network of road junctions. It is usually used to predict total trip times and delays for traffic as a function of green times at junctions. It combines simulation with assignment.	Signalized network operations: Standard measures of network performance. It is also possible to analyze)-D trips making a perticular turning movement or to analyze trip times for each O-D pair.	Estimate operating conditions (e.g., trip times, delay, etc.); Estimate the impacts of various traffic control and signalization strategies (e.g., signla timing, signal optimization, ramp metering); Estimate the impact of incidents; Estimate the impact of route guidance.
How does it operate?	A platoon dispersion model is used in conjunction with a "hill climbing" optimization model.	Interval-scanning simulation moves each vehicle each second according to car-following logic and in response to traffic controls. Position on the network, relation to other vehicles, and kinematic properties are determined for each vehicle.	(1) The simulation submodel is a macroscopic deterministic model that predicts traffic performance as a function of freeway design and demand O-D patterns. (2) The optimization submodel has a linear programming formulation designed to determine the entry control strategies (metering rates and priority cut-off level) that maximizes the passengers' ojective function.	Represents traffic in terms of aggregate measures associated with sections of freeways, each several hundred feet to a mile. The aggregate measures used are flow rate, density, and space-mean-speed within a section. The formulation is based on a fluid-flow analogy. An equilibrium speed-denisty relationship is incorporated into a dynamic speed equasion. Vehicle type is distinguished.	Three separate models for three levels of detail: 1. Vehicle:Event-based simulation of individual vehicles. Vehicles jump ahead at events. No car following. 2. Platoon: Link-specific statistical flow histograms. 3. Arterial: Uses Webster's formula to calculate vehicle delay on arterials.	The movement of traffic is modelled by grouping vehicles together in the form of "packets." Each packet is assigned to its minimum time route through the network, taking into account delays and queues at junctions. The model operates as follows: (1) read network data, (2) order packets, (3) estimate junction delays based on flow, (4) estimate quickest route, (5) add packet to flow estimates on route, (6) return to 3 and iterate subtracting packet from previous route.	Model is based on a two-phase process (1) simulation of delays at intersections, and (2) assignment to determine routes taken. The simulation model determines junction delays using cyclic profiles as in TRANSYT. A power curve is fitted to estimate travel times for any volume. Times are then used in the assignment. Flows are estimated through all-or-nothing assignment.	Routing-based model simulates individual vehicles with self-assignment capabilities. Vehicles enter origin nodes as scheduled departure time. Vehicle then selects link based on minimum path tree. Vehicles are stacked and retained on link for link's travel time then moved to next link on path. Considers inflow, outflow, and concentration, but not platoon dispersion.
Data requirements	Link length, number of alnes, capacities, traffic volumes, fractions of volume from each upstream link, signal control characteristics.	Link length, number of lanes, capacities, (detailed information)	Link lengths, number of lanes, capacities, ramp loctions, design speeds, truck percentages, ramp O-D matrix, existing traffic on alternatives	Link lengths, number of lanes, capacities, ramp locions, freeflow speeds, truck percentages, zonal O-D matrix or turning percentages, entry volumes for each link and time slice.	Link lengths, number of lanes, capacities, free-flow speeds, intersection control, zonal O-D matrix or turning percentage, and entry volumes for each link and time slice.	Network data: link lentgths, free times, saturation flow, link types, and turning movements. Time varying flow demands: Zonal O-D matrix. Signal control: lost time, cycle times, stage duration.	Network data including node coordinates, link lengths, number of lanes, traffic signals, signal phase, signal timing, and link descriptor. Zonal O-D flow rates are provided as a trip matrix.	Node coordinates, link lengths, number of lanes, saturation flow per lane, saturation flow reduction coefficient, traffic signals, signal phase number, link descriptor, zonal O-D flow rates, signal timing, incident location, routeing or traffic.
Output	(1) Traffic performance summary tables: degree of saturation, travel times, delays, stops, queue lengths, fuel consumption. (2) Signal timing tables (phase and interval offset). (3) Calibration data	Traffic performance summary tables: travel, delay, stops, speeds, queues, link occupancies, degree of saturation, cycle failures, fuel consumption, vehicle emissions.	(1) Performance summaries of MOEs on freeway and alternative route by link and by time slice. (2) Optional outputs include contour diagrams of speeds, densities, queue lengths, fuel consumption, emissions, noise.	Performance summaries of MOEs on freeways by link and time slice including: freeway and ramp volume, density, speed, total delay, and travel time.	Performance summaries of MOEs on arterial street system by link and time sliced, including: speeds, flows, densities, queues, delays, fuel consumption, vehicle emissions, etc.	Link flows, queues and turning movements, % saturation and blocking back, journey time and distance, fuel consumption, average point-to-point O-D speeds, vehicle route information, and summary file for input to UFPASC.	Performance summaries of MOEs on signalized arterial street system by link and for total system including: total vehicle hours, travel times for each O-D pair, vehicle stop-starts, etc. Intersection performance measures include: delays for each turn, flow and queue profiles, and warnings of congestion.	Performance summaries of MOEs on integrated freeway/traffic signal network by link and for the total system including: average travel time, total trip time, travel delay, speed, saturation, flow, V/C ratio.

Table 4. Evaluation of Simulations for IVHS Applications

Characteristics	TRANSYT-7F	TRAF-NETSIM	FREQ8PE	CORFLO (FREFLO)	CORFLO (NETFLO)	CONTRAM	SATURN	INTEGRATION
General problems	(1) Does not explicitly optimize the cycle length or phase sequences. (2) Assumes that traffic enters the network at a constant uniform rate. (3) Volumes and proportions of turns remain constant. (4) Traffic dispersion is assumed to be uniform (i.e., fixerd routes). (5) Emphasizes offset (delay from one signal to another)	(1) Computer nontransferability. (2) Limited output. (3) Extensive data requirements. (4) Freeways cannot be modeled. (5) No signal optimization. (6) No routing.	(1) Diversion not same as assignment. (2) Only one direction. (3) Only one alternative route can be modeled. (4) Assumes constant O-D demand.	(1) No queue considerations, (2) Large data requirements.	(1) Freeways and arterials are not integrated so computation requires iteration. (2) Does not consider optimized signal control strategies. (3) TRAFFIC is not a dynamic queueing-based assignment method. (4) Lacks suitable subnetwork interface..	(1) Lacks freeway routines, (2) Simplified representation of traffic signals, (3) Need to store all vehicle packet routes.	(1) Lacks freeway routines, (2) Queue reduction factor is not an adequate approximation of queueing effects, (3) No queue spillback, (4) Cyclic flow prifiles are incompatible with freeway traffic flow dynamics.	(1) No platoon dispersion. (2)
Problems for evaluation of route guidance	(1) Macroscopic simulations treat traffic flow as a fluid. They simulate vehicles in groups (platoons) and report measures of effectiveness (e.g., delay) collectively. This makes it impossible to isolate the "smart" drivers from the "dumb" drivers. (2) The model assumes a constant demand, uncongested traffic, fixed routes and volumes (steady state flows) (3) Freeway facilities cannot be modeled. (4) No traffic assignment capabilities. (5) No treatment of incidents or termporal events.	(1) Freeway facilities cannot be modeled. (2) Preset vehicle trajectories through the network are not possible. (3) No traffic assignment. (4) No treatment of incidents or temporal events.	(1) Macroscopic simulations treat traffic flow as a fluid. They simulate vehicles in groups (platoons) and report measures of effectiveness (e.g., delay) collectively. This makes it impossible to isolate the "smart" drivers from the "dumb" drivers. (2) No traffic assignment.	(1) Macroscopic simulations treat traffic flow as a fluid. They simulate vehicles in groups (platoons) and report measures of effectiveness (e.g., delay) collectively. This makes it impossible to isolate the "smart" drivers from the "dumb" drivers. (2) Traffic assignment is not anticipatory so simulation cannot be used to optimize route guidance.	(1) Macroscopic simulations treat traffic flow as a fluid. They simulate vehicles in groups (platoons) and report measures of effectiveness (e.g., delay) collectively. This makes it impossible to isolate the "smart" drivers from the "dumb" drivers. However, NETFLO-I does provide the micro analysis needed. (2) TRAFIC is not appropriate for assessing time-dependent strategies because it is based on simple travel time-volume/capacity ratio. (3) Traffic assignment is not anticipatory so simulation cannot be used to optimize route guidance.	(1) Traffic assignment is not anticipatory so simulation cannot be used to optimize route guidance. (2) Mesoscopic analysis is does not allow for routing of individual vehicles.	(1) Traffic assignment is not anticipatory so simulation cannot be used to optimize route guidance, (2) Queueing is not directly accounted for in the assignment. (3) Difficulties in reassignment of queues in subsequent time slices. (4) Uses all-or-nothing assignment. (5) mesoscopic assignment does not allow for routing of individual vehicles.	(1) Traffic assignment is not anticipatory so simulation cannot be used to optimize route guidance.
Advantages	(1) Complements FREQ in freeway corridor analysis	(1) Dynamically controlled real-time traffic control, (2) time-varying demand and traffic actuated signals, traffic detection, surveillance, parking	(1) Easiest to use, (2) Optimization of ramp metering, priority lanes, (3) Linear programming optimization, priority entry.	(1) Time varying demand can be modeled, (2) Limited traffic actuated signal analysis, (3) Customize network to reduce computer time, (4) Includes traffic assignment, (5) When combined with NETFLO it simulates surface and freeway traffic as a composite model, (6) Accepts revised input data at user-selected intervals, (7) Extensive application,	(1) Model detail can be tailored for the application. (2) Provides detailed signal and traffic flow routines. (3) When combined with FREFLO it simulates surface and freeway traffic as a composite model,	(1) Superior dynamic traffic assignment technique that considers multidirectional networks while maintaining all appropriate vehicle actions in space and time. (2) Detailed modelling of traffic signals with coordination and optimization capabilities. (3) Synthetic O-D generation. (4) Widely used.	(1) Provides a very detailed analysis of the traffic signal portion of network - traffic signals are modelled with coordination and optimization capabilities. (2) Has the ability to perform assignment in a network consisting of traffic signals. (3) Considers the platoon structure of vehicles arrivals at signalized intersection. (4) Synthetic O-D generation. (5) Extensively used.	(1) Integrates freeway and urban arterial network in a single model. (2) Provides option of integrating signal optimization and other signal timing schemes. (3) Assigns traffic dynamically with consideration given to queues. (4) Provides option of using externally generated signal optimization schemes. (5) Microscopic model enables separation of vehicle types (e.g., those receiving route guidance and those that do not). (6) Unique dyamic traffic assignment does not require iteration. (7) Based on time-varying travel demand. (8) Synthetic O-D generation.

References

Al-Deek, H., Martello, M., May, A., & Sanders, W. (1988). *Potential benefits of in-vehicle information systems in a real-life freeway corridor under recurring and incident-induced congestion.* Institute of Transportation Studies, University of California, Berkeley, CA.

Blankenhorn, R.C., & May, A.D. (1972). *FREQ2: A revision of the FREQ freeway model.* Institute of Transportation and Traffic Engineering, University of California, Berkeley, CA.

Bolland, J.D., Van Vliet, D., & Willumsen, L. (1978). *The reassignment of traffic under traffic management schemes.* Transport Road Research Laboratory SR 568.

Brugeman, J.J., Lieberman, E.B., & Worrall, R.D. (1971). *Network flow simulation for urban traffic control system.* Peat, Marwick, and Co.

Cohen, S.L., & Liu, C.C. (1986). *The bandwidth constrained TRANSYT signal optimization program.* Transportation Research Record, 1057.

Dial, R.B. (1971). A probabilistic multipath assignment model which obviates path enumeration. Transportation Research, 5, 83-111.

Dow, P., & Van Vliet, D. (1979). Capacity restrained road assignment II: Equilibrium methods. Traffic Engineering and Control, 20(6), 299-303.

Gardes, Y., & May, A.D. (1990). *Traffic modeling to evaluate potential benefits of advanced traffic management and in-vehicle information systems in a freeway/arterial corridor.* Report No. UCB-ITS-PRR-90-3, Institute of Transportation Studies, University of California at Berkeley, Berkeley, CA.

Hall, M.D., Van Vliet, D., & Willumsen, L.G. (1980). *SATURN: A simulation-assignment model for the evaluation of traffic management schemes.* Traffic Engineering and Control, 21(4), 168-176,

Imada, T., & May, A.D. (1985). *FREQ8PE: A freeway corridor simulation and ramp metering optimization model.* Institute of Transportation Studies, University of California, Berkeley.

Lieberman, E.B. (1969). *DYNET: Dynamic network analysis of urban traffic flow.* TR-718, General Applied Science Laboratories, Westbur, NY.

Lieberman, E.B., & Rosenfield, W. (1977). *Network flow simulation for urban traffic control system - Phase II.* Extension of the NETSIM simulation model (formerly UTCS-1 to incorporate vehicle fuel consumption and emissions, Vols. 1-5, KLD Associates, Inc.

Lieberman, E.B., & Worrall, R.D. (1974). *Network flow simulation for urban traffic control system - Phase II.* Vols. 1-5, Peat, Marwick, and Mitchel and Co., and KLD Associated, Inc.

Lieberman, E.B., et al. (1972). Logical design and demonstration of UTCS-1 network simulation model. HRR 409, *Transportation Research Board*, Washington, D.C., 45-56.

Lieberman, E.B., Nguyen, S., McShane, W., & Berger, C. (1980). *Macroscopic simulation for urban traffic management: The TRAFLO model. Volume 3: Analytical developments for TRAFLO.* FHWA-RD-80, Federal Highway Administration, Department of Transportation, Washington, D.C.

Nguyen, S. (1974). A unified approach to equilibrium methods for traffic assignment. Proceedings of the International Symposium on Traffic Equilibrium Methods, University of Montreal.

Nguyen, E., & James, L. (1975). TRAFFIC - An equilibrium traffic assignment program. Publication #17, University of Montreal.

Payne, H.J. (1972). *Aggregate variable models of freeway traffic.* Department of Electrical Engineering, University of Southern California, Los Angeles, CA.

Payne, H.J., Thompson, W.A., & Isaksen, L. (1973). Design of a traffic responsive control system for a Los Angeles freeway. *IEEE Transactions on Systems, Man and Cybernetics, SMC-3*(3), 213-224.

Rakha, H., Van Aerde, M., Case, E.R., & Ugge, A. (1989). *Evaluating the benefits and interactions of route guidance and traffic control strategies using simulation.* Conference record of papers presented at the First Vehicle Navigation and Information Systems Conference (VNIS), Sponsored by the IEEE Vehicular Technology Society, Toronto, Ontario, September 11-13, 296-303.

Robertson, D.I. (1968). *TRANSYT: Traffic network study tool.* Fourth International Symposium on the Theory of Traffic Flow. Karlsruth, Germany.

Robertson, D.I. (1969). *TRANSYT: Traffic network study tool.* Road Research Laboratory, LR 253, Crowthorne, England.

Van Aerde, M. (1985). *Modeling of traffic flows, assignment and queueing in integrated freeway/traffic signal networks.* Ph.D. thesis, Department of Civil Engineering, University of Waterloo, Waterloo, Canada.

Van Aerde, M., & Rakha, H. (1989). *Development and potential of system optimized route guidance strategies.* Conference record of papers presented at the First Vehicle Navigation and Information Systems Conference (VNIS), Sponsored by the IEEE Vehicular Technology Society, Toronto, Ontario, September 11-13, 304-309.

Van Aerde, M., & Voss, J. (1988). *Integration 1 users manual.* Department of Civil Engineering, Queens University for the Ministry of Transportation, Ontario.

Van Aerde, M., & Yagar, S. (1988). Dynamic integrated freeway/traffic signal networks: A routing-based modeling approach. *Transportation Research, 22A*(6), 445-453.

Van Aerde, M., & Yagar, S. (1988). Dynamic integrated freeway/traffic signal networks: Problems and proposed solutions. *Transportation Research, 22A*(6), 435-443.

Van Aerde, M., Voss, J., & Blum, Y. (1989). Modeling the Burlington Skyway FTMA during recurring and non-recurring traffic congestion. *Traffic Engineering and Control, 30*(5), 225-240.

Van Aerde, M., Voss, J., Ugge, A., & Case, E.R. (1989). Managing traffic congestion in combined freeway and traffic signal networks. *ITE Journal, 59*(2), 36-42.

Van Vliet, D., & Hall, M. (1987). SATURN 7.1: A users manual - universal version. Institute of Transport Studies, Leeds University.

Wallace, C.E. (1988). *TRANSYT-7F software summary*. University of Florida Transportation Research Center, Gainsville, FLA.

Wallace, C.E., et al. (1988). *TRANSYT-7F users manual*. Transportation Research Center, University of Florida, Gainsville, FLA.

Yedlin, M., Lieberman, E., Andrews, B., Rathi, A., & Torres, J. (1988). *TRAF user guide*. FHWA-RD-88. Federal Highway Administration, U.S. Department of Transportation, Washington, D.C.