A Review of Candidate Freeway-Arterial Corridor Traffic Models

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In order to select a model for application in Ontario's freeway-arterial corridors, a review of potential candidates was performed. The criteria for evaluating suitable alternatives included the quality of the path selection technique, the ability to represent dynamic queueing effects, the accuracy and detail of the traffic flow model, and the resolution of the traffic signal representation on parallel arterials. The following models were initially considered: MACK, FREFLO, FRECON, INTRAS, TRAFFICQ, FREQ, CORQ, CORCON, SCOT, TRAFLO, DYNEV, CONTRAM, SATURN, and MICRO-ASSIGNMENT. On the basis of a literature review and a preliminary evaluation of fundamental requirements, some of these initial models were found to be clearly incompatible with the objective of modeling dynamic assignment and queueing in freeway-arterial corridors. Of the remaining models, which included FREQ, CORQ, TRAFLO, DYNEV, CONTRAM, and SATURN, none could fully satisfy all major criteria. However, it appeared that some could potentially be upgraded, given that a considerable amount of further development effort was applied. In this respect, CONTRAM and CORQ appeared most promising because of their superior queueing-based assignment techniques and their treatment of time varying queues and demands.

The Ontario Ministry of Transportation and Communications (MTC) has an on-going need for models to evaluate traffic management schemes within a number of its freeway-dominated corridors. Specifically, models are required for application to the Queen Elizabeth Way, the Burlington Skyway, Highway 401, and the Ottawa Queensway. Within these corridors the implementation of existing routing, diversion, ramp metering, and other related traffic management strategies must be reviewed, whereas there also exists an on-going need to evaluate new candidate strategies.

At present, MTC already has numerous simulation and optimization models at its disposal for the analysis of various types of traffic facilities. However, because most of these models were developed for different purposes, they usually have characteristics that do not perfectly fit MTC's corridor-oriented needs. It was therefore not clear which of these existing models was at this time best suited for application within Ontario's freeway-arterial corridors and which of them should be considered for further development.

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The first step in the study was to develop a set of criteria for the evaluation and selection process. This was followed by a preliminary survey of the available models in terms of these criteria, which in turn resulted in a short list of models for further evaluation. The final step involved a final critique of this short list in order to arrive at recommendations regarding models to be considered for further study and development or application.

MODEL EVALUATION AND ELIMINATION AND SELECTION CRITERIA

The quality of a freeway-arterial corridor model depends not only on the presence of several different features but also on the quality of their implementation. Although some of these features are desirable but optional, others are strictly essential. However, a model's appraisal depends most heavily on the application considered, because different applications emphasize different model features and alter their relative importance. Based on these considerations, a number of evaluation criteria were developed in conjunction with MTC's traffic systems research and traffic management and engineering personnel. These model evaluation criteria guided the model review process and were classified as follows:

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.

Although no detailed numerical grade could be assigned to each specific criterion, the following relative rating system was found useful in assigning them relative degrees of importance:

Absolutely necessary	***
Desirable now and necessary in future	**
Desirable	*
Not important	—

A detailed listing and rating of the foregoing modeling criteria is provided in Table 1. Based on these ratings, a summary of the most important criteria (those rated ***) was prepared and checked for credibility and consistency. This summary, which guided the review and screening of the initial candidate models, is as follows:

TABLE 1 MODELING EVALUATION CRITERIA

Criterion	Importance Rating
Traffic Engineering Theory	
Freeways	
Queueing	***
Merging and weaving sections	***
Ramp metering	***
Balancing of collector and express lanes	***
Car-following and lane-changing behavior	—
Analysis of shock waves	—
Priority entry and lane provision	**
Oversaturation and queue spillback	***
Traffic signals	
Cycle length, phasing, and green split	***
Coordination and progression	**
Platoon dispersion	—
Critical intersection control	—
Oversaturation and queue spillback	***
Length of time slice effects	*
Dynamic adaptation of capacity	**
Assignment	
Queueing	***
Dynamic reassignment	***
Bidirectional corridors	**
Vehicle and facility types	*
Other factors	
Adaptive learning (day-to-day)	*
Off-line study tool	***
On-line traffic responsiveness	**
Suitability for optimization	***
Program Code, User Friendliness, and Documentation	
Program source code	
Clarity	**
Comments and internal documentation	**
Modular structure	**
Suitability for modification	***
Program efficiency and limitations	
Maximum size of network (500 links, 250 nodes)	**
Execution time (10 min mainframe, 16 hr microcomputer)	**
Efficient to run for optimization of network	**
Portability between mainframes	***
Transferability to microcomputer (PC)	**
Program Code, User Friendliness, and Documentation	
General user friendliness	
Automated input	*
Error checking and messages	*
Editing of input data	*
Synthetic data	*
Accessibility to optimization module	**
Outputs and results	
Flows, queues, travel times, speed by link	***
Graphical presentation	**
Fuel consumption	*
Emissions	*
Noise pollution	*
Summaries by classification	**
External documentation	
Description of model's theory	**
Software installation and maintenance	**
Description of model limitations	**
Interpretation of results	**
Field Validation and Verification	
Data	
Using artificial data	
Using actual data (preferred)	
User	
By model author	
By other users (preferred)	
Availability, Implementation, Cost, and Support	
Model availability	
Cost	***
Source code	***
Additional support and follow-up	***
Implementation	
Common mainframe	***
Minicomputer	**
Microcomputer	**

NOTE: Ratings are defined as follows: ***, absolutely necessary; **, desirable now and necessary in future; *, desirable; — not important.

1. Freeways
   a. Oversaturation and queue spill-back
   b. Merging and weaving
   c. Ramp metering
   d. Balancing of collector and express lanes
   e. Queueing
2. Traffic signals
   a. Cycle length, phasing, and green split
   b. Oversaturation and queue spill-back
3. Assignment
   a. Dynamic reassignment
   b. Queueing
4. Other factors
   a. Off-line study tool
   b. Suitability for optimization
5. Program source code
   a. Availability
   b. Suitability for modification

6. Outputs and results: flows, queues, travel times, speed by link
7. Model availability
   a. Cost
   b. Source code
   c. Additional support and follow-up
8. Implementation: common mainframe or minicomputer

PRELIMINARY SURVEY OF CANDIDATE MODELS

In the preliminary survey a number of different types, groups, or series of corridor-related models were considered. Some of the findings of this initial survey are summarized in the following paragraphs for the following models:

- MACK-FREFLO-FRECON series,
- INTRAS type,
- TRAFFICQ,
- FREQ series,
- CORQ-CORCON series,
- SCOT family,
- TRAFLO,
- DYNEV,
- CONTRAM,
- SATURN, and
- MICRO-ASSIGNMENT type.

As shown, not every existing freeway model was evaluated. Instead, the review concentrated on the most common types and grouped these when they had a common origin or structure, or both. In addition, some of these models are at present clearly unsuitable for modeling freeways, traffic-signalized arterials, queueing, or traffic assignment. However, because the perfect model did not exist, all imperfect models became contenders for consideration during the preliminary evaluation.

MACK-FREFLO-FRECON Series

The MACKII model (*1*) and the original MACK model (*2*) are deterministic, macroscopic models that are basically a set of conservation equations and corresponding set of speed-density equations. A later modification by Koble et al. (*3*) has unofficially been labeled MACKIII. MACK models consider incidents, but there are now no provisions for environmental impact measures or parallel routes (*4*). An evaluation was made by Derzko et al. (*5*), who found it to contain certain instabilities.

The FREFLO model (*6-8*) is a further development of the MACKII model. It contains three general control strategies, can consider incidents, and has options for fuel and emission measurements. However, it cannot model parallel routes. FREFLO is also modular and has been used by second parties (*4*). In general, FREFLO is derived from car-following theory (*2*), but its overall characteristics may also be derived from statistical considerations. Derzko et al. (*5*) also evaluated this model and found that, by virtue of an identical underlying differential equation, FREFLO exhibited the same instabilities as MACK.

FRECON (*9*) and its update FRECONII (*10*) are dynamic, macroscopic freeways simulation models developed from Payne's FREFLO model. The original version simulates freeway performance and generates point detector information for calibration and validation. The model can interact with control programs in order to evaluate pretimed, local traffic-responsive, and segmentwide control strategies. Incident simulation is also possible. Traffic data must be included in the form of on- and off-ramp volumes and volumes of mainline traffic. Optional inputs pertain to detector location and incident description, and the outputs include contour maps of traffic performance measures and time profiles (*11*).

FRECONII contains enhancements to simulate alternative routes (surface streets), as in a corridor. It can simulate a freeway with mixed modes of ramp metering, and the driver's spatial diversion due to ramp metering. Additional outputs include surface street performance, corridor performance, and effects due to occupancy and diversion (*11*).

INTRAS Type

The INTRAS (INTegrated TRaffic Simulation) model (*12*, pp. 95-107; *13*) uses network theory to interrelate freeway and arterial traffic. It is a stochastic, microscopic model especially developed for studying freeway incidents. Its basis is a vehicle-specific time-stepping simulation designed to represent traffic and traffic control in a freeway and surrounding surface street environment (*14*, pp. 23-32).

The program is quite large and complex in order to model all vehicle movements in the corridor. A few control strategies are incorporated into the model, but it may be difficult to allow for access of new control strategies because of the model's structure. Traffic detectors and fuel and emission data are simulated directly from the microscopic flow (*4*). Users of INTRAS have reported problems with some aspects of traffic behavior (*15*), such as vehicles that merge from acceleration lanes, vehicles at exit ramps, and the method of assigning destinations. Some of these problems relate to the complications of communication between vehicles across link boundaries.

FOMIS (*15*) provides a revised model structure that is intended to streamline the simulation process by restricting it to the freeway only, eliminating the link structure and reducing vehicle processing to a single scan. Full derivation of the car-following and lane-changing algorithms is given by Bullen (*16*) and by Bullen and Cohen (*17*). The model is said to be primarily intended as a supplemental tool to current macroanalysis methods.

TRAFFICQ

TRAFFICQ is a simulation model of pedestrian delay, vehicle queueing, and platooning behavior. It takes into account dynamic and stochastic variations, varying road widths, and movements temporarily blocked by other vehicles. Complex control techniques such as linked signals or vehicle- or pedestrian-actuated signals may be modeled, as may priority junctions. Each vehicle or pedestrian is modeled as an individual entity, and the output gives distributions of queue lengths, travel times, and pedestrian delay (*18*, pp. 161-183; *19*).

TRAFFICQ is both dynamic and stochastic. It models, for example, both varying flow levels and random variations in discharge rates of vehicles from stop lines. The technique is aimed at relatively small-scale systems or sometimes just complex isolated junctions.

The program is written in ICL's CSL simulation language, which moves vehicles in discrete time increments (4 to 6 sec). The model is divided into a series of "activities," which are scanned sequentially, and the instructions within them are only performed if a particular condition is met. Such use of simulation permits tracing of dynamic conditions and evaluation of consequences of short-lived effects. In addition, it permits the evaluation of stochastic factors through use of a frequency distribution for the derivation of some traffic parameters. Routes taken by vehicles are prespecified by the user. This makes multirouting possible, but also implies that no internal assignment technique is present. Because each vehicle and pedestrian is considered an individual entity, temporary blockages and queue spill-backs can be modeled in detail.

FREQ Series

Since 1968 the FREQ family of freeway models has been under continuous development at the University of California (*20*). These models are macroscopic and are intended to evaluate a directional freeway and its ramps on the basis of ramp origin-destination (O-D) information. Some diversion to parallel alternatives is considered for vehicles queued at on ramps, but this treatment is not very detailed. Specialized versions of the general model are available for the evaluation of lanes on freeways reserved for carpools or buses, or both, and of priority and normal entry control.

The major input to most FREQ models is a set of O-D tables for each interval or time slice (typically about 15 min). These tables would correspond to volumes or percentages of various vehicle-occupancy classes. The model can calculate the effect of weaving on capacity, and speed-flow relationships can be selected or specified by the user. Ramp characteristics must be input. The model adjusts supply and demand, and predicts a time stream of impacts that includes both spatial and modal traveler responses (*21*). The output consists of freeway performance tables containing travel time, speed, ramp delays and queues, fuel consumption, and emissions.

FREQ6PL (*22*) is used primarily for the evaluation of a freeway lane or lanes reserved for carpools or buses, or both, and FREQ7PE (*23*) was developed primarily for the evaluation of priority and normal entry control on a directional freeway. The latter program simulates the system, optimizes a control strategy through linear programming, and predicts traffic performance and traveler demand responses. Also produced are metering plans, contour maps, and impacts of priority-lane operation (*11*).

CORQ-CORCON Series

CORQ (CORridor Queueing) (*24-26*) is a dynamic assignment technique for allocating time-varying O-D demands to a time-dependent traffic network. The technique models the impact of queueing and ramp metering on traffic assignment within a freeway-arterial corridor. CORCON (*27*) is a modification of the original CORQ program but contains essentially the same core model logic. Consequently, it is not treated separately in further discussions.

CORQ considers time-slice O-D movements for a freeway-arterial corridor and assigns these in accordance with separate minimum-path and equilibrium considerations for each time slice. Traffic flows that are unable to reach their destination within the given time period because of capacity constraints are queued and carried over for reassignment to the network during the subsequent time slice. Vehicles are assigned in variable-sized increments, depending on the capacity of the links of the network, until the entire O-D matrix for a given time slice has been assigned. The solutions for each time slice are then iterated until equilibrium is reached before the analysis proceeds to the next time slice.

Traffic flows are approximated as fluids, and travel times are calculated as simple step functions for both free-flowing and congested (queueing) conditions. The model considers primarily a directional freeway, its ramps, major cross streets, and any competing alternative surface streets. Turning movements can be accounted for, but no explicit modeling of traffic lights or any progression effects takes place. These effects must be input indirectly as link characteristics.

SCOT Family

SCOT (Simulation of COrridor Traffic) (*28*, *29*) is the synthesis of two previous models: UTCS-1 (Urban Traffic Control System-1) (*30*) and the DAFT (Dynamic Analysis of Freeway Traffic) model by Lieberman (*31*), with later modifications (*32*).

UTCS-1 is a microscopic simulation of urban traffic, in which each vehicle is treated as an individual entity as it traverses its path through a network of urban streets. Routing is performed on the basis of specification of turning movements. DAFT is a macroscopic simulation model of freeways, ramps, and arterials. Vehicles are grouped into platoons and lose their individual identities. Platoons are moved along the freeway according to a single prespecified speed-density relation. On nonfreeway links, they travel at the specified free-flow speed for each link and are delayed at traffic signals on the basis of their g/c ratio and the amount of traffic.

For each entry link at the periphery of the study network, traffic volumes are specified according to their destination node. The model distributes the resulting platoons of vehicles over the network according to minimum-cost paths, which are calculated frequently on the basis of current conditions.

Whenever a platoon reaches a network node, its turning movement is dictated by its minimum-cost path as it exists at that instant of time. Hence the model produces a dynamic assignment of traffic as a by-product of the simulation. Although ramp metering is allowed, the inclusion of new control strategies is restricted by the difficulty of program modifications due to the model's structure (*4*).

TRAFLO Type

TRAFLO (*33*) is a system of four traffic simulation models and one traffic assignment model. Essentially, the assignment model calculates the flows on each link, which are subsequently evaluated by using one or more of the simulation models.

Traffic assignment is performed with the TRAFFIC model (*34, 35*), which requires use of the Bureau of Public Roads (BPR) link travel time relationship. By using a representation of Wardrop's first principle (*36*), TRAFFIC assigns a specified trip table to a network that is compatible with the four simulation models. One or more of the simulation models are then used to describe traffic operations in each subnetwork at the desired degree of detail. The user may partition the analysis network into several subnetworks if more than one simulation model is to be used concurrently, but in that case interface nodes must be specified at the junctures.

The following is a brief description of the four component submodels:

1. Urban Level I Model (NETFLO I) is the most detailed; each vehicle is treated as a separate identifiable entity and three vehicle-type distinctions are permitted (automobiles, trucks, and buses). The simulation moves vehicles on the basis of activation times and leaves them dormant between activation times.
2. Urban Level II Model (NETFLO II) is supposed to be an extension and refinement of TRANSYT because the traffic stream is represented in the form of movement-specific statistical histograms. The simulation uses five histograms: Entry, In, Service, Queue, and Out.
3. Urban Level III Model (NETFLO III) is used for the network's major arterials: collectors, distributors, circulators, and connectors. These routes connect traffic generators or high-density areas.
4. The Freeway Model (FREFLO) is said to be an extension and refinement of the MACK model developed by Payne et al. (*37*). Traffic is represented through a fluid-flow analogy considering measures such as flow rate, density, and speed.

DYNEV

DYNEV was developed to estimate evacuation travel times in Emergency Planning Zones (EPZs) as part of the larger software system developed for the Emergency Exercise Simulation Facility (*38*). Its main components are an interactive input routine called PREDYN and a software system called I-DYNEV.

DYNEV is essentially an iterative procedure starting with a data input routine and followed by an assignment procedure and the I-DYNEV traffic simulation model. The simulation model computes network performance measures based on the traffic volumes and turning movements generated within the assignment. Further intermediate steps are possible to modify any controls or the trip table, or both, but then additional model iterations are required. The final analysis is complete when the output of the simulation model is compatible with the assumptions on which the original assignment is based.

The assignment model identifies the best travel times for people to move from specified origins within the EPZs to destinations just outside. It uses a modified TRAFFIC algorithm, but travel times must be calculated based on the BPR relationship of travel time versus volume. The traffic simulation model takes as inputs link volumes and turning movements from the assignment model and replicates the dynamic (time-varying) movements of the traffic stream on all roadway sections. The model is an adaptation of TRAFLO Level II in which the traffic stream is described in terms of a set of link-specific statistical flow histograms. Both the assignment and the simulation model interact with the traffic capacity submodel, which computes service rates by turn movement.

CONTRAM

CONTRAM (CONtinuous TRaffic Assignment Model) is a traffic assignment and evaluation package that models traffic flows in urban networks consisting primarily of signalized, priority, and give-way junctions (*39, 40*). However, at this time there are no freeway (motorway) modeling provisions.

Traffic demands are expressed as O-D rates for each given time interval. These O-Ds are converted into an equivalent number of vehicle packages, which are assigned to the network at a uniform rate for each time interval. Each such packet is indivisible and travels along its own individual minimum path to its destination. For each link along its path, flows and travel times are updated, whereas for each vehicle packet a record is kept of the links used and the arrival time at that link. With the latter information, each vehicle packet can be conveniently removed from the network during any subsequent iterations and a detailed queue diagram can be constructed for each link. A traffic assignment equilibrium is achieved through iterations in which each vehicle packet in turn is removed from the network and reassigned to its new minimum path. Such reassignments consider each driver as truly a marginal user and continue until virtually all reassignments result in the same paths.

The total link travel times are calculated on the basis of any oversaturation delay due to extended queueing, the duration of the red indication at traffic signals, and any random delay effects due to randomness in either arrival or departure rates. As traffic volume estimates become available from an initial assignment, delay functions for traffic signals can be updated to reflect optimized signal splits or cycle lengths, or both, but coordination between adjacent signals is not considered.

SATURN

SATURN (*41, 42*) is a traffic assignment model based on a detailed simulation of intersection delays and an assignment that employs a more general travel time relationship that is derived from the detailed simulation.

Intersection delays are determined primarily by using cyclical profiles, in a fashion much like that used in TRANSYT. Consequently the effects on delay of coordination of signal timings and platoon progression can be accounted for. On the basis of delay estimates at free-flow conditions, at the conditions modeled using the cyclic profiles, and at capacity, an aggregate power curve is fitted to represent delays at any approach volume. This power function is further supplemented with a queueing relationship for oversaturated conditions.

Traffic flows on each network link are estimated by using a weighted combination of all-or-nothing assignments. These new estimates of link flow are then reevaluated with the cyclic profile approach until equilibrium is reached between the evaluation and the assignment. During each iteration, changes in delay due to shifts in the magnitude and structure of vehicle platoons can be included and any impact of changes in opposing-direction flows can be reflected.

SATURN models two types of queues, namely, transient and permanent queues. The account of transient queues, which build up every cycle during the red phase, permits signal coordination to be evaluated but not optimized. The account of permanent queues, which develop when queues exist during the entire cycle, considers the impact on increased travel time directly and the impact on downstream links indirectly.

MICRO-ASSIGNMENT Type

MICRO-ASSIGNMENT is a microscopic adaptation of traditional transport planning assignment techniques. Traffic is assigned in a conventional fashion, but the network is coded in considerably more detail, so that individual movements or lanes, or both, can be considered (*43, 44*).

The network is coded by using an "off-set" system of network representation, in which the nodes are located along the approaches to an intersection, and each permissible traffic movement at the intersection is represented by a separate link.

Two types of delay are considered: zero-volume delay and congestion delay. The former is delay in the absence of other vehicles (acceleration, deceleration for turns, and Stop and Yield signs). The latter is delay due to traffic interference by other vehicles (queueing at signals or caused by conflicting traffic). Originally these delay relationships were based on theoretical formulas, but currently an empirical basis is used.

Assignment is based on an iterative multipath procedure that deals in time periods from 6 min to 24 hr. The technique assigns time-slice O-D patterns to the links in the network so that arrival rates and updated delays can be derived. Although queueing conditions are not modeled explicitly, the higher delays associated with oversaturation are considered in the assignment.

ELIMINATION OF MODELS FROM PRELIMINARY SURVEY

A comparison of the basic features of the initial candidate models is provided in Table 2, which also traces the models' roots and indicates their type and design purpose. To assist in the inclusion and elimination process, any further standout characteristics are noted under the headings Critique and Desirable Features.

A survey of Table 2 indicates that no one model is comprehensive in being able to model all the required factors at the desired level of detail. However, it is clear that some models are more suitable for further development and others clearly are not. Consequently some models were further examined in greater detail, whereas others were eliminated from further consideration, as will be discussed. It should be noted, however, that the elimination of certain models on the basis of freeway-arterial corridor criteria does not imply that they could not be effectively used for other applications that more closely match the models' capabilities or design objectives.

Models Not Suitable for Further Study

Because of the importance of assignment and reassignment in freeway corridors and networks, MACK, FREFLO, FRECON, INTRAS, and TRAFFICQ were eliminated. Each model is very precise in its treatment of traffic flow details, which is important when the dynamics of single facilities are studied. However, the lack of a true assignment procedure often causes these models to analyze in excessive detail traffic flows that, because of traffic diversion and reassignment, are not necessarily correct. Although some models do consider diversion, simple diversion is inadequate when several significant arterial alternatives exist within a corridor.

Alternatively, MICRO-ASSIGNMENT contains a network traffic assignment technique. However, this technique does not consider the details of the dynamics of queueing, which are at the root of the corridor problem. Although delays resulting from oversaturation during a given time slice can easily be accounted for, the impact of the resulting queues on subsequent time slices cannot be considered. The assignment technique employed in this program is in essence a very detailed version of traditional transport planning approaches, which is difficult to modify to accommodate the needs of oversaturation or queueing.

Although the SCOT model appears to satisfy most of the primary criteria, the model is no longer supported. Furthermore, the same authors have subsequently developed TRAFLO and DYNEV, which are said to be improvements over SCOT. Consequently, SCOT was dropped from further consideration.

TABLE 2 INITIAL CANDIDATE MODELS

Model	Assignment: Technique	Assignment: Other	Traffic Flows: Freeway	Traffic Flows: Signals	Roots	Model Type	Model Purpose	Critique	Desirable Features
FREFLO	---		Conservation equation, dynamic speed-density (fluid flow)	---	MACK	Deterministic, macroscopic	Freeway (one direction)		
FRECON	Diversion due to ramp metering		Modified from FREFLO	Simple travel time	FREFLO	Macroscopic	Freeway (one direction)	Diversion not same as assignment	Adaptive discretization of step size
INTRAS (FOMIS)	---		Vehicle-specific, time-stepping simulation	---	NETSIM	Stochastic, microscopic	Study freeway incidents	No O-Ds	
TRAFFICQ	---	Paths specified by user	---	Individual: vehicles, pedestrians	Original	Microscopic	Urban network	No O-Ds	Considers pedestrians
FREQ	Diversion of ramp queue	Considers only subgroup for reselection	HCM (speed-volume)	Simple travel time	Original	Macroscopic	Freeway + evaluate: priority lanes and priority entry	Diversion not same as assignment	Linear programming optimization
CORQ	Incremental/ iterative	Reassignment of queued vehicles	Step function, travel time	Implicit in travel time calibration	Original	Macroscopic	Queueing in freeway corridor	Not user-friendly, directional assignment	Automatic network performance plots
CORCON	Incremental iterative + traffic diversion		Step function, travel time	Implicit in travel time calibration	CORQ	Macroscopic	Queueing in freeway corridor	Problems with implementation	Fuel consumption and emissions
SCOT	UTCS-1: turning movements; DAFT: minimum path		DAFT, platoon flow based on speed-density	UTCS-1: individual vehicles	DAFT, UTCS-1	Microscopic and macroscopic	Test real-time control policies for corridors	Model component incompatibilities; model no longer supported	Composite network
TRAFLO	TRAFFIC (*34*)	Planning oriented, nonqueueing	FREFLO	I: NETSIM, II: TRANSYT, III: WEBSTER	FREFLO, NETSIM, TRANSYT	Microscopic and macroscopic	All networks	146,000 statements; reassignment of queues? Traffic—no queue considerations	Composite network
DYNEV	TRAFFIC (*34*)	Planning oriented, nonqueueing	Flow histogram (NETFLO II)	Flow histogram (NETFLO II)	TRAFLO	Mesoscopic	Emergency evacuation	Nonqueueing assignment	Detailed model of approach lane section
CONTRAM	Incremental/ iterative (packets of about 10 vehicles)	Reiterates over entire peak (traces paths)	---	Delay = $f(G/C, C, V/C)$ + queue delay platoons	Original	Mesoscopic	Evaluate urban signalized and unsignalized network	Modeling of freeways	Good assignment; recalculation of signal timings
SATURN	All or nothing		---	Cyclic file: $TT_n = Ao + BX^n + QT$	Original	Mesoscopic	Evaluate urban signalized and unsignalized network	No freeways; very coarse assignment of queues	Considers progression between signals
MICRO-ASSIGNMENT					Traditional transport planning	Macroscopic		No queue reassignment	Simple structure

Models Retained for Further Study

Candidate models were retained for further study if they appeared to contain the required components or incorporated a model structure that was sufficiently flexible to be amenable to the required modifications. On the basis of these criteria, the following models were retained:

- FREQ
- CORQ
- TRAFLO
- DYNEV
- CONTRAM
- SATURN

The first two, FREQ and CORQ, are the most traditional types of freeway-arterial corridor models, because they consider primarily the freeway and any important or relevant parallel arterials. The FREQ series was retained for further analysis because it is a virtual standard for freeway models, and because it has a number of features not available in other models. The CORQ series was included because it appears to be the only model type that simultaneously considers queueing and reassignment in a freeway-arterial corridor.

The next two models, TRAFLO and DYNEV, have a more network-oriented structure; they can consider assignment in a multidirectional network and appear to model in detail the different facility components. They were retained because the possible increased level of detail could permit very accurate modeling, whereas their networkwide approach is rather unique.

The final two models, CONTRAM and SATURN, are primarily traffic signal-oriented assignment models. They do not currently contain any freeway logic, but because the important capability of modeling traffic assignment in a network that includes traffic signals, they were retained for further study. Furthermore, their traffic modeling and assignment approaches appear to be suitable for extension to include freeways as another link type.

DETAILED MODEL CRITIQUES

The models retained for further study were examined in greater detail in the second phase of the study. Detailed model descriptions prepared as part of this second phase have been provided by Van Aerde and Yagar (*45*), and because of their length are not repeated here. Instead, this section concentrates on the model critiques, which are based on and derived from these detailed descriptions.

The critiques are negative at times, because they often concentrate on limitations, rather than emphasize strengths. However, the focus on limitations is a necessity, considering the objectives of the study. The authors apologize to any authors whose model documentation and descriptions may have unintentionally been misinterpreted. Every effort was made to have reasonable safeguards against this, and a number of the authors were actually consulted directly. Any comments on these critiques would be appreciated.

Finally, because the authors have some vested interests in the CORQ model, every attempt was made to remain unbiased in the evaluations. It is possible that they have been more critical of CORQ than of any other model because of their knowledge of its potential shortcomings.

FREQ

The strength of FREQ models lies in their diversity of traffic impact measures, the comprehensive range of responses that are included, and the extensive field testing that has taken place. Their primary weakness is in relation to the approximate terms in which parallel alternatives are modeled, especially because of the lack of full assignment technique.

Modeling the flow of traffic on any parallel alternatives in only approximate terms may result in potentially large errors when several significant alternatives exist, especially because shifts in path selection decisions are often based only on small changes in relative travel times between competing alternatives. Furthermore, the diversion technique considers only path reselection of those queued on freeway on ramps. It ignores any path reselection from the freeway to the surface street (when the freeway is busy but not congested) and any path reselection from arterial routes to the freeway (if freeway performance improves significantly). All these limitations restrict the use of FREQ to the analysis of only the freeway or a very narrow freeway-based corridor.

Other approximations are made when queues are modeled without taking spillback into account. This affects estimates of downstream volume and the blocking of upstream traffic. In addition, because the destination pattern of queued vehicles is not retained for use in subsequent time slices, considerable errors in downstream traffic volume estimates may occur if O-D patterns change significantly between time slices.

A feature unique to FREQ is its use of a linear program to optimize ramp-metering rates.

CORQ

The main strengths of CORQ lie in its ability to incorporate the effects of dynamic queues into an assignment methodology that uses corridorwide time-slice O-D demands. Its primary weakness is in the lack of an evolutionary sequence of revisions during development and application to case studies. As a result, the actual code is ill-formatted, the output is not very user-friendly, and some obvious simple refinements to the technique are missing.

Of greatest practical significance are the resolution and generation of the current travel time relationship, which is expressed as a static step function. Especially on parallel arterials, the insensitivity of this relationship to changes in signal timings, such as cycle length and green-time allocation, is a major drawback.

Further limitations of the current program are its specialization to unidirectional travel and limitations on the trip length for which the assignment's treatment of nonqueued vehicles is valid. These restrictions are significant when there is a significant opposing-direction flow or when a large percentage of trips are longer than one time slice.

A theoretically less significant problem relates to CORQ's current output format, which tends to provide only raw simulation results. These require significant amounts of further hand processing. Instead, concise summaries and graphics of the relevant flows, travel times, and queues would make it significantly easier to use the model. In addition, the model's use and operation are not very well documented.

TRAFLO

TRAFLO is a combination of a variety of related traffic simulation and assignment models. However, incompatibilities between these component models result in certain limitations for the entire package, especially when it is used for freeway-arterial corridor applications.

TRAFFIC is a good assignment model for planning when behavior according to the BPR equation is valid. However, in terms of traffic operations, the inability of TRAFFIC to deal with queueing, non-steady-state traffic conditions, and dynamic assignment is detrimental. Specifically, the author of TRAFFIC indicated that the model should not be used for networks in which demand exceeds capacity, because the model assumes that link demands in excess of capacity will still be served. Consequently, downstream links are modeled as being loaded with larger-than-actual traffic demands, spillback from these links onto upstream links is ignored, and downstream demand is underestimated when any accumulated queues are served in subsequent time periods.

The availability of different modeling approaches permits the user to tailor the level of detail and accuracy to the specific needs of the various parts of the network. However, each of these models has different operating procedures and assumptions, leaving the user with a mixture of different network performance measures. This makes evaluation difficult and may render any global optimization virtually infeasible. Finally, the current TRAFLO model structure does not contain a feedback loop from the evaluation model to the assignment model. Consequently, the TRAFLO assignment is performed by using a highly simplified relationship of travel time versus traffic flow, resulting in a detailed evaluation of potentially very poor traffic flow estimates.

DYNEV

DYNEV and TRAFLO are very similar in terms of their authors, model philosophy, and many of the model routines. DYNEV does provide some significant improvements over TRAFLO, but the adaptation of the same core structure appears to have left DYNEV with the same fundamental limitations in terms of freeway-arterial corridor applications. Furthermore, DYNEV's use is further limited because its code is currently classified as being proprietary.

The most significant improvement in DYNEV is the introduction of a capacity submodel that permits capacity estimates to be updated within the assignment procedure. This should improve the overall accuracy of the assignment, because the results of the assignment and the evaluation will be more consistent. However, this modification does not correct for any of the queueing problems that were previously also outlined for the assignment procedure present in TRAFLO.

In contrast to TRAFLO's four evaluation submodels, DYNEV models all links using only NETFLO II (a method that models traffic flows as a series of flow histograms). Although one may question the compatibility of TRAFLO's four evaluation submodels, there are also some concerns about using a statistical histogram to replace the functions previously performed by NETFLO I (NETSIM) and FREFLO. Further difficulties derive from the need with DYNEV (and TRAFLO) to model a peak period of, say, twelve 15-min time slices (3 hr) as essentially 12 independent runs, one for each time slice. This is inefficient in terms of the person who must use the model but, more important, it appears to limit the representation of any significant interaction between consecutive time slices and the queueing that links them.

CONTRAM

Although CONTRAM is currently limited to traffic signal applications rather than freeways, its queueing-based dynamic assignment technique makes its model structure superior to that of most current models.

In contrast to traditional models, which generally consider only the last demand increment as being truly "incremental" users, CONTRAM permits each vehicle packet in turn to be a marginal user. As a result, each network user decides on his path seeing a fully loaded network rather than a network that has only been loaded to the extent of the previous increments. A second feature of this assignment technique is that all vehicles passing through a queued link are queued for a short time (depending on the current queue size). By contrast, in most other models a quantity of vehicles equal to the link's saturation flow is not queued at all, and all additional vehicles are queued for a full time slice. Finally, the assignment technique circumvents the approximation of most previous models, which required all vehicles to reach their destination within one time slice unless caught in a queue. The CONTRAM approach permits vehicles to take more than one time slice, even if they are not queued at any point along their path.

CONTRAM's main shortcoming in terms of this study is its lack of model routines for freeways and freeway merging and weaving sections. Such an addition is certainly not a trivial task, but there appears to be no major obstacle within the model's structure to prevent such an enhancement. Of further concern is CONTRAM's extensive use of memory and computer time, which may be important when much larger corridors or networks are considered. Finally, unlike SATURN, CONTRAM does not explictly consider progression of platoons along signalized arterials.

TABLE 3 EVALUATION OF FINAL GROUP OF MODELS

Characteristic	FREQ	CORQ (CORCON)	CONTRAM	SATURN	TRAFLO	DYNEV
Purpose	Directional freeway	Directional freeway-arterial corridor	Network of signalized and unsignalized junctions	Network of signalized and unsignalized junctions	Composite freeway-surface network	Dynamic evacuation
Source of components						
Assignment	n/a	New	New	New	TRAFFIC	TRAFFIC
Traffic flows	New	New	New	New	NETFLO I-III, FREFLO	NETFLO II
Freeway treatment						
Flow representation	Fluid	Fluid	—	—	Fluid	Flow profile
Travel time calculation	HCM (speed/volume)	Empirical step function	—	—	Conservation equations, speed-density	Speed-density
Optimization	Linear program, ramp metering	Demand responsive, ramp metering	—	—	?	—
Merging	HCM (1965)	Included	—	—	—	?
Weaving	HCR (1965)	Window provided	—	—	—	?
Traffic signal						
Evaluation	Davidson's equation	Empirical *tt*-curve	Webster's formula	Cyclic profile	Various	Flow profile
Assignment	Davidson's equation	Empirical *tt*-curve	Webster's formula	Fitted curve	BPR	BPR
Coordination	No	Empirical *tt*-curve	No	Yes	Sometimes	Yes
Self-calculation	No	No	Yes	Yes	?	Probably
Optimization	No	No	Yes (no coordination)	No	No	No
Queueing						
Spillback	Not on ramps	Yes	No	No	—	Assignment, no; simulation, yes
Holdback	Yes	Yes	Yes	Yes (queue reduction factor)	—	Assignment, no; simulation, approximation
Spillover	15 min	15 min	Continuous	15 min	—	Assignment by hand; simulation, approximation
Assignment						
Method	Diversion	Incremental/iterative	Marginal (packets)	Combination of all or nothing	TRAFFIC	Modified TRAFFIC
Freeway	—	Incremental/iterative	—	—	TRAFFIC (*34*)	TRAFFIC (*34*)
Surface	Diversion of ramp queues	Incremental/iterative	Packets	Combination of all or nothing	TRAFFIC (*34*)	TRAFFIC (*34*)

TABLE 3 *continued*

Characteristic	FREQ	CORQ (CORCON)	CONTRAM	SATURN	TRAFLO	DYNEV
Reassignment en route	Queues each time slice	Queues each time slice	Vehicle packets each packet	Queues next time slice	No	No (optional) diversion)
Reassigned O-D pattern	Next slice's destinations	Original destinations	Original destinations	Not clear	—	—
Spatial propagation	Within slice (except in queue)	Within slice (except in queue)	Traced in time	Within slice (except in queue)	Within slice	Within slice
Accessibility						
Implementation						
Mainframe	Yes	Yes	Yes	Yes	Yes	Yes
Microcomputer	No	Yes	No	No	No	No
Source code availability	Yes	Yes	—	—	No	No (proprietary)
Cost ($)						
Fixed	Negligible	0	612	525	Negligible	—
Variable	Negligible	0	2,625	4,900	Negligible	—
Support	Yes	Yes	Yes	Yes	Yes	Yes
Outputs (flows, queues, travel times)	Yes	Yes	Yes	Yes	Yes	Yes
Document						
User's manual	Yes	No	Yes	Yes	Yes	—
Theory	Yes	Yes	Yes	Yes	?	—
Modification						
Unnecessary	No	No	No	No	No	No
Feasible	Possible	Possible	Possible	Possible	Difficult	No
Comments						
Primary weaknesses	No traffic signals, no assignment	No explicit traffic signals	No freeways	No freeways	Different sub-network models, TRAFFIC (nonqueueing), 146,000 lines	Strictly NET-FLO II, TRAFFIC (nonqueueing)
Special strengths	Priority lanes, linear program optimization, priority entry	Modeling of queue spillback/ service	Sophisticated assignment technique	Coordinated signals, recalculation of signal timings	Model detail tailored	Vehicle distribution between lanes, Kalman filter capacity recalculation

NOTE: Dash indicates data unknown.

SATURN

The main strength of SATURN lies in its ability to perform assignment in a network consisting of traffic signals while giving due consideration to the specifics of the platooning structure of vehicle arrivals and the phasing of the signals. An additional feature of the model is its close linkage to a program for generating synthetic O-Ds, which is important in view of the traditional difficulties of obtaining accurate and recent O-D demands efficiently.

The main weaknesses of SATURN are its lack of a true queueing-based assignment and its lack of freeway-modeling routines. Although a number of features have been included to allow the assignment model to approximate a number of queueing impacts, it is not clear that a simple queue reduction factor accurately models all the relevant features. Specifically, in view of queueing considerations, there appear to be difficulties in terms of queue spillback, the reassignment of queues in subsequent time slices, and the use of an "equilibrium assignment technique," which employs a combination of all-or-nothing assignments. It would appear that queueing should be directly accounted for in the assignment rather than being finessed afterwards.

Although these weaknesses may not be crucial for the applications that are usually considered with SATURN, they appear to be critical in terms of the criteria specified for freeway-arterial corridors where queueing effects are a dominant factor in generating control strategies.

FINAL EVALUATION AND ELIMINATION

The final selection of models was performed by considering both the models' current capabilities and their potential to be enhanced. A detailed evaluation of the models on the short list is provided in Table 3. Although the weaknesses and deficiencies tended to drive the elimination process, any special strengths were noted for potential incorporation into the models selected for development and application.

In the final analysis, FREQ was eliminated from further consideration because it is not truly a network-based model. Although its diversion technique may be sufficient for isolated freeway corridors, when there is only one other significant parallel alternative, it is not adequate when several alternatives are possible or when the amount of diversion varies with relative flows and queues.

Because of the basic requirement that a recommended model have a queueing-based assignment technique, TRAFLO and DYNEV were eliminated. The evaluation portion of each of these models has some queueing capabilities, but the TRAFFIC assignment technique does not consider queue assignment or reassignment, and cannot easily be modified to do so.

CONTRAM appears more promising than SATURN for the type of applications that are considered in Ontario. Although neither model has provision for freeways in its current form, the flexibility of CONTRAM's assignment-evaluation-queueing technique appears to make it more suitable. In general, it appears that the model structure of SATURN may be too signal-oriented to permit the model to incorporate freeways without major fundamental changes to its assignment or queueing analysis, or both.

CONCLUSIONS

Both CONTRAM and CORQ were recommended for further development, because they appear best suited for the required modifications and have assignment techniques that can effectively deal with the dynamic growth and decay of queues in a network setting. However, modifications are required for both models, because CONTRAM, which contains a detailed treatment of traffic signals, has no freeway capabilities, whereas CORQ, which emphasizes freeways, has a weaker traffic signal base.

CONTRAM should be studied in greater detail and applied to a sample freeway-arterial corridor to determine its ability to model freeway sections and ramps. This study should identify what further enhancements the model needs and establish whether the network size constraints of CONTRAM are critical in typical freeway-arterial corridors.

Because CORQ was originally designed for freeway-arterial corridors, it automatically scored high on a number of essential requirements. However, before significant further use, the following enhancements are recommended:

- Automation of the generation of relationships of link flow versus travel time and intersection delay,
- Incorporation of a feed-forward mechanism to represent drivers' preknowledge of future network conditions,
- Improvement of link performance summaries and user documentation, and
- Consideration of the effects of spillback through signalized intersections.

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