CURRENT STATUS OF TRAFLO

The TRAFLO program is now complete and is currently undergoing in-house testing by FHWA personnel. More detailed descriptions of TRAFLO appear elsewhere (8).

ACKNOWLEDGMENT

The development of a model such as that described in this paper is the result of the contributions of many people. In particular, we want to acknowledge Guido Radelat and George Tiller of the Traffic Systems Division of FHWA; Mark Yedlin and Manfredo Davila of KLD Associates, Inc.; William McShane of the Polytechnic Institute of New York; and Fred Wagner of Wagner/McGee Associates.

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Abridgment

Hybrid Macroscopic-Microscopic Traffic Simulation Model

M. C. DAVILA AND E. B. LIEBERMAN

The Level I model, a component of the TRAFLO macroscopic traffic simulation program designed to evaluate transportation system management strategies, is described. The Level I model is designed to explicitly treat traffic control devices, include all channelization options, and describe traffic operations at grade intersections in considerable detail. Other features include actuated signal logic, right turn on red, pedestrian interference, and source-sink flow. Automobiles, buses, carpools, and trucks are explicitly treated as individual entities. The simulation processing uses "event-based" logic, which moves these vehicles intermittently, as required, rather than at every time step (interval scanning). Thus, this model is hybrid in the sense that the entities are microscopic but the processing is macroscopic in treatment. An overview of the Level I model logic is presented, the input requirements and measures of effectiveness provided by the model are indicated, and program efficiency and validation results are discussed.

This paper briefly describes the Level I model, a component of the TRAFLO macroscopic traffic simulation program (1), which has been designed to evaluate transportation system management (TSM) strategies. Level I is the most detailed simulation model within TRAFLO. It provides a microscopic description of the traffic stream and a macroscopic description of each vehicle movement. This approach is designed to provide a reasonably high resolution of detail as well as economy of operation.

Ideas embedded in several existing traffic simulation models have been selected, synthesized, refined, and expanded to form the Level I logic. These include the System Development Corporation macroscopic model (2), the TRANS model (3), the NETSIM (formerly UTCS-1) model (4), and the SCOT-Q model (which is not documented). The basic concept of processing each vehicle only when it is time to do so is called (in GPSS terminology) "event-based transactions". The intrinsic benefit of this concept is that it greatly reduces computing time, particularly when each event is widely spaced in time.

A careful analysis of these existing models revealed that it would be feasible and desirable to use an event-based approach in processing all vehicles; that is, even when a vehicle is in queue state, it could be "jumped" to the stop line and yet the mechanism of the queue discharge expansion wave could be preserved. By treating each vehicle in the traffic stream individually, the model is able to explicitly distinguish between different vehicle types (automobiles, carpools, trucks, and buses) and to treat each type according to its respective operating characteristics. Furthermore, much of the stochastic nature of the traffic flow process can be explicitly represented.

MODEL DESIGN

For the purpose of simulation, in the Level I model an urban street network is decomposed into a set of unidirectional links (streets) and nodes (intersections). Each link may contain as many as six moving lanes. The control at a node may take the form of a traffic signal, two-way stop signs, and yield sign control. To accurately model delay at an intersection, each vehicle at the head of a queue, prior to the onset of the green signal phase, is stochastically assigned a start-up delay that must be exhausted after the green phase is activated and before the vehicle is discharged. When a vehicle is discharged, the remaining members of the queue move up in response to a "green wave" propagating upstream at a speed of 1 vehicle/s ($\approx$20 ft/s). Thus, the fifth vehicle in a queue when the green phase is activated remains motionless for 4 s after the first vehicle discharges. As each following vehicle comes to the head of the queue, it is stochastically assigned a discharge headway that is related to (a) the specified mean headway value, (b) the statistical distribution about the mean, (c) the vehicle's original position in queue, (d) its vehicle type, (e) the type of the vehicle previously discharged, and (f) any additional surcharge to account for pedestrian interference.

Bus traffic is explicitly and realistically treated by the model. Buses have their own vehicle length and operational characteristics and traverse prescribed paths (routes) through the network, servicing those stations assigned to that route. The probability of stopping and the duration of dwell time are assigned to each vehicle stochastically. Impedance from other traffic, queuing that prevents buses from accessing their stations, the possibility of a saturation of station capacity, and many similar factors are rigorously modeled.

Scheduling of Vehicle Movement

Since the Level I model uses an event-based simulation logic, it is necessary to create a schedule of events internally. Two vehicle-scheduling arrays are used. In one array for near-term events, vehicles with an activation time (AT) within the current scheduling period (i.e., an AT lower than some clock time into the future) are stored. All other vehicles fall by default under the "imaginary" long-term-event array and are not stored. When the simulation clock reaches the end of a scheduling period or the near-term scheduling array is empty, a new scheduling period is defined. At this point, all vehicles in the network are scanned and those whose AT is within the new scheduling period are stored in the near-term scheduling array.

Vehicle Processing

A vehicle is only processed (i.e., moved) when its AT is equal to the current simulation clock time. Each vehicle is then generally moved to a point downstream, either on its current link or onto a receiving link, subject to the constraints imposed by other vehicles and by the signal control. The vehicle's new location, speed, and AT are computed in the process. This vehicle then remains "dormant" until the simulation clock time advances to the new AT, whereupon the vehicle is again processed.

A small number of cases that, in aggregate, span the entire spectrum of possible conditions were identified (see Figure 1). For each such case, explicit analytic expressions have been derived.

The number of times that a vehicle is processed on any link varies according to the following conditions:

1. Whether the vehicle will encounter a queue,
2. Whether the vehicle will be stopped by the control at the intersection,
3. The vehicle's turn movement,
4. Whether the vehicle will experience cycle failure as a result of congestion,
5. Whether intersection blockage prevails, and
6. Whether the control is actuated.

It appears that a vehicle will be processed once if it is unconstrained and encounters a go indication. If it is constrained (by control or by joining a queue), and if the control is fixed time and there is no intersection blockage, it will be processed twice. In the presence of intersection blockage or cycle failure, a vehicle may be processed three or more times. If the signal control is actuated and its indication is no-go, it is not possible for the software logic to predict when the go phase will become active. The program is then forced to revert to a time-scanning approach for the lead queued vehicle until the indication switches to go.

Car-Following Model

To ensure that the kinematic relation between the subject vehicle and its leader is realistic, a car-following relation used in the Integrated Traffic Simulation (INTRAS) model (5) is applied to cases 3, 6, and 9 in Figure 1.

The car-following relation applies only when the presence of the lead vehicle actually affects the trajectory of the subject vehicle. This depends on the separation of the two vehicles in time and space and on their respective speeds at the activation time of the subject vehicle.

Intersection Capacity

An analytical model of approach capacity that is applicable to all geometric and control configurations was developed as part of this project and is discussed in a paper by McShane and Lieberman and a paper by Lieberman elsewhere in this Record. This model provides relevant lane capacities (service rates), given the geometrics, control policy, conflicting flows, and lane-specific mix of through and turning traffic volume. It also finds the lane-specific deployment of traffic, stratified by turn movement, given the geometrics, traffic volume, control policy, and turn-movement-specific service rates.

Unlike some models that use a constant, reconstrained speed (2,3), the Level I model treats the acceleration and deceleration of all vehicle trajectories explicitly. In addition, the calculation of vehicle trajectories is based on the known distance L (of the time of vehicle movement) to the rear of a queue or to the stop line. This refinement affects the results obtained.

Input

In general, the inputs of the Level I model include geometric characteristics, traffic volumes, traffic control specifications, and driver and traffic

Figure 1. Flow chart of decision process used to obtain vehicle-processing cases.

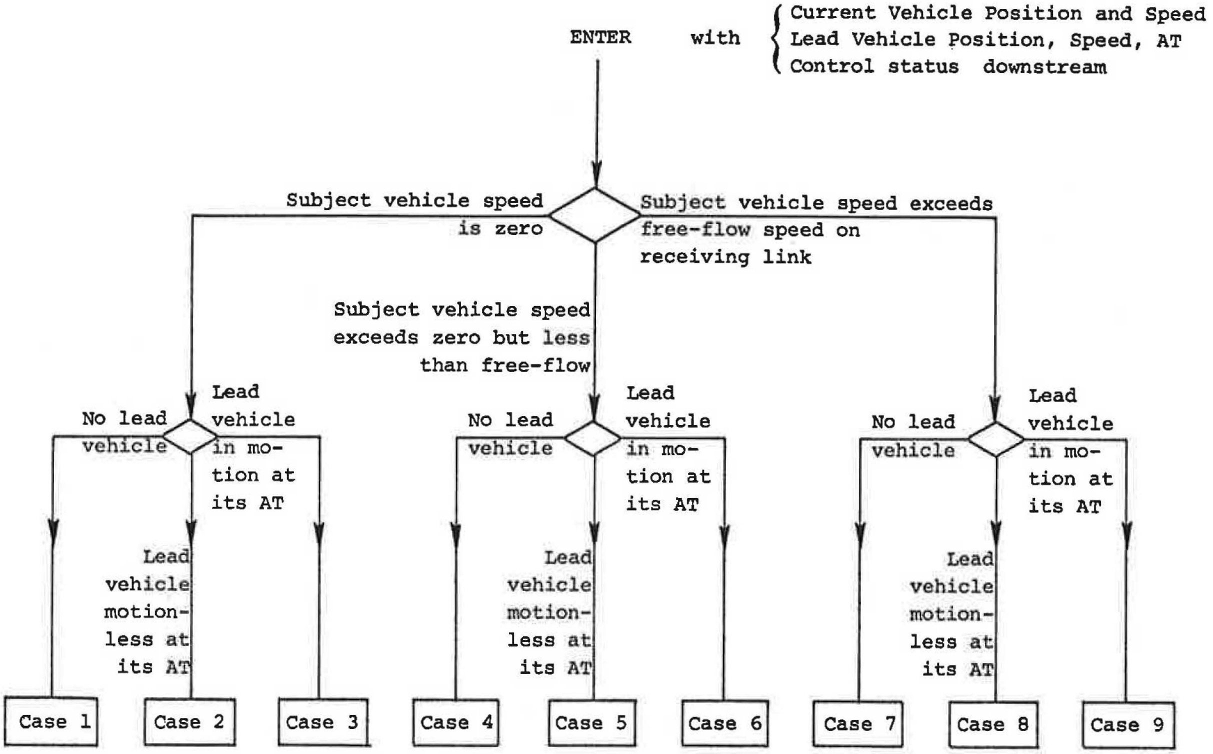

Table 1. Level I validation: networkwide comparison of measures of effectiveness.

		Measure							
		Travel Time (min)		Vehicle Miles		Total Delay (min)		Mean Speed (miles/h)	
Case	Run	Model	Field	Model	Field	Model	Field	Model	Field
Peak	1	11 015	10 505	1780	1701	6911	6479	9.69	9.71
	2	10 919	10 505	1776	1701	6822	6479	9.76	9.71
	3	11 024	10 505	1780	1701	6918	6479	9.69	9.71
Off-peak	4	8 522	8 841	1330	1286	5479	5814	9.36	8.73
	5	8 621	8 841	1335	1286	5564	5814	9.29	8.73
	6	8 349	8 841	1321	1286	5325	5814	9.50	8.73

operational characteristics. Considerable effort was made to design the input requirements so as to minimize data collection and preparation and the computer storage required to accommodate the data.

Output

A comprehensive set of traffic performance measures is generated periodically, either as cumulative output or as more detailed intermediate output, at the option of the user. The cumulative output is presented both in link-specific form and for the network as a whole. Intermediate outputs provide "snapshots" of system status and additional information for individual links. Separate statistics are provided for bus traffic along the lines of the NETSIM model output. Statistical estimates of fuel consumption and vehicle emissions for each vehicle type are also provided (6).

VALIDATION RESULTS

The Level I model was successfully validated by using a network in the central business district of Washington, D.C. This network exhibited many short links, significant bus traffic, turn pockets, and other features that rigorously tested the model.

Three model runs (replications) were executed on morning peak and off-peak traffic situations so that the influence of stochastic variations on the test results could be determined. Each simulation run was extended over a (simulated) time of 32 min, broken down into a sequence of eight 4-min time periods. Input data, such as traffic volumes and turning movements, varied for each time period.

Table 1 gives some networkwide comparisons of measures of effectiveness in the peak and off-peak cases for model results and results obtained in the field. The results show that the Level I model performs with a high degree of accuracy.

OPERATING EFFICIENCY

Computer running time is affected by the duration of the simulation, the number of vehicles, and the specification of user options. For the Level I model, the most meaningful operational statistic is the ratio of vehicle seconds of travel time to seconds of computer processing time. This ratio is 20 000:1 for the CDC 7600, which is approximately five times faster than the ratio for the NETSIM model (4).

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The development of a model such as that described in this paper represents the contributions of many people. In particular, we wish to extend our thanks to Guido Radelat and George Tiller of the Traffic Systems Division of the Federal Highway Administration; Barbara Andrews and Mark Yedlin of KLD Associates, Inc.; William McShane of the Polytechnic Institute of New York; and Fred Wagner of Wagner/McGee Associates. This work was performed under contract with the U.S. Department of Transportation.

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Service Rates of Mixed Traffic on the Far Left Lane of an Approach

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The effect of left-turning vehicles on approach capacity has been observed and studied, but a complete model has been lacking. As part of the development of the TRAFLO simulation model for the Federal Highway Administration, the capacity of a signalized intersection approach was modeled. The most complex component of this capacity model, that for left-turn lanes, is discussed. Three basic types of intervals for the vehicle discharge process are identified, and the probabilities of each are found. Expressions for expected vehicle discharge per cycle and for saturation flow rates per hour of green are reported. Reasonable results have been obtained.

The problem of a left-turn lane that serves both turning and through vehicles has been addressed in various ways, as has the problem of lanes that serve turners only (1-3). The 1965 Highway Capacity Manual (4) provides some empiric assessment of left-turn capacity without special phasing; other treatments include equivalencies for left turners facing opposing traffic (5). But none of the existing treatments provides the level of information and detail necessary for inclusion in the TRAFLO model currently being developed for the Federal Highway Administration (FHWA).

The TRAFLO model includes a determination of service rates on approaches to a signalized intersection. (It also includes appropriate treatments of unsignalized intersections, but these are not treated in this presentation.) The discharge service rates of vehicles on the individual lanes are strongly linked to the mechanism by which the through vehicles distribute themselves among the lanes in a self-optimizing fashion. Computationally, the service rates of the mixed traffic lanes (i.e., those that contain turning and through vehicles) are functions of the percentage of turning vehicles in the lanes. This interdependence of service rates and the lateral distribution of vehicles on an approach creates a feedback that can be addressed by the following iterative computations:

1. Assuming that all vehicles in the outermost lanes turn, the service rates of these lanes can be computed from appropriate models to begin the procedure.
2. Based on these service rates, the principle of drivers optimizing their individual travel time is applied in order to compute the implied percentage of turns in each lane that serves mixed (i.e., through and turning) traffic.
3. If the lane percentages differ from the assumed values, the initial computation is repeated but the latest lane percentage is used.

The overall procedure implied in these steps is discussed and justified in a paper by Lieberman elsewhere in this Record. It has been shown that convergence is obtained and that few iterations are required.

This paper is restricted to the model of the lane that contains through and left-turning vehicles, as required in the statement "computed from appropriate models" in step 1 above. The complexity of the process makes a closed-form solution infeasible, but the formulation obtained is both complete and tractable. It is certainly well suited to the original purpose--inclusion in the TRAFLO model--and could potentially be a component in a general procedure for estimating intersection capacity.