FREEVU: A Computerized Freeway Traffic Analysis Tool

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FREEVU (Freeway Evaluation with Visual Understanding) is a personal computer simulation model intended for freeway design and analysis. It allows the user to specify a freeway section, including lanes, grades, exits and entrances, posted speed limits, and detector locations. The section can then be viewed to confirm the proposed design. A variety of traffic situations can be specified, including percentage trucks, distribution of car and driver characteristics, and entrance and exit percentages. The user can simulate the traffic situation for various freeway design alternatives and then evaluate the design through two methods. First, the information from the specified detector locations can be used to evaluate average volumes, speeds, and densities over time. Second, an animation of the simulation results can be viewed to evaluate weaving sections, stability of traffic flow, impacts of trucks, and so forth. The model is a descendent of the simulation models INTRAS and FOMIS. As in these two models, vehicle movement is based on classic car-following theory and collision-avoidance restrictions. However, FREEVU also incorporates behavioral lane changing algorithms and vehicle performance constraints. FREEVU is user-friendly with extensive menus and default values. The simulation model has been evaluated using different sites and was generally found to represent simulation traffic flow accurately.

Freeway systems have typically been the major infrastructure element used to meet traffic demands in large urban centers. However these freeway systems are becoming more heavily congested for longer periods of the day. Engineers and designers require more-sophisticated tools to help them analyze and evaluate freeway segments and understand the dynamics of traffic flow on these segments.

The *1985 Highway Capacity Manual* (HCM) is widely used for design and analysis. However, because the HCM is based primarily on aggregated empirical results, it often lacks the ability to provide an understanding of the dynamic nature of the traffic flow.

Simulation models can be used to provide additional understanding. FREEVU was developed as a first attempt at providing engineers and designers with such a simulation tool.

The simulation model FREEVU is presented here. Four questions are presented and answered: What is FREEVU? What is the simulation logic basis? How can FREEVU be used? How well does FREEVU perform?

WHAT IS FREEVU?

FREEVU (pronounced "free view") is a stochastic, microscopic, freeway traffic simulation program, for use on a personal computer. It stands for Freeway Evaluation with Visual Understanding. It combines a user-friendly interface with a simulation core to produce an effective freeway traffic analysis tool.

Data inputs are minimal. Data entry is facilitated by a menu system and on-screen input forms. Error checking is carried out on data input. High-resolution graphics are used to display the freeway section as well as portray simulation results in the form of a movie, with individual vehicles depicted as they traverse the freeway section.

Model Capabilities

Specifically, FREEVU can model the following freeway components:

- Unidirectional, multilane freeway segments of two to eight lanes in width;
- Lane adds and drops;
- On-ramps—single lane from either the right or the left side of the freeway;
- Off-ramps—single and multiple lanes from either the left or the right side of the freeway;
- Posted speed limit or other speed restrictions; and
- Vertical alignment with the ability to specify unique grades for individual lanes or ramps.

FREEVU does not explicitly model all factors affecting traffic flow (i.e., lane width, horizontal curvature, passing sight distance, weather, road surface conditions, incidents, and rubber-necking); however, these factors tend to inhibit traffic speed, so many of these effects can be represented in the simulation by specifying a reduced speed limit for the affected lane and section. In this manner, speed can act as a surrogate means for simulating these other effects.

Because of computer hardware and software limitations, the restrictions presented in Table 1 have currently been selected for FREEVU.

History of Development

FREEVU's simulation core is a descendent of the INTRAS model (*1*). The INTRAS model itself is a stochastic, microscopic model created primarily for studying freeway incidents (*2*). Developed in 1975, the model was designed to represent traffic and traffic control elements in a freeway and surrounding surface street environment.

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TABLE 1 Current Restrictions Applicable to FREEVU

Item	Maximum Permitted
Section length	10 km
Traffic lanes	8
Entrances, including on ramps	20
Exits	20
Detector Locations	20
Geometric segments	15
Speed limit zones	20
Vertical alignment segments	20
Different vehicle types	100
Simultaneous vehicles	2500

INTRAS has been widely applied, with reported uses ranging from freeway reconstruction design evaluation (*3–5*), conflict analysis for weaving areas (*6*), energy conservation studies (*7*) and as a benchmark for validation of other models (*8,9*).

However, according to Van Aerde et al. (*10*), users of INTRAS have reported problems with some aspects of traffic behavior such as merging behavior and vehicle behavior at off-ramps (*11*).

In response to some of these criticisms and as an attempt to provide the unique capabilities of INTRAS in a more compact and structured form, FOMIS was developed (*11*). FOMIS restricts the simulation process to the freeway only, eliminates the link structure of INTRAS, and reduces vehicle processing to a single scan.

In the course of a study of the impact of large trucks on traffic flow, a microscopic simulation model was required. FOMIS was evaluated, in light of the study's requirements, and found to be lacking in the following three areas:

- The model was not simple to understand.
- The model was difficult to use.
- The model did not simulate many important components of the freeway system, including grades, trucks, driver's lane-changing decision-making process, speed limits, and truck restricted lanes.

FREEVU consists of four distinct program modules: traffic performance, freeway specification, data translation, and simulation (Figure 1). The first three modules are part of the integrated design shell; the fourth module is the simulator.

Integrated Design Shell

The user can directly interact with two modules in the design shell, freeway specification and traffic performance. The third interface module, which is invisible to the user, translates the data input by the user into the correct format required by the simulator.

The program's interface structure is constructed around the common menu. It is thought that this approach provides a simple, familiar, easy-to-understand appearance to the user with the minimum of complex program code. The structure consists of a menu tree; each menu presents the user with a number of possible alternatives.

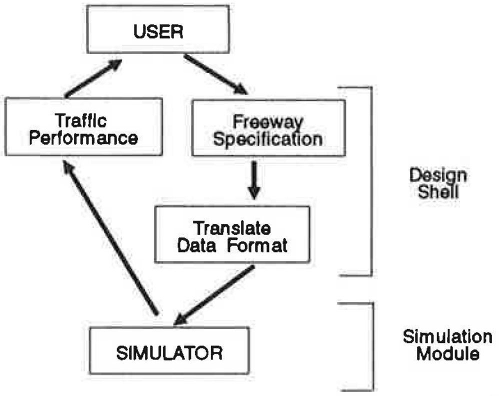

FIGURE 1 Modular structure of FREEVU.

Data input is highly structured and controlled by internal checking routines. The user is informed of the data required and only permitted to enter data of the specified type (i.e., integer or alphabetic) and within specific ranges dependent on previous input. Speed of input is facilitated by default values given when possible, allowing the user to simply accept the values and move on to the next input cell. Logical errors in the user's definition of the freeway section are checked. If found, the user is informed and given the opportunity to modify the data.

Simulation Module

The freeway segment is structured as a single continuous unit, with elements (i.e., vehicles or fixed objects) located by their distance from the upstream boundary and the lane number. Fixed objects are used to define the geometry and characteristics of the section, including lane adds and drops, on- and off-ramps, weaving sections, speed limits, grades, and detector locations.

Vehicles are processed in order of their location, regardless of lane, from downstream to upstream. A single pass is made for each time interval, during which each vehicle is processed.

WHAT IS THE SIMULATION LOGIC BASIS?

Within FREEVU, vehicle movements are governed by four controlling elements:

- Classic car-following theory,
- Collision-avoidance restrictions,
- Behavioral lane-changing algorithms, and
- Vehicle performance.

The first two elements are unchanged from INTRAS. However, the use of extensive algorithms to represent drivers' lane-change decision making is an innovation. A decision algorithm is hypothesized and subsequently tested using observed data, as is the variation in vehicle performance on grades.

Car Following

The car-following algorithms are essentially unchanged from FOMIS and INTRAS. A full derivation of the car-following algorithm is available in the literature (*1*).

The car-following model is built on the underlying assumption that drivers will attempt to maintain their spatial headway as a function of the driver's characteristics, the speed of the leading and following vehicle, and the length of the leading vehicle. A driver will modify his acceleration in order to maintain this desired spatial headway.

Collision Avoidance

In addition to the basic car-following relationship, an emergency constraint exists that overrides the basic car-following algorithm in order to prevent collisions. Again, this constraint is the same as that developed for INTRAS.

Behavioral Lane Changes

It was observed from data gathered from the Queen Elizabeth Way near Toronto, Ontario, and from general observance of freeway traffic that significant numbers of lane changes occur for reasons other than origin and destination requirements and that these lane changes are not random, as was previously assumed.

Both INTRAS and FOMIS represent these lane changes by simply specifying a constant probability that any vehicle will at any time make a lane change. It was believed that this did not adequately represent reality, and because no algorithms could be found in the literature, lane-changing algorithms were hypothesized, implemented into the model, and later tested using observed data. It now appears that similar algorithms were simultaneously developed for the FRESIM model (*12*).

On the basis of the assumption that many driver actions are governed by a driver's self-interest, it was hypothesized that there exist two types of behavioral lane changes:

- Passing to increase speed, and
- Yielding to following traffic.

Passing

Passing is predominately governed by a driver's self interest—that of maintaining or increasing speed. The process of a driver deciding to make a passing maneuver was divided into four phases.

- Driver becomes dissatisfied,
- Driver evaluates alternatives,
- Driver decides whether the improvement is significant enough to warrant the maneuver, and
- Driver attempts to change lanes.

Phase 1 To determine if a driver will attempt a lane change, it must first be established that the driver is unhappy with the present state. A driver is assumed to be dissatisfied with the present state if the vehicle is not accelerating and is traveling at a speed less than the desired speed. The assumption is that if the driver is not traveling at his or her desired speed and is not accelerating, then the driver is being impeded by some other downstream vehicle and may be able to improve the situation by making a lane change. Because a driver traveling slower than desired may be undergoing a small acceleration and still not be satisfied, a threshold acceleration value of 0.3 m/sec^2 (1 ft/sec^2) was chosen. Any driver accelerating at greater than this value is assumed to be satisfied with the current state and will not consider a passing maneuver.

Because it is not realistic for every dissatisfied driver to consider passing, some measure of the driver's dissatisfaction or frustration is required.

It was hypothesized that two factors affect a driver's frustration: the vehicle's acceleration potential and the difference between the driver's desired free speed and the vehicle's current speed. The frustration index (FI) reflecting the driver's dissatisfaction is the product of the two factors.

It was assumed that the probability that a driver is frustrated enough to consider passing, during any scanning interval, is directly proportional to FI. However, as each vehicle is scanned each second, a maximum probability of 40 percent was imposed to reflect the fact that drivers are not likely to make passing decisions every second (Equation 1).

$$P[\text{frustrated}] = \begin{cases} \text{FI} & \text{if FI} \leq 40 \\ 40 \text{ percent} & \text{otherwise} \end{cases} \qquad (1)$$

Phase 2 If the driver is frustrated enough to consider passing, a more favorable state must exist, or else no lane change is warranted. A more favorable state is one that gives the driver the longest period of unimpeded travel. This is measured by the time required for the driver to overtake the next downstream vehicle in the lane being considered. This time is a function of the speeds of the two vehicles, their respective positions, length, and accelerations. Because it is assumed that acceleration is constant over the time interval, simple equations of motion can be used to describe the vehicles' movements.

Phase 3 If the current state is found to be more favorable than the available alternatives, no lane change is made. However, if the perceived improvement of either adjacent lane is greater than that of the current state, a lane change may be attempted. It is assumed that there must be a significant advantage to making the lane change. A value of 13 sec was chosen as an initial threshold value.

Having evaluated the alternatives, the driver decides which one provides the greatest improvement. It is assumed that drivers tend to prefer passing on the left to passing on the right. Therefore, an improvement of five times is required for lane changes to the right over the left.

Having decided on a potential alternative, there is a probability that a driver will choose to change lanes. This probability is based on the amount of improvement over the current state the driver will receive. Equations 2 and 3 provide the relationship for passing to the left and right, respectively.

The parameter values in these equations have been assumed as initial estimates. Note that a maximum probability of 40 percent was again imposed.

$$P[\text{left}] = \min\begin{cases} 0.15(T_L - T - 13) \\ 40 \text{ percent} \end{cases} \tag{2}$$

$$P[\text{right}] = \min\begin{cases} 0.73(T_R - T - 13) \\ 40 \text{ percent} \end{cases} \tag{3}$$

where

T_L = left-lane unimpeded travel time,
T_R = right-lane unimpeded travel time, and
T = current-lane unimpeded travel time.

Phase 4 For a lane change to occur, it must be physically possible for the vehicle to complete the lane change (i.e., a sufficient gap must exist). This criterion is checked in the same manner as for all lane changes.

Yielding

Yielding maneuvers, changing lanes to the right to benefit the following vehicle, are governed more by courteousness to other drivers than by self-interest. Yielding maneuvers can occur in two situations: if a vehicle cannot maintain its speed on a grade and if the driver simply desires to travel more slowly than other vehicles. In either case, for a driver to consider yielding, the driver's vehicle must be impeding the following vehicle.

$$P[\text{yield}] = \min\begin{cases} 1.6[A_{\max}(S_c - S_d)] \\ 80 \text{ percent} \end{cases} \tag{4}$$

where

$A_{\max}$ = maximum possible acceleration,
S_c = current speed, and
S_d = desired speed.

For the second yielding situation, in which a vehicle desires to travel much slower than other vehicles, there is a 5 percent probability that it will yield during any simulation interval.

The vehicle considering a yielding maneuver will only attempt the maneuver if it will not be impeded by a downstream vehicle after the lane change is made.

These algorithms and probability functions were hypothesized and then implemented in the model. During model evaluation, a quantitative analysis of the hypotheses was made and found to be reasonable for the cases studied.

Vehicle Performance

The last element that controls vehicle movement is vehicle performance. Up to 100 vehicle types can be defined for use in FREEVU. In defining these types, the vehicle's horsepower, gross vehicle mass, and frontal area are required, because these characteristics dictate vehicle performance.

Each second, the maximum possible acceleration a vehicle can undergo is computed using the concept of tractive effort and tractive resistance. Tractive resistance is the sum of the grade, rolling, and drag resistances. Tractive effort is dependent on the vehicle's power and current speed. The equations and coefficients required for these computations are available in the literature (*13*). This process does not incorporate momentum effects.

The performance of most cars today is not significantly affected, except on very steep grades. However, heavy truck configurations regularly experience substantial degradation in performance on even moderate grades. It is primarily for the realistic modeling of trucks that vehicle performance has been addressed in FREEVU at this level of detail.

HOW CAN FREEVU BE USED?

FREEVU is intended to complement, not replace, existing methods of evaluation. FREEVU is intended to provide the engineer with qualitative and quantitative results regarding a proposed alternative. This alternative can take the form of a geometric improvement (i.e., a truck climbing lane), an expected increase in traffic demand, an anticipated change in traffic composition (i.e., more heavy trucks), or the implementation of a new policy (i.e., truck restricted lanes).

Input Data Requirements

The user is required to input data on section geometry, detector locations, vertical alignment, and posted speed limits for each freeway section.

Geometry

FREEVU represents freeway sections linearly, with all positional data taken as the distance, in meters, along the centerline from the upstream boundary. The upstream boundary is the upstream end of the simulated section at which vehicles are generated.

To illustrate, consider, in Figure 2, the freeway section to be modeled. Figure 2 also shows this section represented linearly as it appears on the computer screen. The user inputs the total length of the section to be modeled and the maximum

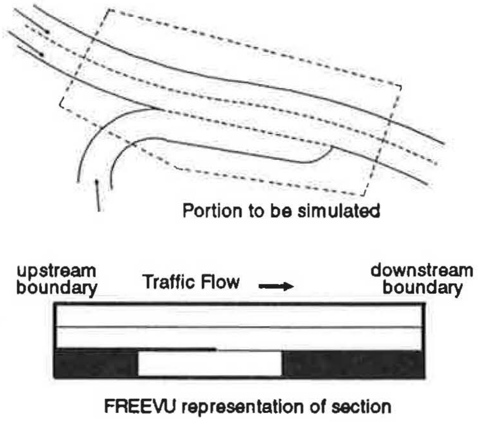

FIGURE 2 Freeway segment and portion to be modeled.

number of lanes. Having defined the area of the section, the lane type must be defined over each lane's total length. This is accomplished for each lane, by defining a number of segments of lane homogeneous in lane type. Both the upstream and downstream end of each segment must be specified. Each segment may contain only one lane type. Permissible lane types are presented in Table 2. For example, in Figure 2, the middle lane has three segments; a left lane, a center lane and a right lane. Permissible physical features are also given in Table 2.

Detectors

The detectors provided in FREEVU represent paired induction loop detectors. Defining a detector location places detector loops in all traffic lanes across the freeway section at that point.

Vertical Grades

In defining vertical grades, segments of the freeway having a consistent grade are defined. Each lane of the freeway may have a unique integer grade defined for each of the defined segments.

Speed Limits

The primary purpose for allowing the user to define speed limits is to enable the model to more realistically reflect the effects of reduced speeds of vehicles on ramp sections. However, speed limits can also be used to reflect other factors that affect speed but can not be explicitly modeled using FREEVU. For example, if a section of the freeway has very poor pavement surface conditions, it may be desirable to designate this area as having a posted speed limit of 90 km/hr to reflect the effect the poor surface has on speed.

Figure 3 shows how the different type of lane segments are independent of each other and are layered by FREEVU to define the characteristics of the freeway section.

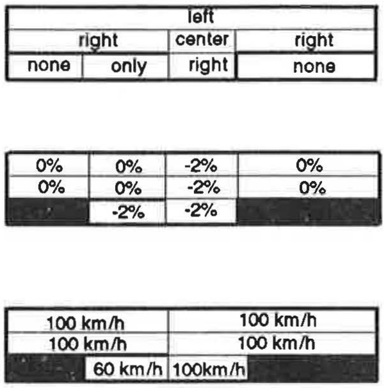

FIGURE 3 Segment types used to define a freeway section: *top*, geometric; *middle*, vertical alignment; *bottom*, speed limit.

Traffic Performance

Graphical Output

The on-screen output consists of a movie of the freeway that can be viewed. Detector information is displayed at the top of the screen. Average 30-sec volume, speed, or density is displayed for each lane at each detector location.

TABLE 2 Permissible Physical Features and Lane Types

Physical Features	Lane Types
Lane Drop	Center
Lane Add	Right
Off Ramp End	Left
On Ramp Start	Only
System Start	None
Lane Type Change	
Bull Nose	

This movie feature allows for instant visual feedback to the designer about the microscopic level of interaction occurring on the freeway. For example, at the development level, this feature was invaluable for debugging of the program, reducing the time required by an estimated 80 percent. During the movie animation, the user can pause the display, advance a single frame at a time, change the displayed detector information, and speed up or slow down the movie.

This display mode is extremely useful to gain an immediate understanding of how well the freeway is operating. This feature prompted the name FREEVU, Freeway Evaluation with Visual Understanding. Visually, one can immediately identify queues forming, platoons existing behind slow trucks, effects of lane changes, and the amount of disruption in the vicinity of merging areas.

Numerical Output

Currently four output files can be generated:

- Standard detector information—speed, volume, and density;
- Record of the number and type of lane changes that occurred during the simulation;
- Record of the number and type of maneuvers by vehicle class; and
- The average travel times, in seconds, for each origin-destination pair for cars and trucks; the standard deviation and number of vehicles observed is also given.

It is expected that as design experience with FREEVU is obtained, the output will be refined.

HOW WELL DOES FREEVU PERFORM?

Scope of Evaluation

In addition to validations conducted during development of FREEVU, the ancestor programs, INTRAS and FOMIS, have been validated and evaluated by a number of different users

(*1,3,11,14–16*). These validations of FREEVU's ancestors can be referred to as the first level of validation of the model. Care has been taken not to change parameters unless there was considerable evidence from two or more sites, to support new values.

Initial modifications were made to FOMIS to permit the modeling of trucks on grades. This enhanced FOMIS version was evaluated using data from the Queen Elizabeth Way (QEW) on the Burlington Skyway in Hamilton, Ontario. The model was found to perform reasonably well, but areas for improvement were identified. These improvements were made and can be considered to be second-level enhancements. They include the interface design shell and the behavioral lane-changing algorithms. This new model, FREEVU, was evaluated and validated using a data base obtained from FHWA and data from the QEW in Mississauga, Ontario. Conclusions and recommendations from this evaluation form the basis for recommended future third-level enhancements.

A more detailed reporting of these evaluation results can be found in the literature (*17*).

Validation Results

Data from the QEW eastbound between Highways 403 and 427 were obtained from the Ministry of Transportation of Ontario (MTO). A section of the QEW eastbound, corresponding to one of the loop detector stations, was videotaped during the morning peak period.

The FHWA data set (*18*) consists of digitized aerial photography taken at different sites across the United States. Each site had been filmed for approximately 1 hr. From the film, complete vehicle trajectories were produced, recording the vehicle's position for each time interval. Data from four sites describing different geometric configurations were selected (Table 3).

Mesoscopic—Lane-Changing Rates

Normalized nonmandatory lane-change rates were determined from the data for each of the five sections. Mandatory lane changes are those that have a ramp lane as either the origin or destination lane during a lane change.

Data had been assembled from five separate sites, four from the FHWA data, and the QEW section in Mississauga. Each site was simulated using FREEVU. Lane-change data were recorded. Normalized lane-change rates for nonmandatory lane changes were calculated and compared with those presented in Table 4.

TABLE 3 FHWA Sections Used for Validation

Site Number	Location	Section Type
2	I-95 S.B. at Backlick Road (Route 617), Fairfax County, Virginia	Ramp
3	I-395 S.B. (Shirley Highway) at Duke Street (Route 236), Alexandria, Virginia	Off-Ramp
4	I-405 N.B. at Mulholland Drive, Los Angeles, California	Tangent
5	I-405 S.B. at Santa Monica Blvd., Los Angeles, California	On-Ramp

Total simulation lane-change rates compared well with those observed; the discrepancies were within 14.3 percent, except for the QEW section and FHWA Site 3. FHWA Site 3 had a major interchange about 300 m downstream of the site. This interchange affected lane-changing maneuvers, but it was not known in what way. As such, it was difficult to determine the nonmandatory lane-change rate with accuracy.

For the QEW section, the distance over which lane changes were recorded was estimated to be 200 m, based on an observed queue of 20 cars at near-jam density. However, it is possible that this distance was underestimated and that the distance per vehicle was in the range of 15 to 17 m. This would result in the lane-change rate error of only −6.1 percent.

The lane-changing algorithms implemented in the model had been hypothesized. The required parameters had been selected intuitively and subjectively before any validation. From the results presented in Table 4, the hypothesis regarding drivers' lane-changing decision process is reasonable, and the parameters chosen, appropriate, given the available data.

Macroscopic—Section Flow and Speed

To more fully evaluate FREEVU, a macroscopic analysis of the FHWA data sets was conducted. From results presented in Table 5, FREEVU reproduces observed section flows within 13.7 percent of those observed. FREEVU produces weighted average section speeds that are within 16.5 percent of the observed weighted speeds.

Qualitative Evaluation

In addition to the model features evaluated previously, the distribution of total volume across lanes, merging behavior,

TABLE 4 Comparison of Simulated and Observed Nonmandatory Lane Changes Per Vehicle-km

Site number	Observed			Simulated			Error (%)
	Left	Right	Total	Left	Right	Total	
QEW	0.091	0.048	0.139	0.015	0.062	0.077	-44.6
2	0.217	0.135	0.352	0.285	0.091	0.376	6.8
3	0.082	0.140	0.222	0.195	0.254	0.449	102.3
4	0.186	0.234	0.420	0.307	0.173	0.480	14.3
5	0.386	0.098	0.484	0.416	0.094	0.510	5.4

TABLE 5 Comparison of Simulated and Observed Section Flows and Speeds

Site #	Number of Lanes	Average Section Flow (vph)			Average Section Speed (km/h)^a		
		Simulated	Observed	Error (%)	Simulated	Observed	Error (%)
2	3	4,581	5,115	10.4	60.3	57.4	-5.1
3	3	5,066	5,824	13.0	63.6	66.3	4.0
4	5	7,634	7,357	-4.5	65.8	78.8	16.5
5	4	5,884	6,820	13.7	50.6	56.4	9.7

[a] Speed is average lane speed weighted by volume

TABLE 6 Qualitative Evaluation of Simulation Features

Evaluation Feature	Validation Site				
		FHWA			
	QEW	2	3	4	5
Lane Distribution	P	F/P	F	F	F
Merging Behavior	F	F	n.a.	n.a.	F
Breakdown Process	G	G	n.a.	n.a.	G

G = Good; F = Fair; P = Poor; n.a. = Not Applicable

and the flow breakdown process were also evaluated. A qualitative assessment was made and is summarized in Table 6.

The validation exercises undertaken in this work have been primarily based on nonaverage traffic conditions. All of the FHWA sites were specifically chosen for their high levels of congestion and poor operating conditions. Thus, the evaluation of FREEVU was based on demanding situations, well beyond the scope of existing average methods of analysis.

Observations on Driver Behavior

During the course of the evaluation exercise, the observed data files were converted into a format such that they could be displayed graphically using FREEVU's interface. This permitted the unique opportunity to see visually what the numerical data files represented.

It appears that drivers have the ability to anticipate downstream traffic conditions and respond to observed downstream events. FREEVU determines each vehicle's actions on the basis of the next downstream vehicle in the current lane. This results in a traffic stream that behaves in a nature more reactive than anticipatory.

Driver behavior varies significantly between commuter and noncommuter traffic streams: commuter streams seem to be more aggressive and homogeneous in nature than noncommuter streams. At times, drivers appear to be insensitive to short separation distances and accept, at least temporarily, unsafe following distances.

CONCLUSIONS

FREEVU is a first attempt at a freeway analysis tool that goes beyond the capabilities of existing methods to meet designers' needs.

FREEVU is very designer-friendly and represents the mechanics and dynamics of traffic flow reasonably well. The ability of FREEVU to provide a view of the dynamic behavior of the traffic flow greatly improves understanding of traffic flow and the traditional measures of effectiveness.

The incorporation in a simulation program of extensive lane-changing decision algorithms based on drivers' self-interest is a unique innovation.

Evaluations of FREEVU's simulation capabilities at the mesoscopic level indicate that nonmandatory lane-change frequencies are within 15 percent of those observed for three of the five sites investigated. It is concluded that the hypothesized lane-changing algorithm can be accepted as realistically reflecting a driver's decision process. However, it is recognized that as further work is carried out, the parameters used in the lane-changing algorithms may require further calibration.

FREEVU simulated many traffic situations well; however, it had difficulties in realistically simulating the actions of merging and, to some extent, diverging vehicles under some moderate- to high-volume conditions. However, it was found that these situations also vary widely in reality.

The implementation of a driver's desired free speed based on the posted speed limit was useful. This permitted the control of overall speeds, particularly for ramp sections.

The aspects of FREEVU that appear to inadequately reflect reality—such as merging and diverging behavior, drivers' anticipation of downstream events, and vehicle's traveling at unsafe following distances—all require extensive, accurate microscopic data bases in order to understand each event fully.

A number of potential third-level enhancements can be identified:

- Enhance merging behavior at high volumes;
- Improve modeling of vehicles accessing off-ramps;
- Incorporate concepts of driver anticipation;
- Investigate how and if the distribution of driver sensitivity to desired distance headway changes over time; and
- Determine if effects of momentum should be modeled.

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