FREEVU
A COMPUTERIZED FREEWAY TRAFFIC ANALYSIS TOOL

B.R. Hellinga
Department of Civil Engineering,
Queen's University
Kingston, Ontario, Canada
Phone: (613) 545-2139
Fax: (613) 545-2128

J.H. Shortreed
Department of Civil Engineering,
University of Waterloo
Waterloo, Ontario, Canada
Phone: (519) 885-1211 X3377
Fax: (519) 888-6197

NOTE: No Tables or Figures are included with this version. Please see the published paper in Transportation Research Record 1360 for the tables and figures.

ABSTRACT

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 percent 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. Firstly the information from the specified detector locations can be used to evaluate average volumes, speeds, and densities over time. Secondly, 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, in addition, 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 a number of different sites and generally found to accurately represent simulation traffic flow. However, weaknesses of the model are identified, along with specific situations for which the simulation model was not able to accurately reflect reality. A number of statements are made regarding observed driver behaviour patterns. Recommendations are made for further simulation and design enhancements.

1. INTRODUCTION

Freeway systems have typically been the major infrastructure element used to meet traffic demands in large urban centres. However, increasingly, these freeway systems are becoming more heavily congested for longer periods of the day.

Opportunities to build more and larger freeways to alleviate congestion are diminishing as available land is scarce, and construction costs soar. As a result, the job of the traffic engineer, responsible for managing the freeway, and the designer, responsible for reconstruction design, is becoming increasingly more difficult. Too little un-used capacity remains for rule-of-thumb approaches to be acceptable. Intuition is no longer enough for design and management decisions.

Engineers and designers require more sophisticated tools to help them analyze and evaluate freeway segments, and to understand the dynamics of traffic flow on these segments.

The 1985 Highway Capacity Manual (HCM) is widely used for design and analysis. However, as 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.

This paper presents the simulation model FREEVU. Four questions are presented and answered; "What is FREEVU?", "What is the simulation logic basis?", "How can one use FREEVU?", and "How well does FREEVU perform?".

2. WHAT IS FREEVU?

FREEVU (pronounced free view) is a stochastic, microscopic, freeway traffic simulation program, for use on a personal computer. 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.

2.1 Model Capabilities

Specifically, FREEVU is able to model the following freeway components:

- unidirectional, multilane freeway segments of 2 to 8 lanes in width.
- lane adds and drops.
- on ramps -- single lane from either the right or left side of the freeway.
- off ramps -- single and multiple lanes from either the left or right side of the freeway.
- posted speed limit or other speed restrictions.
- vertical alignment with the ability to uniquely specify 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, "rubber necking"), however, as these factors tend to inhibit traffic speed, 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.

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

2.2 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.

INTRAS has been widely applied, with reported uses ranging from freeway reconstruction design evaluation [3,4,5], conflict analysis for weaving areas [6], energy conservation studies [7] and as a bench mark 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 behaviour [11], such as merging behaviour and vehicle behaviour at off ramps.

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 the model 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. This revised structure can be implemented on personal computing systems with reasonable execution times.

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, having little documentation, was not simple to understand.
- The model, having no interface, was difficult for the user to use. An intimate knowledge of the model's structure and assumptions was necessary to ensure proper usage. Data files needed to be constructed by the user and no error checking of the data format or values occurred.
- 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.

Based on this evaluation, it was felt that though FOMIS was not adequate in its present form, it could be used to form the core of an effective evaluation tool. The model was obtained and extensively modified, the product being FREEVU. Attention was focused on improving the ease with which the model could be applied by a non- computer expert, and in ensuring that important items of freeway traffic behaviour were reflected by the model.

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, while the fourth module is the simulator.

2.3 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.

Much effort was invested into the design and structuring of the design shell. Without a clear and easy to understand interface, the design tool would not be useful, regardless of the quality of the simulation core.

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, with each menu presenting the user with a number of possible alternatives.

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, 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, and if found, the user is informed and given the opportunity to modify the data.

2.4 Simulation Module

This module carries out the microscopic simulation of individual vehicles over the user defined freeway section.

Within this 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.

3. 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.
- 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.

3.1 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.

3.2 Collision Avoidance

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

The constraint ensures that the following vehicle can maintain a safe headway if the leading vehicle decelerates at some maximum emergency deceleration.

3.3 Behavioral Lane Changes

It was observed from data gathered from the Queen Elizabeth Way near Toronto, Ontario, and general observance of freeway traffic, that significant numbers of lane changes occur for reasons other than origin/destination requirements and that these lane changes are not random as 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 felt that this did not adequately represent reality, and since no existing 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].

Based on 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.
- Yielding to following traffic.

3.3.1 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 manoeuvre was divided into four phases:

- The driver becoming dissatisfied.
- The driver evaluating alternatives.
- The driver deciding whether the improvement is significant enough to warrant the manoeuvre.
- The actual attempt to change lanes.

Phase 1: To determine if a driver will attempt to 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 currently not accelerating and is travelling at a speed which is less than the desired speed. The assumption is that if the driver is not travelling at her desired speed and is not accelerating, then she is being impeded by some other downstream vehicle, and may be able to improve her situation by making a lane change. Since a driver travelling slower than desired may be undergoing a small acceleration and still not be satisfied, a threshold acceleration value of 0.3 m/s^2 (1 $ft./s^2$) was chosen.

Any driver accelerating at greater than this value is assumed to be satisfied with their current state and will not consider a passing manoeuvre.

Since 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 2 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% was imposed to reflect the fact that drivers are not likely to make passing decisions every second (Equation 1).

$$P[Frustrated] = \begin{cases} Fl & if\ Fl \le 40 \\ 40\% & otherwise \end{cases}$$ **Error! Switch argument not specified.** [1]

Phase 2: If the driver is deemed frustrated enough to consider passing, a more favourable state must exist, else no lane change is warranted. A more favourable state is one which provides the driver with the longest time 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. Since 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 favourable than available alternatives, then 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 seconds was chosen as an initial threshold value.

Having evaluated the alternatives, the driver decides which alternative provides the greatest improvement. It is assumed that there exists among drivers a tendency to prefer passing on the left, rather than on the right. Therefore, a five times greater improvement is required for lane changes to the right than to the left.

Having decided on a potential alternative, there is a probability that a driver will actually choose to make the lane change. This probability is based on the amount of improvement over the current state the driver will receive. Equation 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% was again imposed.

$$P[left] = \min\begin{cases} 0.15(T_L - T - 13) \\ 40\% \end{cases}$$ **Error! Switch argument not specified.** [2]

$$P[right] = \min\begin{cases} 0.73(T_R - T - 13) \\ 40\% \end{cases}$$ **Error! Switch argument not specified.** [3]

where;

T_L = left lane unimpeded travel time
T_R = right lane unimpeded travel time

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 criteria is checked in the same manner as for all lane changes.

3.3.2 Yielding

Yielding manoeuvres, changing lanes to the right to benefit the following vehicle, are governed more by courteousness to other drivers than by self-interest. Yielding manoeuvres can occur in two situations; if a vehicle can not maintain its speed on a grade or if the vehicle simply desires to travel more slowly than other vehicles. In either case, for a vehicle to consider a yielding manoeuvre, it must be impeding the following vehicle.

For a vehicle unable to maintain its speed, the probability function for yielding is similar to the frustration index, in that it is composed of the product of the maximum attainable acceleration and the difference between desired free speed and the current speed (Equation 4). The probability of yielding is limited to a maximum of 80%.

$$P[yield] = \min \begin{cases} 1.6\left(A_{\max}\left(S_c - S_d\right)\right) \\ 80\% \end{cases} \quad [4]$$

Error! Switch argument not specified.

where;

A_{max} = maximum possible acceleration
S_c = current speed
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% probability that it will yield during any simulation interval.

The vehicle considering a yielding manoeuvre will only attempt the manoeuvre 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.

3.4 Vehicle Performance

The last element which controls vehicle movement is vehicle performance. Up to 100 different vehicle types can be defined for use in FREEVU. In defining these vehicle types, the vehicle's horsepower, gross vehicle mass, and frontal area are required, as 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 modelling of trucks, that vehicle performance has been addressed in FREEVU at this level of detail.

4. HOW CAN ONE USE FREEVU?

FREEVU is intended to compliment, 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 on 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).

Given an alternative, the engineer can interactively evaluate this alternative using FREEVU as part of the planning and evaluation process.

4.1 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. The user is prompted to provide the required data in the order as discussed below.

4.1.1 Geometry

FREEVU represents freeway sections linearly, with all positional data taken as the distance, in metres, along the centre line from the upstream boundary. The upstream boundary is the upstream end of the simulated section where vehicles are generated. No data is required concerning horizontal alignment since horizontal curvature is not explicitly modeled.

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 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 only contain one lane type. Permissible lane types are given in Table 2. For example, in Figure 2, the middle lane has three segments; a *right* lane, a *centre* lane and a *right* lane.

For each lane segment, the physical geometric feature marking the upstream boundary must be specified. Permissible physical features are also given in Table 2.

4.1.2 Detectors

The detectors provided in FREEVU represent paired induction loop detectors. They can be placed at any location along the freeway section being modeled. Defining a detector location places detector loops in all traffic lanes across the freeway section at that point.

4.1.3 Vertical Grades

In defining vertical grades, segments of the freeway having a consistent grade, are defined. Defined grade segments are not lane specific, but apply to all lanes. However, each lane of the freeway may have a unique integer grade defined for each of the defined segments. Permissible grades range from -10% to +10%.

4.1.4 Speed Limits

The entry of speed limits proceeds exactly as for the definition of grades. In this case, segments are portions of the freeway having the same posted speed limit. Permissible speed limits range from 40 km/h to 120 km/h.

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 which affect speed but can not be explicitly modeled using FREEVU. For example, if a section of the freeway has very poor pavement surface conditions, one may wish to designate this area as having a posted speed limit of 90 km/h to reflect the effect the poor surface has on speed. Other applications for this artificial posted speed include narrow lane widths, horizontal curves, and areas of poor visibility.

Figure 3 illustrates 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.

4.2 Traffic Performance

FREEVU provides the user with two types of output - graphical on-screen output and formatted output written to the disk.

4.2.1 Graphical Output

The on-screen output consists of a movie of the freeway which can be viewed. The freeway section is depicted in plan view and the individual vehicles in the stream are represented as scaled rectangles as they travel down the freeway. Detector information is displayed at the top of the screen. Average 30 second volume, speed or density is displayed for each lane at each detector location.

This "movie" feature allows for instant visual feed back 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%. 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. All of this is apparent from the ability to view the vehicles. In addition, standard detector output provides the usual quantitative data to the user.

4.2.2 Numerical output

Complimenting the visual output provided by the animation feature, hard output is also produced by FREEVU. Currently four output files can be generated, each providing different information on the performance of the freeway section and quality of traffic flow.

- Standard detector information - speed, volume and density aggregated over a user specified time period.

- Record of the number and type of lane changes that occurred during the simulation. The user can choose to produce a summary of the lane changes, or the complete record of each lane change that occurred.
- Record of the number and type of manoeuvres by vehicle class, made during the simulation.
- 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.

The output files presented here have been created to satisfy needs arising during model development and evaluation, however, with minor alterations and additions to the program code, almost any type of output can be created. It is expected that as design experience with FREEVU is obtained, the output will be refined.

5. HOW WELL DOES FREEVU PERFORM?

5.1 Scope of Evaluation

In order to determine how well FREEVU represents reality, a number of validation and evaluation exercises were carried out. In addition to validations conducted during development of FREEVU, the ancestor programs, INTRAS and FOMIS, have been validated and/or evaluated by a number of different users [1,14,15,3,11,16]. 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 modelling 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 a number of areas for improvement were identified. These improvements were made and can be considered to be second level enhancements. Included in these enhancements was the interface design shell and the behavioral lane changing algorithms. This new model, FREEVU, was evaluated and validated using a data base obtained from the Federal Highway Administration (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].

5.2 Validation Results

The purpose of the second evaluation was to:

- Calibrate and validate at a mesoscopic level the alterations made to the model - particularly the lane changing algorithms.
- Reinforce the previous validation's conclusions that the model simulates freeway traffic reasonably well at the macroscopic level.
- Ensure that a variety of data was used for validation to avoid any site specific inherent characteristics which would unduly bias the validation.

Data from the QEW eastbound between Highways 403 and 427 were obtained from the Ministry of Transportation of Ontario (MTO). To allow for visual validation of this detector data and provide lane change frequency data, a section of the QEW eastbound, corresponding to one of the loop detector stations, was video taped during the morning peak period.

The FHWA data set [18] consists of digitized aerial photography, taken at different sites across the U.S. Each site had been filmed for approximately 1 hour. From the film, complete vehicle trajectories were produced, recording the vehicle's position for each time interval. Data from 4 sites, describing different geometric configurations were selected (Table 3).

5.2.1 Mesoscopic - Lane Changing Rates

Normalized non-mandatory lane change rates were determined from the data for each of the five sections. Mandatory lane changes are those which have a ramp lane as either the origin or destination lane during a lane change. In other words, mandatory lane changes are those that the driver must make in order to achieve his destination. Non-mandatory lane changes are simply those lane changes which are not mandatory changes. Rates were normalized by dividing the number of lane changes observed, by the length of the section over which observation took place, and the total number of vehicles observed over this section.

Data had been assembled from five separate sites; four from the FHWA data, plus the QEW section in Mississauga. Each site was simulated using FREEVU. Lane change data was recorded. Normalized lane change rates for non-mandatory lane changes were calculated and compared to those observed (Table 4).

Total simulation lane change rates compared well with those observed, with the discrepancies within 14.3%, except for the QEW section and FHWA site #3. FHWA site #3 had a major interchange located approximately 300 metres downstream of the site. This interchange affected lane changing manoeuvres, but it was not known in what way. As such, it was difficult to determine the non-mandatory lane change rate with accuracy.

For the QEW section, the distance over which lane changes were recorded was estimated to be 200 metres, 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 - 17 metres. This would result in the lane change rate error of being only -6.1%.

Given the presence of these uncertainties in the data from these two sites, the large lane change rate errors have little meaning. As a result, based on data from the remaining three sites, it can be concluded that the model does reflect reality well, in terms of non-mandatory lane change rates.

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

5.2.2 Macroscopic - Section Flow and Speed

To more fully evaluate FREEVU, a macroscopic analysis of the FHWA data sets was conducted. Similar traffic characteristics and flow patterns between the simulation and reality were necessary. At the macroscopic level, average section flows and speeds from the simulation were compared to the observed data.

Based on results shown in Table 5, FREEVU reproduces observed section flows within 13.7% of that observed. Section flow is defined as the total flow across all lanes as measured by loop detectors. For these same four sites, FREEVU produces weighted average section speeds that are within 16.5% of the observed weighted speeds.

5.2.3 Qualitative Evaluation

In addition to the model features evaluated previously, an evaluation was made of the following selected model features; distribution of total volume across lanes, merging behaviour, and the flow breakdown process. Since it is difficult to quantitatively evaluate these features, a qualitative assessment was made and is summarized in Table 6.

The distribution of vehicles across lanes was not well represented by FREEVU. Similarly, merging behaviour was also not well represented by FREEVU. However, it should be noted that each of these sites had very high demands in terms of both the mainline and merging flows. For low demand situations, FREEVU appears to behave more reasonably, however, this has not been tested with observed data.

For the three sites for which breakdown occurred, FREEVU was able to replicate the process well. However, the breakdown process tended to occur at somewhat lower volumes in the simulation than observed.

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

5.3 Observations on Driver Behaviour

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 visually see what the numerical data files represented. In doing so, a number of observations about driver behaviour were made which help to explain why FREEVU was unable to adequately reflect the observed data under certain conditions.

It seems that drivers have the ability to anticipate downstream traffic conditions and respond to observed downstream events. FREEVU determines each vehicle's actions based on the next downstream vehicle in the current lane. This results in a traffic stream behaving in a more reactive nature than anticipatory. This lack of anticipation in the model also explains the discrepancies in volume distributions across lanes in the vicinity of ramp areas.

Driver behaviour varies significantly between commuter and non - commuter traffic streams. Commuter streams seem to be more aggressive and homogeneous in nature than non-commuter streams. At times drivers appear to be rather insensitive to short separation distances, and accept, at least temporarily, unsafe following distances. FREEVU, based on collision avoidance algorithms, does not permit vehicles to follow at unsafe distances, except while in the process of making a lane change. Due to this, FREEVU is unable to achieve very high flow rates (i.e. in excess of 2000 vphpl), as was seen in a few instances in the observed data.

6. 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 behaviour of the traffic flow greatly improves understanding of traffic flow and the traditional measures of effectiveness.

Incorporating, in a simulation program, 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 non-mandatory lane change frequencies are within 15% 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 drivers' 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 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 which seem to inadequately reflect reality, such as merging and diverging behaviour, drivers' anticipation of downstream events, and vehicle's travelling at unsafe following distances, all require rather extensive, accurate microscopic data bases in order to fully understand each event. The FHWA data used in this study would partially fulfil this need, however, this data only reflects areas of high congestion due to restrictive geometry. Some other sources would be required to investigate these phenomena in detail, in order to observe them under a wide range of flow rates.

Based on the observations made and conclusions drawn, a number of potential, third level enhancements can be identified;

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

ACKNOWLEDGMENTS

This work was carried out under contract with the Ministry of Transportation of Ontario. The authors would like to thank Alex Ugge of the Research and Development Branch and Rye Case of the Transportation and Energy Branch for their contributions.

REFERENCES

1. Wicks, D.A., and Lieberman, E.B. *Development and Testing of Intras, a Microscopic Freeway Simulation Model*. Volumes 1-4. FHWA, Washington D. C. October 1980 Final Report.

2. May, A.D. "Models for Freeway Corridor Analysis", *The Application of Traffic Simulation - Special Report 194*. Transportation Research Board, Committee on Sociotechnical Systems, Washington, D.C., 1981.
3. Skabardonis, A.M., May, A.D. and Cohen, S. *The Application of Simulation to Evaluate the Operation of Major Freeway Weaving Sections.* Presented at the Transportation Research Board's 68th Annual Meeting, Washington, D.C., January 1989.
4. Cohen, Stephen L. "Application of Traffic Simulation to Analysis of Freeway Reconstruction Alternatives - A Case Study", *Management and Control of Urban Traffic Systems*. Proceedings of the Engineering Foundation Conference. New England College, Henniker, New Hampshire. Editor Sam Yagar. June, 1987.
5. Cohen, S.L. and Clark, J. "Analysis of Freeway Reconstruction Alternatives Using Traffic Simulation." *Transportation Research Record 1132*. Transportation Research Board. Washington, D.C. 1987.
6. Fazio, J. and Rouphail, N.M. *Conflict Simulation in INTRAS Application to Weaving area Capacity Analysis*. Presented at the Transportation Research Board's 69th Annual Meeting, Washington, D.C., January 1990.
7. Torres, J.F. *Freeway Control and Management for Energy Conservation - Final Report*. JFT Associates, Los Angeles, Calif., Jan. 1982.
8. Rathi, Ajay K. and Nemeth, Zoltan J. "FREESIM: A Microscopic Simulation Model of Freeway Lane Closures", *Transportation Research Record 1091*. Transportation Research Board, Washington, D.C., 1986.
9. Michalopoulos, P.G. and Lin, J. "Integrated Modelling of Freeway Flow and Application to Microcomputers", *Transportation Research Record 1091*. Transportation Research Board, Washington, D.C., 1986.
10. Van Aerde, M., Yagar, S., Ugge, A. and Case, E.R. "A Review of Candidate Freeway-Arterial Corridor Traffic Models", *Transportation Research Record 1132*. Transportation Research Board, Washington, D.C., 1987.
11. Bullen, A.G.R. "Development of Compact Microsimulation for Analyzing Freeway Operations and Design." *Transportation Research Record 841*, Transportation Research Board, Washington D.C., 1982.
12. Halati, A., Torres, J.F., and Mikhalkin, B. *Freeway Simulation Model Enhancement and Integration - FRESIM Technical Report*. Federal Highway Administration. February, 1990.
13. Homburger, W.S., Keefer, L.E., and McGrath, W.R. *Transportation and Traffic Engineering Handbook, Second Edition*. Institute for Transportation Engineers. Prentice-Hall Inc., Englewood Cliffs, New Jersey 07632. 1982. pp. 162-169.
14. Waurick, Pamela. *Evaluation of the Intras Microscopic Freeway Simulation Model Using P.M. Peak Congestions on Q.E.W. Westbound at Hwy 427*. Internal Report. Traffic Systems Research, Research and Development Branch, Ministry of Transportation and Communications. Downsview, Ontario. Sept. 1985.

15. Goldblatt, R.B. *Development and Testing of Intras, A Microscopic Freeway Simulation Model, Vol. 3 Validation and Application*. Federal Highway Administration, Report FHWA/RD - 80 / 108, Washington, D.C., 1980.

16. Bullen, A.G.R. and Cohen, S.L. "Car Following and Lane Changing Laws in INTRAS Model." *National Meeting of the Institute of Management Science and Operation Research Board*, Washington D.C., 1980.

17. Hellinga, B. and Shortreed, J. *FREEVU- A Computerized Freeway Traffic Analysis Tool.* Research and Development Branch, Report TDS-91-01, Ontario Ministry of Transportation, January, 1991.

18. Smith, Steven A. *Freeway Data Collection for Studying Vehicle Interactions - Technical Report.* U.S. Department of Transportation, Federal Highway Administration, Report FHWA/RD - 85 / 108, Washington D.C., May 1985.