REFERENCES

1. T.F. Larwin and H. Rosenberg. Traffic Planning for Light Rail Transit. Institute of Transportation Engineers, Washington, D.C., 1978.
2. De Leuw, Cather and Company. Southeast Corridor Preliminary Engineering: Traffic Control. Draft. Denver Regional Transportation District, Denver, Colo., Aug. 1982.

Publication of this paper sponsored by Committee on Traffic Flow Theory and Characteristics.

Evaluation of Queue Dissipation Simulation Models for Analysis of Presence-Mode Full-Actuated Signal Control

FENG-BOR LIN

ABSTRACT

Full-actuated signal control may rely on long inductive loop detectors for detecting the presence of vehicles. The operation of this mode of control is governed primarily by the interactions between the detectors and queueing vehicles. To facilitate reliable simulation analyses of such a signal control, the queue dissipation characteristics in relation to the detectors should be properly modeled. The queue dissipation models used in the NETSIM program and the Value Iteration Process--Actuated Signals program are evaluated. These models are found to be capable of producing realistic departures of queueing vehicles from a detection area. The models are rather weak, however, in representing other aspects of vehicle-detector interactions. Possible modifications of the models are discussed.

Queue dissipation is a troublesome phenomenon that has to be dealt with in the simulation of traffic flows at a signalized intersection. Proper modeling of this phenomenon is imperative if a model is to be used for simulation analysis of presence-mode full-actuated signal control. The reason for this can be found in the logic of this mode of control.

The basic logic of presence-mode full-actuated control is rather simple. A vehicle can demand or hold the green light by occupying a detection area. The detection area is usually defined by a long inductive loop detector. After the vehicle leaves the detection area, the green is extended by a duration equal to a preset vehicle interval. To continue holding the green, another vehicle must enter one of the detection areas of the same signal phase before the vehicle interval expires. The phase duration is limited by a preset maximum green interval. The timing of this interval begins with the actuation of a detector by a vehicle in an opposing phase.

Because the vehicle interval is usually set at a value close to 0 sec, the queueing vehicles in a lane have a much better chance of holding the green than do those not in the queue. Consequently, the phase durations of this mode of control are governed by the queue dissipation characteristics in relation to the detectors. In a dissipating queue, vehicles enter and depart from a detection area in a dynamic and probabilistic manner. This results in a sequence of detector actuations and departures that determines whether the queueing vehicles can extend the green continuously. If such relationships are not properly modeled, the simulated operation of the signal control will deviate from reality.

The dynamic and probabilistic nature of the interactions between the queueing vehicles and the detectors is rather difficult to simulate adequately. To compound the problem, past efforts at modeling queue dissipation were focused on queue discharge headways (1). Not until recently have efforts been made to investigate the nature of the queue dissipation in relation to presence detectors (2). The lack of a comprehensive treatment of this subject is unsettling. It raises the issue of whether the queue dissipation models used in existing signal simulation programs are realistic.

The purpose of this paper is to explore this issue by evaluating two existing queue dissipation simulation models. These models are part of the microscopic simulation models used, respectively, in the Value Iteration Process--Actuated Signals program (3) and the NETSIM program (4). The evaluation entails a comparison of simulated queue dissipation characteristics with those observed in the field.

The field data used for the comparison are extracted from data collected as part of a project sponsored by the U.S. Department of Transportation (5). The original data include observations made on queueing flows of various directional movements. These flows were not interfered with by pedestrians and parking maneuvers, nor were they impeded by downstream flows. The approach speeds of the observed vehicles were less than 35 mph. Without sacrificing the generality of the comparison, only straight-through flows are dealt with in this paper. Furthermore, because the field observations include a negligible number of trucks and buses, all vehicles are considered to be passenger cars.

QUEUE DISSIPATION SIMULATION MODELS

Pitt Car-Following Model

The Value Iteration Process--Actuated Signal (VIPAS) computer program uses the Pitt car-following model (6) for simulating queue dissipation. The model was originally developed for freeway simulation. It contains a basic equation and several constraints. The basic equation is

$$a = 2[x^* - y - L - 10 - v(k + T) - bk(u^* - v)^2]/(T^2 + 2kT) \quad (1)$$

where

- a = acceleration of follower in the interval $(t, t + T)$,
- k = car-following parameter (driver sensitivity),
- L = length of the leading vehicle,
- T = time scanning interval,
- y = position of follower at time t,
- v = speed of follower at time t,
- x^* = position of leader at time $t + T$,
- u^* = speed of leader at time $t + T$, and
- b = constant.

The units in this equation are feet and seconds.

The Pitt car-following model is based on the premise that a following vehicle will attempt to maintain a space headway of $L + kv + 10$ ft. To prevent collision between two vehicles in a car-following maneuver, several constraints are incorporated into the model to override the acceleration rate as determined from the basic equation. These constraints ensure that a following vehicle can stop safely behind its leader under two conditions: the leader decelerates to a stop at a specified maximum emergency deceleration rate, and the follower starting at a driver reaction or lag time (c) later decelerates to a stop behind the leader at a deceleration rate within the maximum emergency deceleration limit. Mathematical relationships are used to impose these constraints on car-following behavior.

The model described has been modified in the VIPAS program for simulating car-following maneuvers. One modification involves the replacement of the constant 10 in Equation 1 with

$$A = \begin{cases} 7 + (3v/20) & \text{if } v \leq 20 \quad (2a) \\ 10 & \text{if } v > 20 \quad (2b) \end{cases}$$

Another modification deals with the driver sensitivity parameter (k). The value of k as used in the original model approximates (3)

$$k = (2{,}718 - Q_S)/687.5 \quad (3)$$

where Q_S is the saturation flow rate applicable to the flow in a given lane. The value of k is adjusted in the VIPAS program to

$$k = 3.539 - 0.0012985\, Q_S \quad (4)$$

To account for differences in car-following behavior among individual drivers, a multiplication factor is also used in the VIPAS program. This factor is generated randomly according to a specified probability distribution. In this distribution the multiplication factor is divided into the following seven levels: 1.7, 1.2, 1.1, 1.0, 0.9, 0.7, and 0.5. The probabilities associated with these levels are, respectively, 0.1, 0.2, 0.1, 0.2, 0.1, 0.2, and 0.1. A generated value of this factor is applied to the saturation flow rate to obtain a k value for a driver.

For queue dissipation, the VIPAS program uses b = 0 in Equation 1. The scanning interval is 1 sec. Furthermore, the acceleration rate is limited to 7 ft/sec² for passenger vehicles moving at speeds of not more than 16 ft/sec and to 5 ft/sec² when the speeds exceed 20 ft/sec. The maximum emergency deceleration rate is assumed to be 10 ft/sec².

After an acceptable acceleration rate is calculated from the model, the speed and position of a following vehicle at time t + T (i.e., the end of the scanning interval) are computed as

$$v^* = v + a\,(T - c) \quad (5)$$

and

$$y^* = y + vT + [a(T - c)^2]/2 \quad (6)$$

where

- v^* = speed of follower at time $t + T$,
- y^* = position of follower at time $t + T$, and
- c = driver reaction time ($c < T$).

The driver reaction time (c) has a calibrated value of 0.2 for deceleration and 0.3 for acceleration.

NETSIM Model

The queue dissipation model used in the NETSIM program is essentially a heuristic algorithm consisting of a number of decision rules. These rules are contained in the MOVE, ADJQ, GOQ, and other related subroutines of the program. They determine the speed, acceleration, and position of a vehicle in each scanning interval of 1 sec. The model is not as straightforward as the Pitt car-following model. The flow chart shown in Figure 1 gives an insight into the heuristic nature of the model. The flow chart omits those vehicle-processing functions of the model that are beyond the scope of this paper.

In processing the dissipating queueing vehicles in a given scanning interval, the leading vehicle of a queue upstream of an intersection is identified first. If this vehicle is also the leading vehicle when the signal is red, then it is assigned a loss time. This loss time determines when the vehicle will discharge into a downstream lane. The loss time can assume a deterministic value as specified by the user of the NETSIM program. It may also be generated from one of two imbedded distributions (4). As an example, one such distribution consists of the following 10 levels of loss time: 5.6, 3.6, 3.2, 3.0, 2.6, 2.2, 2.0, 1.6, 1.2, and 0.6 sec. Each of these loss times has the same probability of being generated in the simulation process.

If a leader can discharge in the current scanning

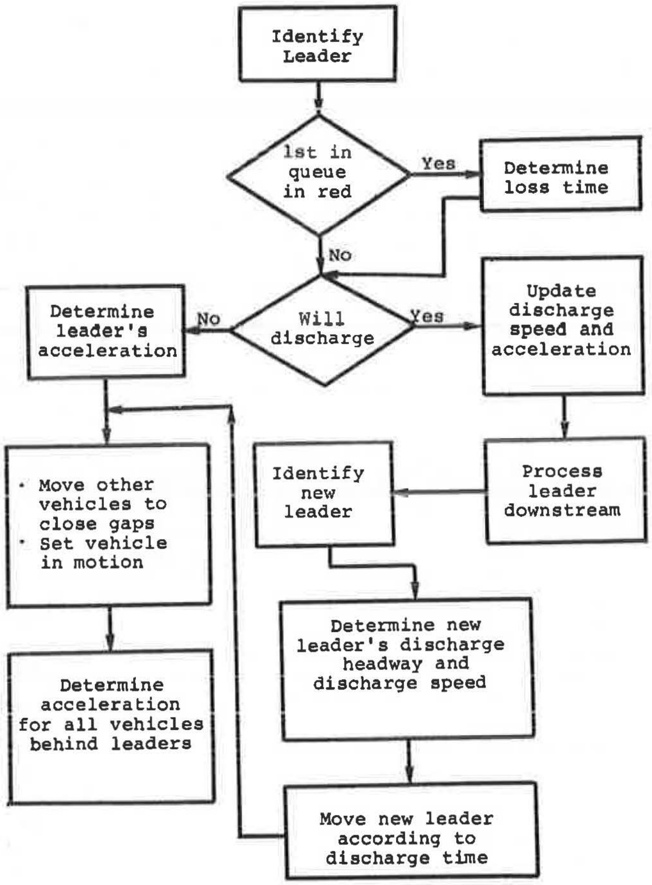

FIGURE 1 Schematic of NETSIM queue dissipation simulation process in a one-second scanning interval.

interval, its discharge speed and acceleration are determined. The vehicle is then processed into a downstream lane. The discharge speed of this vehicle becomes the basis for determining that of the following vehicle. The change in the discharge speed from one vehicle to another follows a predetermined pattern. The discharge speed of the first queueing vehicle at the onset of the green is assumed to be 9 ft/sec. This speed is increased by 4 ft/sec for each additional discharging vehicle until it reaches 40 ft/sec.

Following the processing of a leader that will discharge, a new leader is identified. The discharge headway of the new leader is then generated to determine the corresponding discharge time. This headway may also be generated randomly from an imbedded probability distribution. In addition to the discharge headway, the intended discharge speed of the new leader is determined. The current speed of the new leader is subsequently compared with this discharge speed to determine whether the vehicle should accelerate or decelerate. If an acceleration is warranted, an acceleration rate of 4 ft/sec^2 is applied to passenger cars that are moving at speeds of less than 17 ft/sec. When vehicle speeds exceed 17 ft/sec, a rate of 3 ft/sec^2 is used instead.

These threshold acceleration rates may be revised in the scanning interval when a vehicle first becomes the new leader. In such an interval the time remaining before discharge is computed for the new leader. This time duration is then used to calculate the average speed required for the new leader to discharge on time. The average speed, in turn, forms the basis for determining the needed acceleration rate. This newly calculated rate is limited to a maximum of 5 ft/sec^2. It is further reduced to 3 ft/sec^2 if the current speed exceeds 16 ft/sec.

In every scanning interval the model also checks to see if a queueing vehicle can start moving. It is assumed that queueing vehicles will start moving in succession at 1-sec intervals after a green phase begins. The model sets the queueing vehicles in motion according to this backward wave speed of one vehicle length per second. The spacing of the queueing vehicles that remain stationary is checked. The model adjusts the spacings so that they equal a specified effective length of the vehicles.

For vehicles that are set in motion behind the leader, normal acceleration rates are set at a value of 6 ft/sec^2 for speeds of less than 17 ft/sec and 3 ft/sec^2 for speeds exceeding 17 ft/sec. The initial acceleration rates allowed for stationary vehicles are 6 to 8 ft/sec^2, depending on the queueing positions of such vehicles. A car-following relation (7) is incorporated into the model to prevent a collision in the event that a leading vehicle implements a panic stop at a deceleration of 10 ft/sec^2. This car-following relation defines an upper bound of the acceleration rates. Furthermore, the acceleration of a vehicle is limited to a value that will not cause its speed to exceed the designated discharge speed.

EVALUATION

The movements of dissipating queueing vehicles bring about a series of interactions between the vehicles and the detectors. The basic elements of such interactions in a traffic lane include the departure of a vehicle from a detection area, the arrival of a vehicle at the upstream end of a detector, and the dwell of a vehicle in a detection area. These three elements can be modeled in terms of departure time, arrival time, and dwell time.

Departure time of a vehicle is used herein to denote the time elapsed from the onset of the green to the moment the rear bumper of the vehicle crosses the downstream end of a detector. Departure time can be represented by the sum of a sequence of queue discharge headways. Arrival time represents the time elapsed from the onset of the green to the moment the front bumper of a vehicle reaches a detector. This definition applies only to those vehicles upstream of a detector at the onset of green. Dwell time is the difference between departure time and arrival time.

These time-related variables are under the influence of drivers' behavior. Because drivers differ in their behavior, substantial variations in the values of these variables have been observed. For example, departure times and arrival times of those vehicles in a given queueing position could differ by as much as 6 sec. The corresponding dwell times also vary from 40 percent to more than 200 percent of their average value. The queue discharge headways can be expected to vary from less than 1 sec to more than 5 sec for vehicles in the same queueing position.

These variations are difficult to simulate, but their inclusion in the simulated characteristics of a queueing flow is indispensable. Consider the representative average observed departure times and arrival times given in Table 1. The average characteristics indicate that, with a 30-ft detector, those vehicles in the fourth queueing position or further upstream cannot move into the detection area before the vehicle ahead departs from the same area. If a model applies such average characteristics to individual vehicles, a distorted picture will

TABLE 1 Representative Average Departure Times and Arrival Times of Straight-Through Queueing Vehicles

Queueing Position	Departure Time (sec)	Arrival Time (sec)	
		30-ft Detector	50-ft Detector
1	3.3		
2	5.9	2.9	
3	8.3	5.9	4.5
4	10.6	8.5	7.4
5	12.8	10.9	9.9
6	15.0	13.2	12.2
7	17.1	15.4	14.4
8	19.2	17.6	16.7
9	21.3	19.8	18.8
10	23.4	22.0	20.9

emerge. For example, consider a signal phase that involves only a single-lane flow and has a vehicle interval of 0 sec. In such a case the average characteristics would not allow the fourth queueing vehicle to extend the green. Thus, a premature termination of the green would take place whenever more than three vehicles were in the queue. On the other hand, the average departure times and arrival times associated with a 50-ft detector would allow every queueing vehicle to hold the green.

In reality, not every queueing vehicle in the fourth queueing position or further upstream is unable to move into a 30-ft detector early enough to hold the green. Similarly, not all queueing vehicles can extend the green continuously when a 50-ft detector is used. This phenomenon is shown in Figure 2 in terms of the probabilities of premature termination of the green. These probabilities are derived from observed queue dissipation characteristics of single-lane flows. They reveal that the premature termination of the green could occur even when a 50-ft detector is used along with a vehicle interval

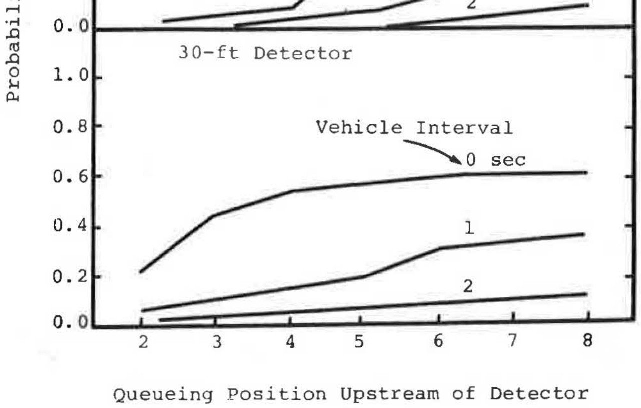

FIGURE 2 Probabilities of queueing vehicles facing prematurely terminated green duration.

of 2 sec. When two lanes are associated with a signal phase, 50-ft detectors in combination with 0-sec vehicle intervals can still lead to a high probability of premature phase termination (5).

Therefore, the variations in the queue dissipation characteristics of individual vehicles have to be realistically represented in a simulation model. Otherwise, significant errors may be introduced into the simulated operation of a signal control. This would reduce the usefulness of a model for comparing alternative control strategies.

In light of these implications, there is a minimum requirement a simulation model should satisfy. This requirement demands that simulated departure, arrival, and dwell characteristics conform to probability distributions that can be identified in the field. These three aspects of the queue dissipation characteristics are not unrelated. For a given vehicle, any two of these aspects define the remaining one. Therefore, it is not necessary to test a model in terms of all the aspects. In this paper the Pitt car-following model and the NETSIM model are tested in terms of departure and dwell characteristics.

Pitt Car-Following Model

The application of this model requires the specification of a saturation flow rate as an input. To test the model, a saturation flow rate of 1,700 veh/hr is used to represent the movements of straight-through queueing flow. This flow rate corresponds to a stabilized queue discharge headway of about 2.1 sec. The driver reaction time (c) used for the test is 0.3 sec for acceleration and 0.2 sec for deceleration as specified in the VIPAS program. A higher value of 0.5 sec for acceleration is also used to examine the sensitivity of the model outputs to the choice of c. Following the VIPAS program, the first queueing vehicle is assumed to accelerate at 7 ft/sec^2 when its speed is less than 17 ft/sec and at 5 ft/sec^2 when its speed exceeds 20 ft/sec. The space headways between stationary queueing vehicles are allowed to vary randomly between 20 and 30 ft.

The departure and dwell characteristics of the queueing vehicles in the Pitt car-following model are internally generated data. Therefore, both aspects have to be compared with the field data. To facilitate the comparison, the characteristics of 60 dissipating queues are simulated.

The data given in Table 2 indicate that the average discharge headways generated from the model agree rather well with the observed values. To test the variations in the simulated individual discharge headways, the headways of those vehicles in a given queueing position are normalized by expressing them

TABLE 2 Observed and Simulated Average Queue Discharge Headways

Queueing Position	Discharge Headway (sec)		
	Observed		
	Case 1	Case 2	Pitt Model
1	3.2	3.6	3.3
2	2.5	2.6	2.8
3	2.3	2.4	2.5
4	2.3	2.4	2.3
5	2.2	2.4	2.3
6	2.2	2.1	2.2
7	2.2	2.2	2.3
8	2.1	2.2	2.2
9	2.2	2.1	2.2
10	2.1	2.1	2.1

as percentages of their average value. The field data reveal that the cumulative probability distributions of such normalized headways fall in a well-defined range. The two solid lines in Figure 3 define the representative range of the observed distributions. The simulated distributions are also shown in the same figure.

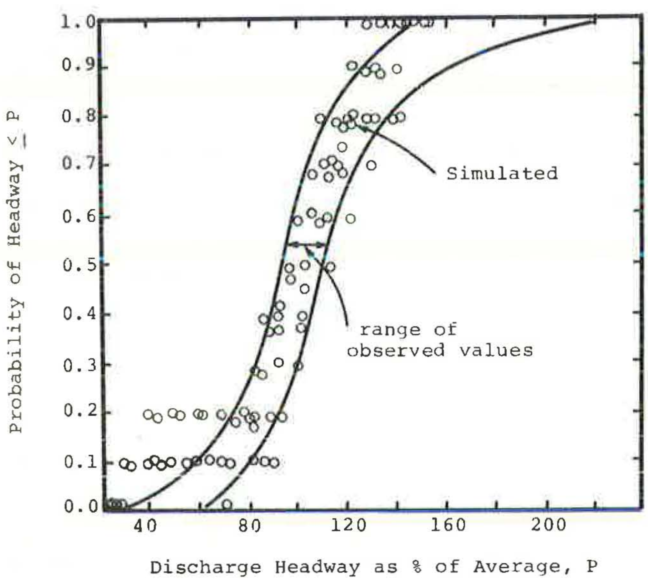

FIGURE 3 Simulated discharge headway distributions by Pitt model in comparison with observed distributions.

It can be seen from Figure 3 that the simulated distributions lack headways that exceed 140 percent of the averages. In contrast, the field data indicate that there is about a 10 percent chance that a discharge headway will exceed 140 percent of the average. The model also tends to produce a larger percentage of small headways. Between 60 and 140 percent of the averages, however, the simulated distributions conform reasonably well to the observed distributions.

The simulated average dwell times follow the general trends of the observed values. Two types of discrepancies, however, are evident in Figure 4. For a vehicle immediately upstream of a detector at the onset of the green, the simulated dwell time is much longer than the observed value. Those vehicles much further back in the queue have simulated values that are smaller than the observed values. The discrepancies involving 50-ft detectors and 80-ft detectors are relatively large. These discrepancies may be manipulated by changing the space headways of the stationary queueing vehicles. However, reducing the discrepancies for those in the front of a queue may increase the discrepancies for those in the back.

Because the simulated departure characteristics are in close agreement with the observed data, such discrepancies must be due to biases in the simulated arrival times. On the basis of Figure 4, it appears that the simulated queueing vehicles just upstream of a detector at the onset of green move into the detection area too early whereas those further upstream move into the detection area too late. One possible cause of this problem is the use of the same car-following rule in the model for vehicles in all queueing positions. This feature of the model makes it difficult to calibrate the model to satisfy the observed departure and dwell characteristics simultaneously.

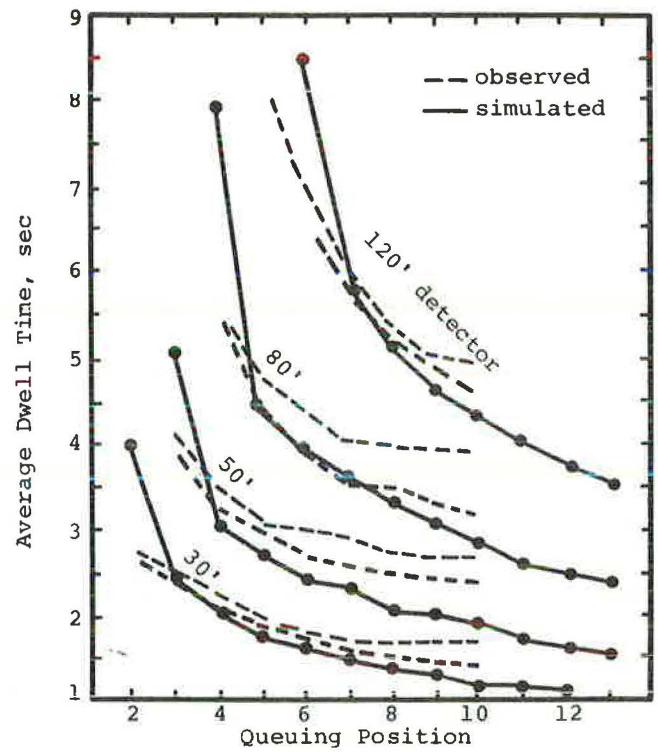

FIGURE 4 Simulated average dwell times by Pitt model in comparison with observed values.

For example, a longer driver reaction time (c) may be used to raise the simulated dwell times. The data in Table 3 indicate how an increase of c from 0.3 to 0.5 sec for acceleration affects the simulated queue discharge headways and dwell times. The use of c = 0.5 sec has appreciable effects on the dwell times of only the first two vehicles upstream of a detector. At the same time, the queue discharge headways become unreasonably high although the input saturation flow rate remains the same. This simple

TABLE 3 Sensitivity of Simulated Dwell Times and Queue Discharge Headways to the Choice of c

Queueing Position	Discharge Headway (sec) c = 0.3	Discharge Headway (sec) c = 0.5	Average Dwell Time (sec) 30-ft Detector c = 0.3	30-ft Detector c = 0.5	80-ft Detector c = 0.3	80-ft Detector c = 0.5
1	3.3	3.3				
2	2.8	3.7	4.0	4.5		
3	2.5	2.9	2.4	2.8		
4	2.3	2.5	2.0	2.0	7.9	8.6
5	2.3	2.6	1.8	1.7	4.7	5.0
6	2.2	2.6	1.6	1.7	3.9	4.0
7	2.3	2.6	1.5	1.6	3.5	3.6
8	2.2	2.5	1.4	1.5	3.3	3.4
9	2.2	2.5	1.3	1.4	3.0	3.2
10	2.1	2.5	1.2	1.4	2.8	3.0

example indicates that the limited number of variables used in the model cannot adequately explain the wide range of queue dissipation characteristics. Allowing vehicles in different queueing positions to follow different car-following rules may be one way of alleviating this problem.

In addition to the problem associated with average dwell times, the simulated distributions of individual dwell times also differ significantly from the observed distributions. Figure 5 shows that the simulated dwell times of individual vehicles in a given queueing position are concentrated in a range from 90 to 110 percent of their average. In contrast, the field data show a variation of from about 40 percent to more than 200 percent of the average. If deterministic space headways are used for stationary queueing vehicles, the simulated distributions have even lower variations. Apparently, the treatment of the driver sensitivity factor as the only probabilistic variable is not sufficient to account for real-life variations. This weakness will probably become insignificant if more variables are included in the model and the driver reaction time (c) is also treated as a random variable.

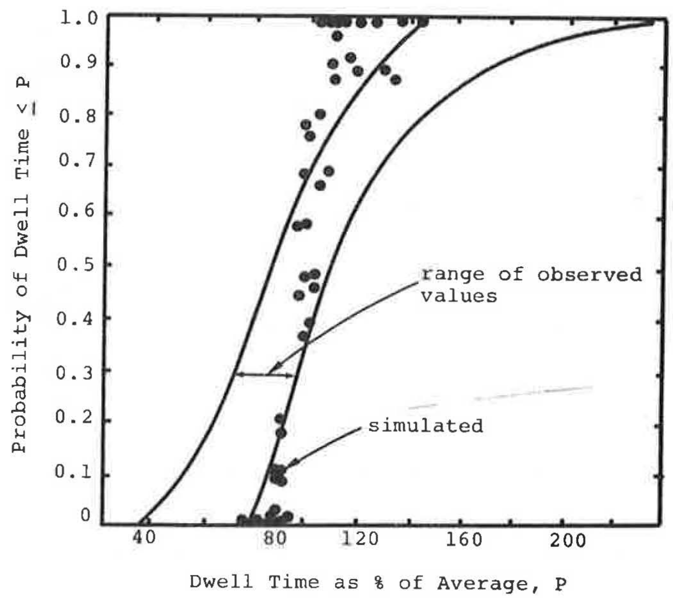

FIGURE 5 Simulated dwell time distribution by Pitt model in comparison with observed distribution.

NETSIM Model

To test the queue dissipation model of the NETSIM program, an effective length of 25 ft for passenger cars is used as an input. The space headway between two adjacent queueing vehicles at the onset of the green is made equal to this effective length. At the same moment, the front end of the first vehicle in a queue is assumed to coincide with the downstream end of the detector.

Another input specified for the model is an average discharge headway of 2.1 sec for those vehicles in the fourth queueing position or further upstream. This input is used with the imbedded discharge time of each vehicle. The headway distribution allows the generated headways to vary from 50 to 170 percent of the specified average of 2.1 sec. For vehicles in the second and the third queueing positions, 0.5 and 0.2 sec are added, respectively, to the generated headways. This implies that vehicles in the second queueing position have an average discharge headway of 2.6 sec and those in the third queueing position have a 2.3-sec average. The discharge times of the vehicles in the first queueing position are generated separately from the loss time distribution described previously.

Discharge time is considered to be the time at which a queueing vehicle moves and reaches the downstream end of a detector after a green phase begins. Therefore, this vehicle will travel a car length before it departs from the detection area. The length of a car is assumed to be 20 ft. The departure times are determined from the discharge times generated in the simulation process. The arrival times are estimated from the speed profiles of individual vehicles. These estimates are then used to compute dwell times. The movements of 120 dissipating queues are simulated to provide needed statistics for examining the model.

The average simulated dwell times as a function of the queueing position are shown in Figure 6. The simulated values differ from the observed values in two respects. First, the simulated values for vehicles in the fifth through the tenth queueing positions tend to be smaller than the observed values. Second, instead of continuing to decrease as expected, the simulated values of those vehicles in the eighth queueing position or further upstream increase with queueing position. These two types of deviations are systematic instead of random among detectors of 30 to 120 ft in length. This suggests that the model has built-in biases in representing observed queue dissipation characteristics. Such biases are also rather evident in Figure 7 when the distributions of the simulated dwell times are compared with those of the observed dwell times.

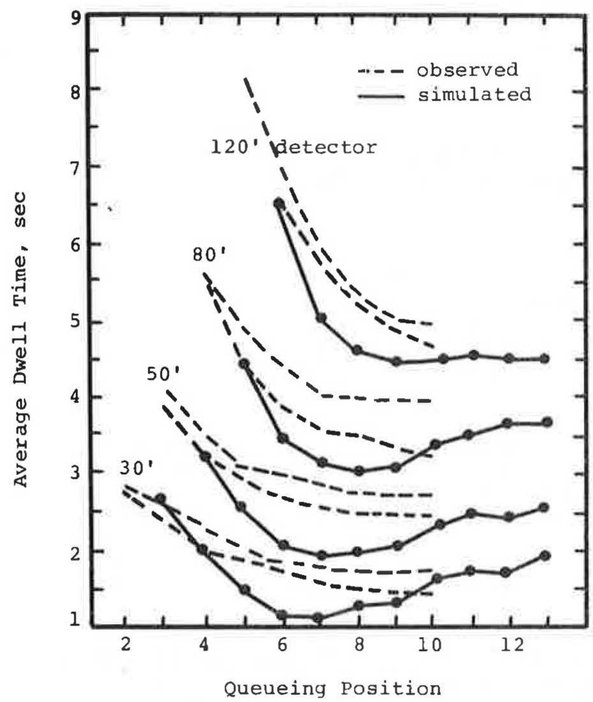

FIGURE 6 Simulated average dwell times by NETSIM in comparison with observed values.

The simulated departure times do not play a significant role in creating the biases in the dwell times. They are found to be a good representation of the observed characteristics. It should be cautioned, however, that the degree of realism in the simulated departure times depends in part on the loss time generated for the vehicle in the first queueing position. Such loss time is a parameter not clearly defined in the documentation of the NETSIM program. An examination of the MOVE subroutine indicates that loss time represents the time elapsed

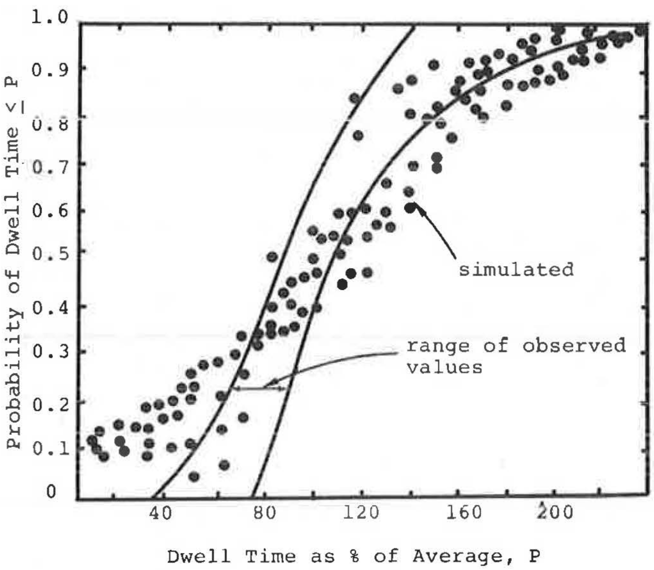

FIGURE 7 Simulated dwell time distribution by NETSIM in comparison with observed distribution.

from the onset of green to the moment the first queueing vehicle is allowed to move. The imbedded loss time distribution used for the test has an average value of about 2.6 sec. If this distribution were replaced by a user-specified input of 1.6 sec, the average departure time of vehicles in any queueing position would be reduced by about 1 sec. This would aggravate the biases in the simulated dwell times. Therefore, the specification of loss time should take into consideration the departure times that are being simulated.

A major weakness of the model is its lack of responsiveness to variations in the discharge times of those vehicles in a given queueing position. This feature could lead to incompatibilities between the generated discharge times and the speed profiles of individual vehicles. As described previously, the discharge time of a vehicle is not determined until the vehicle becomes the new leader in a certain scanning interval. This discharge time is used only in the same scanning interval to adjust vehicle speed. After this interval the speed of the new leader is adjusted according to predetermined acceleration rates. Furthermore, before a vehicle becomes a new leader, its acceleration is governed by a different set of threshold values, by a need to prevent collisions, and by the requirement that the resulting speed be no more than the designated discharge speed. Overall, this simulation process has little to do with the time at which a vehicle is expected to discharge. Consequently, by the time a vehicle becomes the new leader, it may be at a location and moving at a speed that does not allow it to discharge at the designated moment in a normal fashion. This is one reason why the simulated dwell times are biased. This problem can be avoided if vehicles are allowed to discharge only according to deterministic headways. In that case, the model could be calibrated readily to fit average characteristics of queue dissipation. However, the simulated distributions of departure times and dwell times would be unrealistic.

There are other factors that may contribute to the discrepancies between the simulated and the observed dwell times. For example, discharge speeds are increased in the model at a rate of 4 ft/sec per discharging vehicle. This allows the discharge speed of the ninth vehicle in a queue to reach 40 ft/sec. On the basis of the observed average dwell times in 30-ft detection areas and a vehicle length of 20 ft, the average speeds in such detection areas can be estimated for vehicles in different queueing positions. These speeds approximate the discharge speeds. Figure 8 shows that the rates of increase in discharge speeds are only about 1 ft/sec per vehicle for those behind the sixth queueing position; the average discharge speed of those vehicles in the ninth queueing position is on the order of 30 ft/sec.

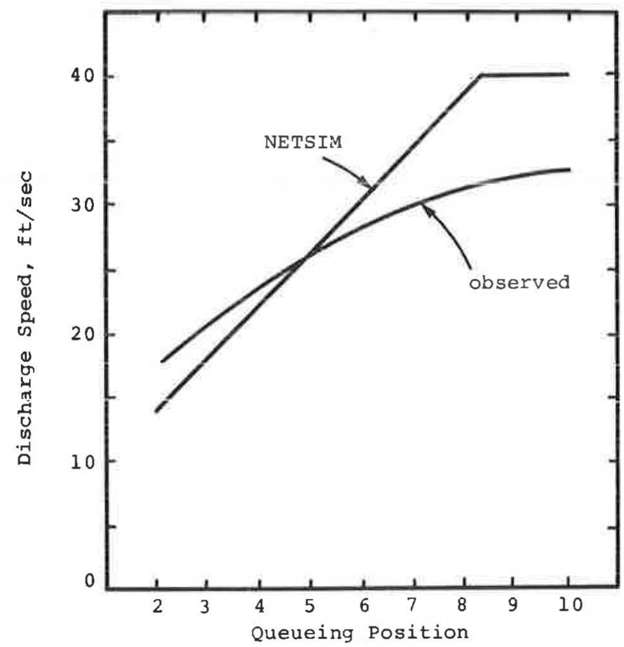

FIGURE 8 Allowable discharge speeds in NETSIM and estimates based on field data.

A few modifications can be made to alleviate the shortcomings of the model. One modification is to adjust the speed of a leader continuously with respect to the discharge time. Another modification is to generate the discharge time of a vehicle either at the onset of the green or in the scanning interval when this vehicle joins a queue. The generated discharge time is then used as a determinant of vehicle acceleration. These modifications provide more time for the model to adjust the speed profile of a vehicle to match the discharge time.

The discharge speeds used in the model can also be revised to conform to the derived relationship shown in Figure 8. This requires only minor changes in the ADJQ subroutine. A critical modification that should be made involves the allowable acceleration rates for vehicles behind a leader. For stationary vehicles, the model allows initial acceleration rates of from 6 to 8 ft/sec^2, depending on the queueing position. When a vehicle has started moving, the allowable rate is either 6 ft/sec^2 or 3 ft/sec^2. These rates should have been calibrated in terms of observed dwell characteristics.

A summary of the allowable acceleration rates that produce a reasonably close fit to the observed dwell times is given in Table 4. Generally, these rates indicate that, in the first few seconds after a vehicle starts moving, the vehicle should be subject to substantial restrictions in its movement. The restrictions need to be more severe for those in the back of a queue than for those in the front.

TABLE 4 Allowable Acceleration Rates of Vehicles Behind a Leader

Distance from Stop Line (ft)	Speed (ft/sec)	Allowable Acceleration (ft/sec²)
D ⩽ 100	0	2
D > 100	0	1
D < 100	< 3	3
150 ⩽ D < 180	< 2	2
180 ⩽ D < 200	< 3	2
200 ⩽ D < 230	< 4	2
D > 230	< 7	2
All other conditions		3

The acceleration rates given in Table 4 are allowed to be increased or decreased with respect to the discharge times when vehicle speeds exceed 25 mph. They are also subject to the same constraint that was applied in the original model to prevent collisions. The average dwell times simulated according to the modifications described are shown in Figure 9. The agreement between the simulated and the observed average dwell times is good. The simulated dwell time distributions are also found to conform to the observed distribution.

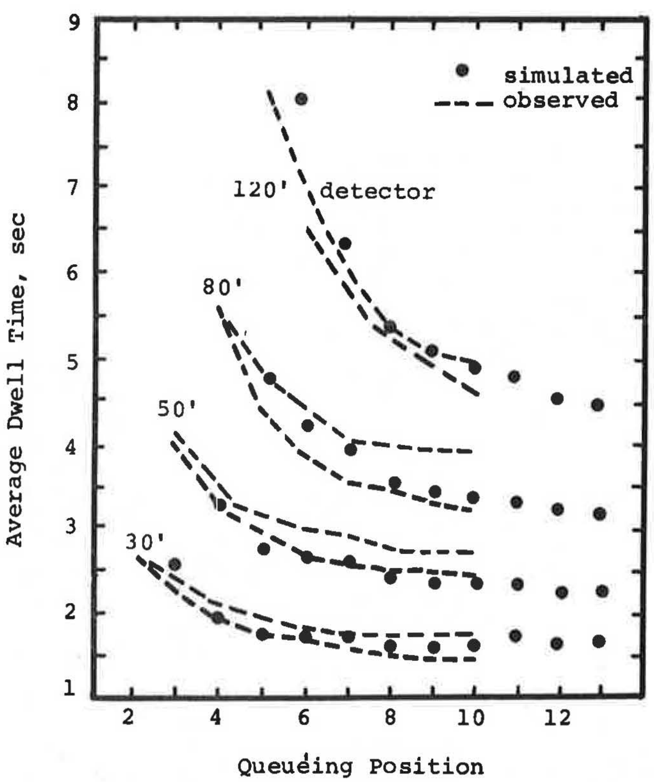

FIGURE 9 Simulated average dwell times by modified NETSIM in comparison with observed values.

CONCLUSIONS

For simulation analysis of presence-mode full-actuated signal control, the queue dissipation models used in the VIPAS program and the NETSIM program, respectively, have significant limitations. Both models are capable of producing realistic departure characteristics of queueing vehicles in relation to detectors, but they are inadequate in representing other vehicle-detector interactions such as the dwell times of vehicles. This reduces the usefulness of both simulation programs for analysis of a wide range of traffic flow and signal control conditions.

The Pitt car-following model used in the VIPAS program relies on mathematical relationships to simulate car-following maneuvers. It can be easily adopted for various applications. However, its limited number of variables and parameters does not provide a flexible model structure for calibration. The outputs of the model cannot be made to conform easily and simultaneously to observed departure, arrival, and dwell characteristics of queueing vehicles. The dwell times produced by the model are also more or less deterministic. This contrasts with the large variations observed in the field. The model needs additional variables to better represent queue dissipation characteristics in relation to detectors. More random variations should also be introduced into the simulated dwell characteristics of queueing vehicles.

The queue dissipation model used in the NETSIM program is essentially a heuristic algorithm for processing vehicles. This program relies on deterministic threshold acceleration rates and discharge speeds to guide the movements of queueing vehicles. A major weakness of the model is that the simulated movements of queueing vehicles have little to do with the discharge times generated separately from a probability distribution. Consequently, the simulated speed profiles may not be compatible with the discharge times. This, in turn, leads to systematic biases in the simulated dwell characteristics.

This model can be modified in several respects. For example, the discharge times of individual vehicles can be generated long before the vehicles are about to discharge. These discharge times can then be used continuously to guide the vehicle movements. And, more important, the threshold acceleration rates and discharge speeds should be modified to reflect actual variations in queue dissipation characteristics from one queueing position to another. With these modifications, a significant improvement of the simulated queue dissipation characteristics can be achieved.

Past efforts in modeling queue dissipation for simulation analysis of traffic-actuated signal controls have paid little attention to vehicle-detector interactions. This negligence could direct the search for improved signal controls in wrong directions.

ACKNOWLEDGMENT

This study is sponsored in part by the U.S. Department of Transportation Program of University Research.

REFERENCES

1. G.F. King and K.M. Wilkinson. Relationship of Signal Design to Discharge Headway, Approach Capacity, and Delay. In Transportation Research Record 615, TRB, National Research Council, Washington, D.C., 1976, pp. 37-44.
2. F.B. Lin. and M.C. Percy. Vehicle-Detector Interactions and Analysis of Traffic-Actuated Signal Controls. In Transportation Research Record 971, TRB, National Research Council, Washington, D.C., 1984, pp. 105-111.
3. J.A. Breon. Value Iteration Process-Actuated Signals, Vol. 1. Fiscal and Systems Management Center, Pennsylvania Department of Transportation, Harrisburg, 1983.

4. Traffic Network Analysis with NETSIM--A User Guide. Implementation Package FHWA-IP-80-3. FHWA, U.S. Department of Transportation, 1980.
5. F.B. Lin. Optimal Timing Settings and Detector Lengths of Presence-Mode Full-Actuated Control. Draft Final Report. Office of University Research, U.S. Department of Transportation, Dec. 1984.
6. Development and Testing of INTRAS, A Microscopic Freeway Simulation Model, Vol. 1. Report FHWA/RD-80/106. FHWA, U.S. Department of Transportation, 1980.
7. Network Flow Simulation for Urban Traffic Control System--Phase II, Vol. 5. FHWA-RD-77-45. FHWA, U.S. Department of Transportation, 1977.

Publication of this paper sponsored by Committee on Traffic Flow Theory and Characteristics.

Another Look at Identifying Speed-Flow Relationships on Freeways

BRIAN L. ALLEN, FRED L. HALL, and MARGOT A. GUNTER

ABSTRACT

Despite approximately 50 years of research on highway operating characteristics, the way in which the speed-flow relationship moves between free flow and congested flow conditions is still not clearly understood. The speed-flow relationship as it pertains to those transitions is investigated using an extensive data set collected on the Queen Elizabeth Way freeway in Ontario. Two different analytical approaches are used: time-connected plots of mean speed and mean flow and an event-based trace, averaged with respect to the transition to and from congested flow. The results confirm several aspects of conventional understanding but also raise questions that are hard to answer with the conventional interpretations of speed-flow relationship.

Highway capacity and the operational characteristics of uninterrupted traffic flow have been the focus of research for at least the past 50 years. Since Greenshields' work in the 1930s, traffic researchers have devoted considerable attention to investigating and interpreting the fundamental characteristics of traffic flow on freeways. The dozens of research papers produced during those 50 years have typically documented either the results of interpretive empirical studies or the degree of success achieved in relating those results to known or proposed theoretical concepts (models). Certainly it is a well-known and well-researched area. Why then another paper on this subject?

The answer consists of three complementary parts. First, the subject area itself remains relevant. As freeway systems become more complex and experience ever-increasing traffic loads, the effective management of those systems becomes increasingly important. To manage them effectively, operating agencies must have reliable information about traffic flow on which to base appropriate actions. This is true whether overall system management or more specific and data-demanding activities, such as entrance ramp control or incident detection and response, are considered.

Second, it is well accepted that the representation of speed-flow relationships first presented in the Highway Capacity Manual (HCM) (1), and more recently updated in the Interim Materials on Highway Capacity (2), cannot completely reflect all actual conditions witnessed on the many different existing freeway systems. There is little doubt that at the very least a further updating of those curves is required to reflect current operating characteristics, even if the only result is simply to "calibrate," on a site-specific basis, the traditional approach to highway capacity and level of service.

This leads to the third part of the answer. In trying to calibrate the traditional approach with their data, many traffic engineers have had difficulty with the traditional approach to describing the speed-flow relationship as a smooth, continuous curve as depicted in the HCM material and the vast majority of standard traffic engineering references. Some researchers, suspecting that the curves are not in fact continuous and perhaps not always smooth, have proposed other solutions. Perhaps it is appropriate even after 50 years of research to take yet another look at precisely what does happen with traffic flow on freeways.

In this paper only the relationship between speed