after runs, it was possible to state the following findings (all are for a peak hour) in changing from five phase to two phase.

1. 3300 s less stopped time will be incurred overall at the intersection (an 11 percent reduction).
2. Six percent fewer vehicles will stop (50 percent, down from 56 percent).
3. One hundred fewer through vehicles will have to stop on the main street (40 percent, down from 50 percent).
4. A 5-s reduction in average stopped time will be obtained by through vehicles on the main street.
5. A 10- to 15-s increase in average stopped time will be accrued by left-turning vehicles on the main street.
6. The main street's signal split will increase from 53 percent to 68 percent.

With these data in hand, an interoffice memo was written to the city manager's office justifying the phasing change. The memo also included items on accident experience, field observation, warrants, and citizen response. Final approval has not yet been received, and there is a chance that the recommendations may be overruled. Richardson is still a small city, and citizen input is a very important factor in decisions made by the city council and manager's office. The quantitative data provided by the TEXAS model have added considerable support to the initial field observations and recommendations made to the city manager.

This small problem required only 1 h to code and run, then another 1-2 h to evaluate the results. Considering the total amount of time spent on this project, these 3 h probably were the most productive. Likewise, it is felt that the TEXAS model can easily provide the practicing traffic engineer with delay and speed data that are nearly impossible to measure in the field, but are very useful in evaluating proposed transportation system management changes. It is hoped that, in the near future, the model will be available through more agencies (such as FHWA) so that more local traffic engineers will be able to use this tool.

Comparison of NETSIM Results with Field Observations and Webster Predictions for Isolated Intersections

Christian F. Davis and Timothy A. Ryan

The results described here are offered as examples of user experience with the NETSIM computer program. They deal with research (1) that grew out of previous work conducted for the Connecticut Department of Transportation on prediction of air pollution generated by vehicular traffic. While it was felt that the vehicle emissions and fuel consumption options of NETSIM would give results that could be used directly, it was also felt that the simulation model could be used as a research tool to investigate the range of applicability and sensitivity of various analytic approaches. Consequently, the re-

Figure 1. Intersection of Route 195 and South Eagleville Road.

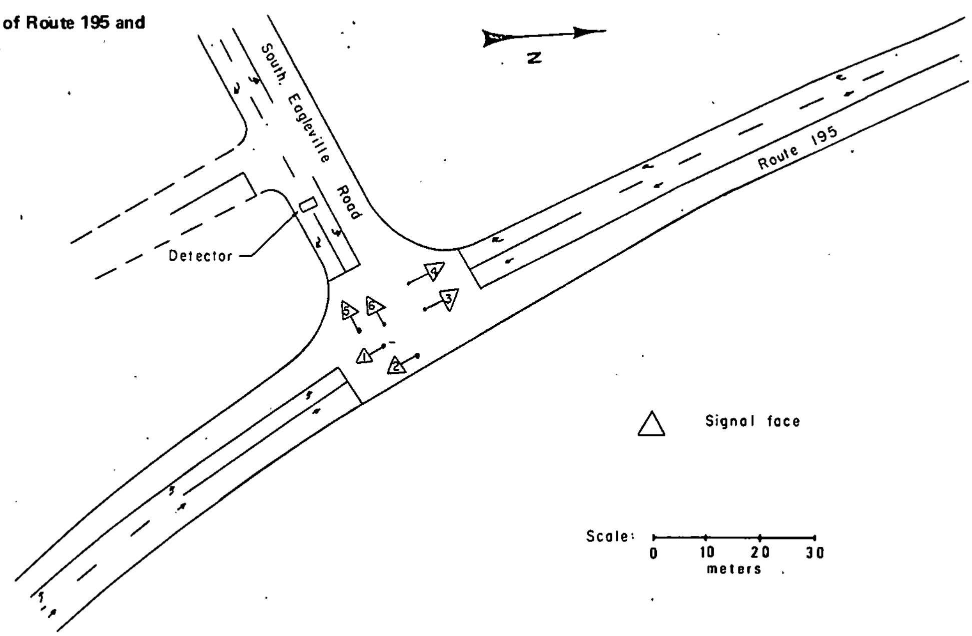
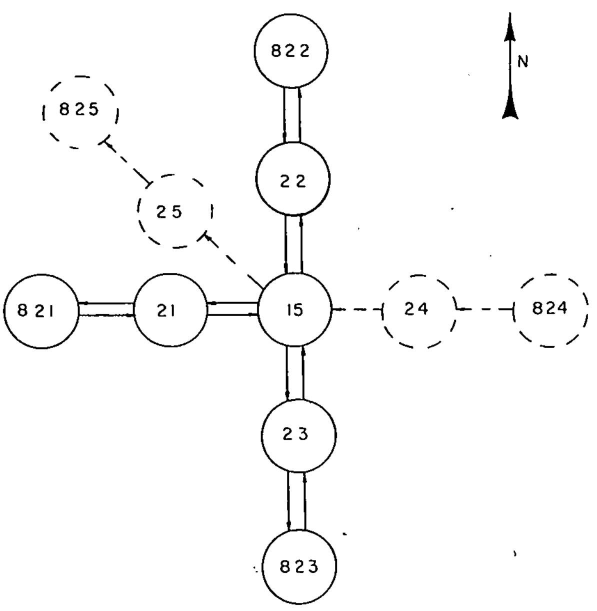


Table 1. Timing chart for semi-actuated signal at Route 195 and South Eagleville Road.

FACE	PHASE A				PED. ACT.		PHASE B					FLASH.
NO.	ADV.	ART.	CL. 1	CL. 2	WALK	CL.	NIT.	VEH.	MAX.	CL. 1	CL. 2	OPER.
1	G←	G	A	R	R	R	R	R	R	R	R	FL. A
2	G	G	A	R	R	R	R	R	R	R	R	FL. A
3	R	G	A	R	R	R	R	R	R	R	R	FL. A
4	R	G	A	R	R	R	R→	R→	R→	A	R	FL. A
5	R	R	R	R	R	R	R→	R→	R→	A	R	FL. A
6	R	R	R	R	R	R	R←	R←	R←	A	R	FL. A
P	← DON'T WALK →				WALK	FL.D.W	← DON'T WALK →					OFF
	#1 #2											
ACT. SET.	5" 12"	31"	4"	2"	7"	13"	8"	3"	35"	3"	2"	

Figure 2. Link-node diagram for Route 195 and South Eagleville Road.



search was directed at establishing confidence with the operation of the model through a comparison with field observations and an examination of sensitivity to input parameters.

The examples described here are two of several cases examined in 1979 and described by Davis and Ryan (1). It should be noted that the version of NETSIM used was that supplied by FHWA in 1978 and that various corrections, additions to, and deletions from the model have been made since that time. It should also be noted that, although (as the acronym suggests) NETSIM was specifically developed to handle networks, there are many instances when the capability to model an isolated intersection is of value. Thus, in the first example, an isolated semi-actuated signal is examined by the use of NETSIM, and the results are compared with field observations. In the second example, a hypothetical intersection was used to compare delay as predicted by the Webster technique (2) with that predicted by NETSIM.

ISOLATED SEMI-ACTUATED SIGNAL

This example deals with the T-intersection shown in Figure 1. The intersection is located near the campus of the University of Connecticut in Storrs and is controlled by a semi-actuated signal with sequence and timing as shown in Table 1. For the simulation, the intersection was represented by the link-node diagram shown in Figure 2 with lengths and grades as given in Table 2. Average vehicle length was taken to be 6.1 m (20 ft). In actuality, the right-turn pocket on link (22,15) has a capacity of 14 vehicles. However, the version of NETSIM used allows no more than nine vehicles for right-turn pocket capacity and, hence, that number was used in the simulation. Since the driveway shown in Figure 1 carries an insignificant volume, it does not appear on the link-node diagram.

It was necessary to use several "tricks" to handle certain features of the intersection. Thus, pedestrians were treated as "vehicles" by using the dummy links (824,24), (24,15), (15,25), and (25,825) as their own exclusive path through the network. These pedestrian vehicles never use any other links. In reality, there are no intersections at nodes 21, 22, 23, 24, or 25; they were included because NETSIM does not compute some of the desired statistics for entry links. Also, link (21,15) is, in reality, channelized, with one lane reserved for left-turning vehicles and one lane reserved for right-turning vehicles. For the simulation, this link was described as having only one moving lane and a left-turn pocket.

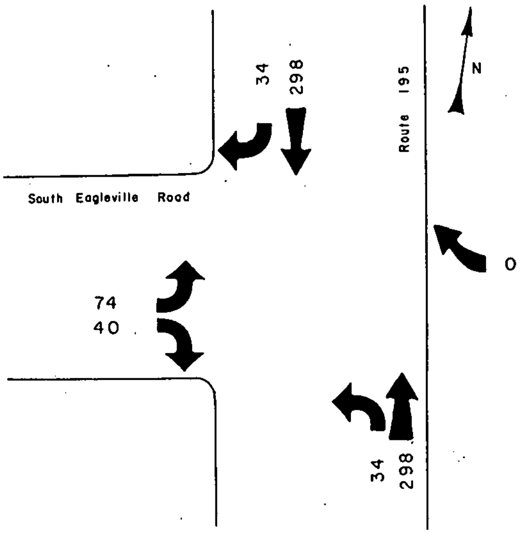
Link operation cards were completed by assuming no right-turn-on-red, one moving lane per link, de-

Table 2. Lengths and grades of links for first example.

Link	Length (ft)	Grade (%)[a]	Link	Length (ft)	Grade (%)[a]
821,21	500	-2.0	824,24	500	0
21,15	170	0	24,15	500	0
822,22	500	0	15,21	170	0
22,15	320	-1.8	15,22	320	+1.8
823,23	500	+3.2	15,23	370	-3.2
23,15	370	+3.2	15,25	500	0

[a]Positive grades are ascending; negative grades are descending.

Figure 3. Hourly volumes.



sired free-flow speed of 48.4 km/h (30 mph), and a queue discharge rate of 2.1 s/vehicle for each link. The default distribution for start-up delay was used and, since it was assumed that all pedestrians use their own "links", the condition "no-pedestrian traffic" was specified for each of the other links. From the field observations, the hourly approach volumes were found to be as shown in Figure 3.

The single-ring controller is not coordinated, the rest-in-red option was not applied, and the detector switching feature was inactive. Referring to Table 1, we note that, for this study, ADV #1 was used. Also note that the phase A advance green must be treated as a separate phase in NETSIM. Therefore, as far as NETSIM is concerned, the signal cycle has four phases, not three. The phases were designated as shown below.

Actual Phase	NETSIM Phase
Phase A advance green	1
Remainder of phase A	2
Pedestrian-actuated phase	3
Phase B	4

Phase 1 and phase 2 are both nonactuated, but the version of NETSIM used in this study allows only one nonactuated phase for a semi-actuated signal. This was handled by treating phase 1 as though it were actuated and by setting both the minimum interval and the maximum green to 5 s and the passage time (the vehicle interval) to 0 s. The controller is not of the volume-density type; the recall switch was on; amber duration, red clearance duration, and red revert time were all 0 s. The detector serving this phase is of the presence type, and the phase overlaps no other phases.

Phase 3 is the pedestrian-actuated phase and one additional minor adjustment was made in order to

Figure 4. Queue lengths at intersection of Routes 195 and 275 at start of green interval.

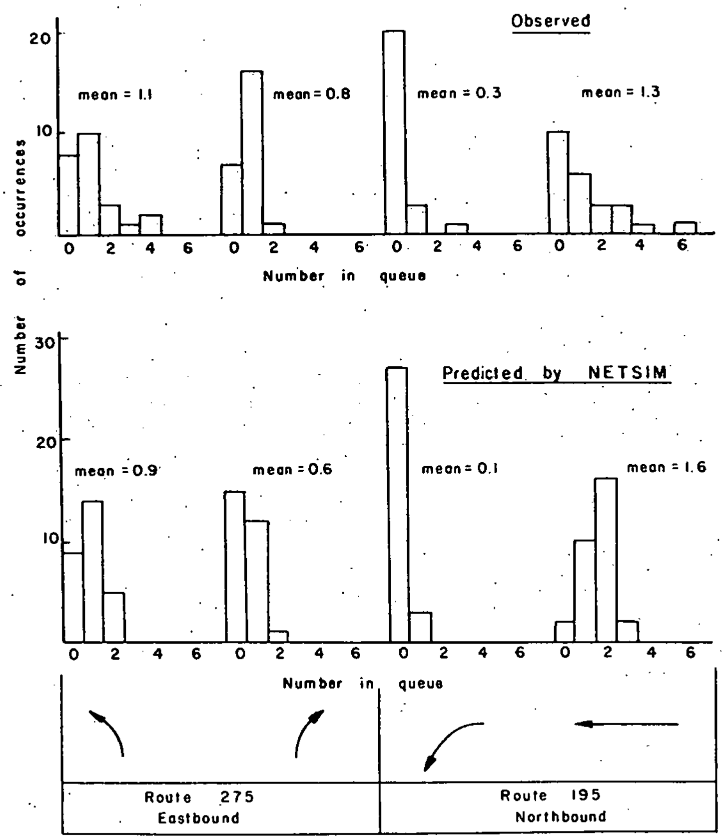


Figure 5. NETSIM-Webster comparison with 3-s lost-time and equal-approach volumes.

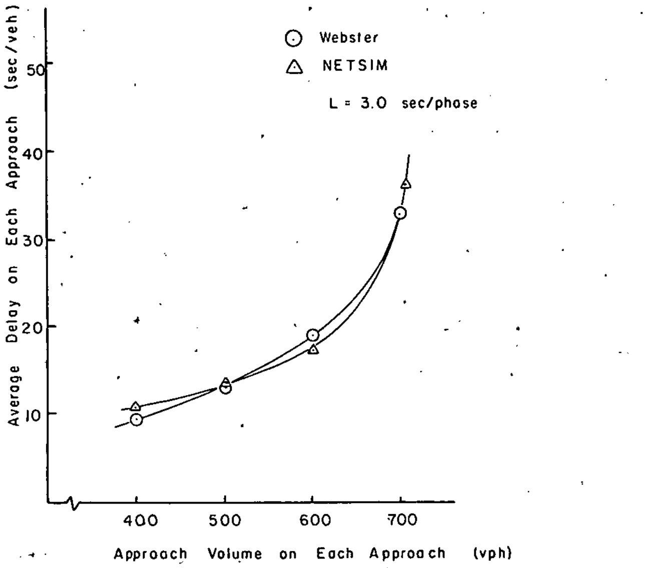
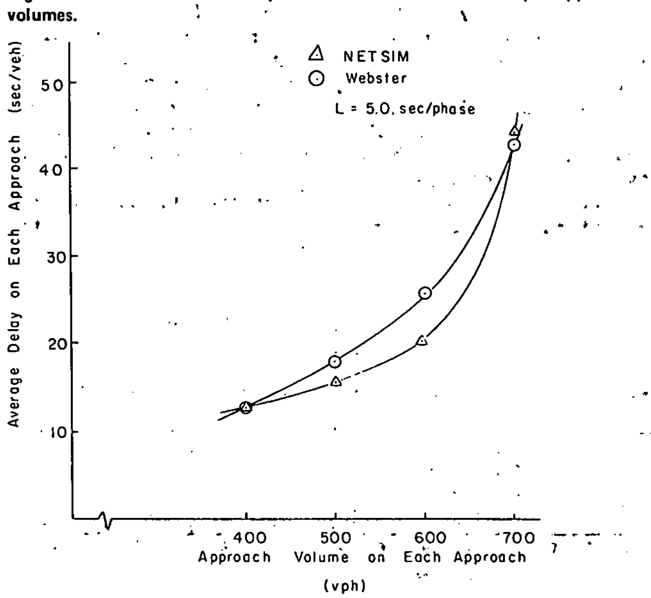


Figure 6. NETSIM-Webster comparison with 5-s lost-time and equal-approach volumes.

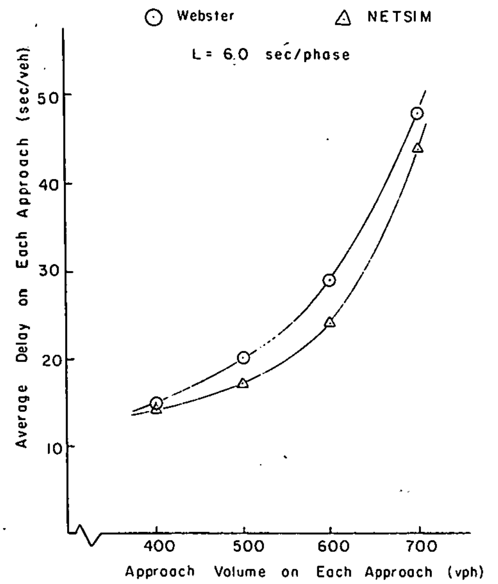


prepare the data card for this phase. The length of the amber (flashing "don't walk") interval is 13 s, but the program allows for a maximum amber duration of only 9 s. Therefore, the four extra seconds were added onto the green (walk) interval.

The volume cards (type 20) were prepared by using Figure 3 and noting that there were no trucks and no intralink source-sink nodes. Also, since the pedestrian phase was not called during field observations, the volume of pedestrian vehicles was set equal to zero.

In this case, comparison with field observations was based on queue length at the start of the green interval. Simulation was performed for two 15-min periods by using two different seeds for the random number generator. The resulting data were aggregated to give the 30-min "predicted" values at queue length shown in Figure 4. Since there was no constant cycle length, it was necessary to request output at 2-s intervals. It may be seen that, although the comparison is difficult due to light volumes, the average numbers in each of the queues seem to agree reasonably well (with the exception of the left turn off Route 195). Note that the queue lengths predicted by NETSIM are generally slightly shorter than those observed, and the variances of queue lengths are greater in the observed case than in NETSIM. In general, this same situation obtained for comparisons with field observations for fixed-time and fully actuated signals.

Figure 7. NETSIM-Webster comparison with 6-s lost-time and equal-approach volumes.



COMPARISON WITH WEBSTER FOR HYPOTHETICAL INTERSECTION

The work of Webster (2) is commonly used for the calculation of delay and queue lengths. In this section, a hypothetical four-legged intersection with single-lane approaches, controlled by a fixed-time signal, is used for a comparison between the predictions of NETSIM and those of the Webster technique. In the comparisons of Figures 5 through 7, the approach volumes are equal on all legs and the measure of interest is average delay per vehicle. It may be noted that this delay is defined by Webster as "the difference between the average journey time through the intersection and the time for a run which is not stopped or slowed down by the signals." The definition given in the NETSIM User's Manual (3) is "the difference between the total time and ideal travel time based on target speed for link."

The figures show the variation in average delay for various approach volumes with assumed lost times of 3, 5, and 6 s, respectively. Cycle lengths are taken as the optimal determined by the Webster technique. Amber time is 3 s in every case.

For this hypothetical intersection, the results seem to suggest that, in general, NETSIM predicts about the same or less delay than the Webster technique until nearing capacity at which time NETSIM predicts higher average delay. Put another way, the capacity indicated by NETSIM is consistently lower than that indicated by Webster. As might be expected, the lost time assumption has a significant effect on the Webster results--with increased lost time yielding increased delay. That this should also be the case for NETSIM is not so apparent because lost time was stochastically assigned in the simulation. Thus, the increased delay seen in the simulation would seem to reflect the effect of the change in cycle length. This increase in delay with increased cycle length seems to hold until nearing capacity, at which time NETSIM is relatively insensitive to the cycle length.

CONCLUSIONS

Although NETSIM was developed to simulate a network, our work with isolated intersections seems to indicate that for the conditions simulated, it is convenient and reasonably representative of what might be expected in the field. Specifically, average queue lengths at the beginning of the green phase as predicted by NETSIM are generally slightly shorter than those observed and the variances in queue lengths are greater in the observed case than in NETSIM.

For a simple, four-way intersection controlled by a fixed-time signal with cycle lengths at optimum as predicted by the Webster technique, NETSIM predicts about the same or less average delay per vehicle as does Webster until nearing capacity at which NETSIM predicts higher average delay.

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Summary Evaluation of UTCS-1/NETSIM in Toronto

Sam Yagar and E.R. Case

The UTCS-1 forerunner of NETSIM was studied and evaluated on a Toronto network (1) in 1974. The network consists of Bloor Street and its intersecting links. This paper summarizes some of the operational characteristics of UTCS-1, which have been essentially preserved in NETSIM, along with other empirically estimated operational characteristics of the model, and describes some potential applications and pitfalls.

STANDARD FOR COMPARISON

The workshop for teachers, researchers, and developers (Workshop 2 at this Conference) addressed the problems of random variation, not only in the model's predictions but also in the data standards against which the model is tested. The former occur mainly as a result of varying the random number seed in the model. This can be beneficial in providing a measure of random variation in network performance. On the other hand, in comparing various control strategies it is often preferable "to control the randomness" so that the strategies can be compared on an equal basis and their true differences measured with greater significance. The results of varying the random number seed of UTCS-1 to represent day-to-day variation in performance are reported here.

Prior to addressing the random variation and confidence in the model's prediction, it is appropriate to consider the same factors with respect to the empirical data against which the model is evaluated. For the Bloor Street network that was studied in Yagar (1), the standard of comparison consisted of floating-vehicle data collected as part of a study conducted for the Metro Toronto Traffic Control Centre. The statistical reliability of results obtained from floating-vehicle studies is often less than desirable because of random fluctuations in operating conditions and small-sized samples of data. The validity of floating-vehicle results is generally accepted, usually by default, as there is often not a viable alternative method of obtaining link flow-travel time characteristics. Because this study deals with the application of a micromodeling technique to a detailed network, which theoretically could be more precise than the floating-vehicle standard against which it is being tested, some discussion of the reliability of the floating-vehicle standard is in order.

The results of the floating-vehicle study on Bloor Street (network model shown in Figure 1) for the 24 sections of the network are summarized in Table 1. It is noted that the sample variance of the floating-vehicle data for any given combination of link and time slice may be relatively large. The standard deviations of link travel times ranged up to approximately 50 percent of the means. The absolute standard deviations of link speeds were in the range from 2 to 10 mph. Chi-square goodness-of-fit tests were performed on the speed distributions, for each link individually and for all of the links combined. In each case the distributions were compared with normal distributions that had similar means and standard deviations. None of the tests rejected normality at the 0.05 level of significance.

The UTCS-1 predictions of link speeds were compared with the above floating-vehicle standards for the Bloor Street network and with TRANSYT's speed estimates for the same links (2). It was found that the difference between the two models was small relative to the potential random error in the empirical data. In addition to this, the sensitivity of UTCS-1 predictions to aggregation of time slices and to varying random number seeds was studied. The results are reported below.

SENSITIVITY TO AGGREGATION OF TIME SLICES

The effort required in data handling is approximately proportional to the number of subintervals used to represent the time variations in flow. By aggregating the flow volumes over a number of successive time intervals, one reduces the data re-