cause 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.

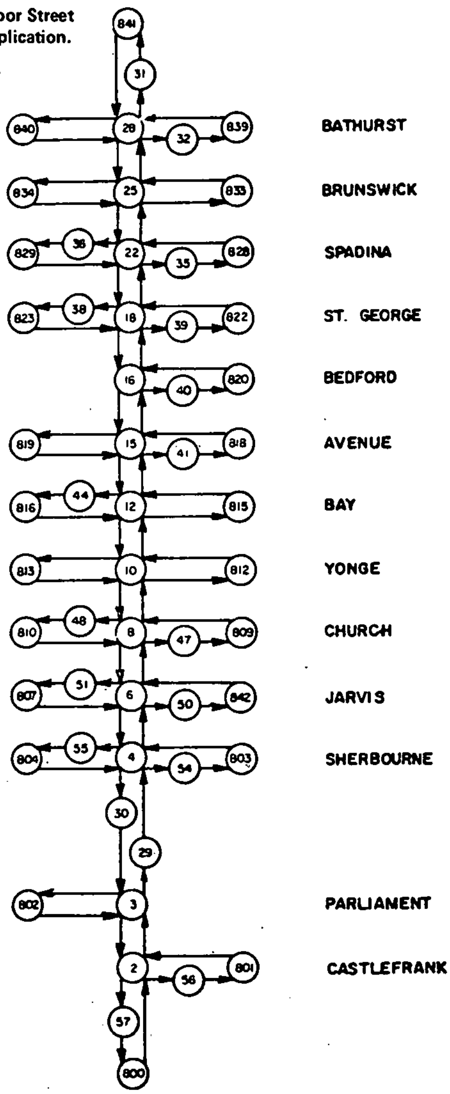
The results of the floating-vehicle study on Bloor Street (network model shown in Figure 1) for the 24 sections of the network are summarized in Table 1. It is noted that the sample variance of the floating-vehicle data for any given combination of link and time slice may be relatively large. The standard 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-

Figure 1. Simplified Bloor Street network for UTCS-1 application.




quirements. However, it is important to know how a model reacts to the aggregation of different demand rates. If it is not sensitive to this, then the additional cost of simulating different time intervals is not justified. Depending on the ultimate requirements of the simulation, the model itself may not be of use if it is not sensitive to flow aggregation. If the flows vary with time and if this flow variation affects the operation of the system, the model should be sensitive to it.

The simulation of the peak hour from 7:40 to 8:40 a.m. on Bloor Street was performed by using three contiguous 20-min time slices and then by using the aggregated flows for the entire peak hours, without considering the variation from one subinterval to the next.

The link speeds predicted by UTCS-1 are plotted in Figure 2 for each of the three 20-min time slices and for the aggregated peak-hour flow rates. The simulation results indicate some inconsistencies relative to what one might expect from a consistent model, which is of greater concern than the loss in detail due to aggregation. On link 2 the speed simulated for the aggregated demands is lower than that predicted for any of the time slices. This cannot be rationalized in terms of delays shifted to or from the adjacent links 1 or 3. Similarly, the speeds simulated with the aggregated demands for links 10, 11, and 12 are higher than those simulated for each of the individual time slices. Again, this cannot be rationalized in terms of delays shifted to adjacent links, at least in the case of link 11.

The UTCS-1 statistical package was used to compare the results obtained for each time slice with those for the aggregated demands by using the t-, Wilcoxon-, and U-tests. The differences were generally not significant.

These results seem to indicate that UTCS-1 is not sensitive to the time aggregation of demands. In this case it has even yielded results that are inconsistent. Checking of the data did not reveal any errors, and it was therefore concluded that UTCS-1 was not sensitive to time aggregation of demands.

Table 1. Floating-vehicle data for Bloor Street network.

| Section | | 7:40-8:00 a.m. | | | | 8:00-8:20 a.m. | | | | 8:20-8:40 a.m. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | Node to Node | Avg Travel Time (s) | SD in Travel Time (s) | Avg Speed (mph) | Sample Size | Avg Travel Time (s) | SD in Travel Time (s) | Avg Speed (mph) | Sample Size | Avg Travel Time (s) | SD in Travel Time (s) | Avg Speed (mph) | Sample Size |
| 1 | 2,3 | | | | | 27.8 | 5.33 | 25.74 | 11 | | | | |
| 2 | 3,4 | | | | | 66.5 | 23.05 | 18.38 | 11 | | | | |
| 3 | 4,6 | | | | | 49.1 | 10.47 | 14.75 | 11 | | | | |
| 4 | 6,8 | | | | | 33.2 | 14.85 | 17.15 | 11 | | | | |
| 5 | 8,10 | 91.7 | 4.43 | 7.54 | 11 | 103.8 | 39.61 | 7.71 | 11 | | | | |
| 6 | 10,12 | 38.6 | 5.61 | 13.32 | 11 | 37.0 | 6.80 | 14.14 | 11 | | | | |
| 7 | 12,15 | 40.6 | 4.30 | 21.86 | 10 | 40.1 | 4.44 | 22.15 | 11 | | | | |
| 8 | 15,16 | 32.1 | 13.62 | 21.84 | 20 | | | | | | | | |
| 9 | 16,18 | 20.8 | 12.22 | 25.55 | 20 | | | | | | | | |
| 10 | 18,22 | 31.4 | 5.20 | 24.85 | 20 | | | | | | | | |
| 11 | 22,25 | 35.7 | 3.74 | 19.29 | 10 | | | | | 38.6 | 12.55 | 19.59 | 10 |
| 12 | 25,28 | | | | | | | | | 54.0 | 20.89 | 15.28 | 10 |
| 13 | 28,25 | | | | | | | | | | | | |
| 14 | 25,22 | | | | | 60.7 | 18.82 | 13.10 | 10 | | | | |
| 15 | 22,18 | | | | | 49.6 | 10.31 | 16.26 | 10 | | | | |
| 16 | 18,16 | | | | | 16.8 | 1.81 | 27.75 | 10 | | | | |
| 17 | 16,15 | | | | | 61.5 | 3.98 | 10.06 | 10 | | | | |
| 18 | 15,12 | | | | | 74.6 | 7.28 | 11.88 | 10 | | | | |
| 19 | 12,10 | | | | | | | | | | | | |
| 20 | 10,8 | | | | | | | | | | | | |
| 21 | 8,6 | 22.9 | 5.36 | 22.36 | 11 | | | | | | | | |
| 22 | 6,4 | 25.6 | 3.32 | 27.25 | 11 | | | | | | | | |
| 23 | 4,3 | 63.4 | 33.16 | 21.35 | 11 | | | | | | | | |
| 24 | 3,2 | 40.1 | 21.35 | 21.98 | 11 | | | | | | | | |

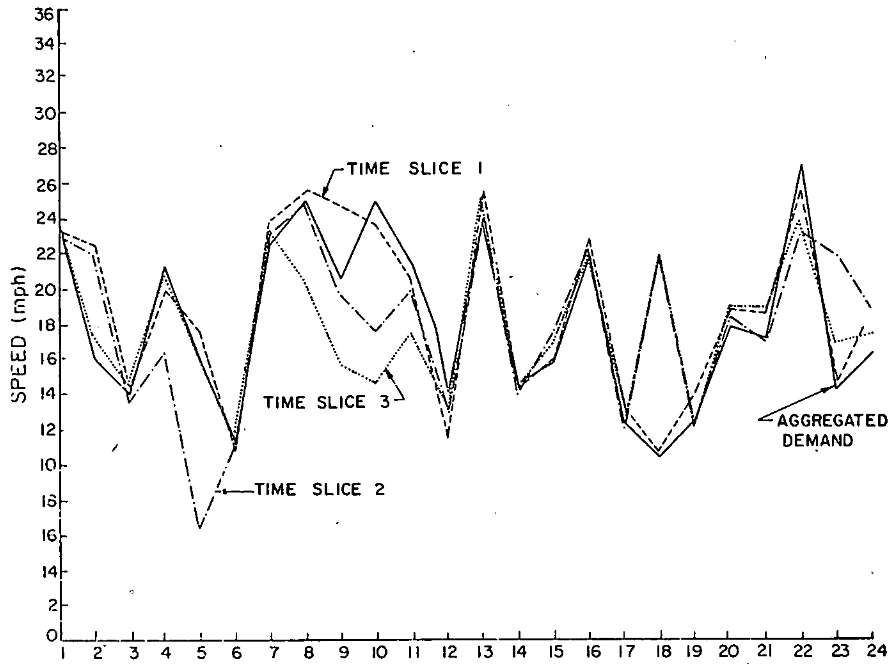



**Figure 2. Comparison of simulated section speeds for individual time slices and aggregated demand.**

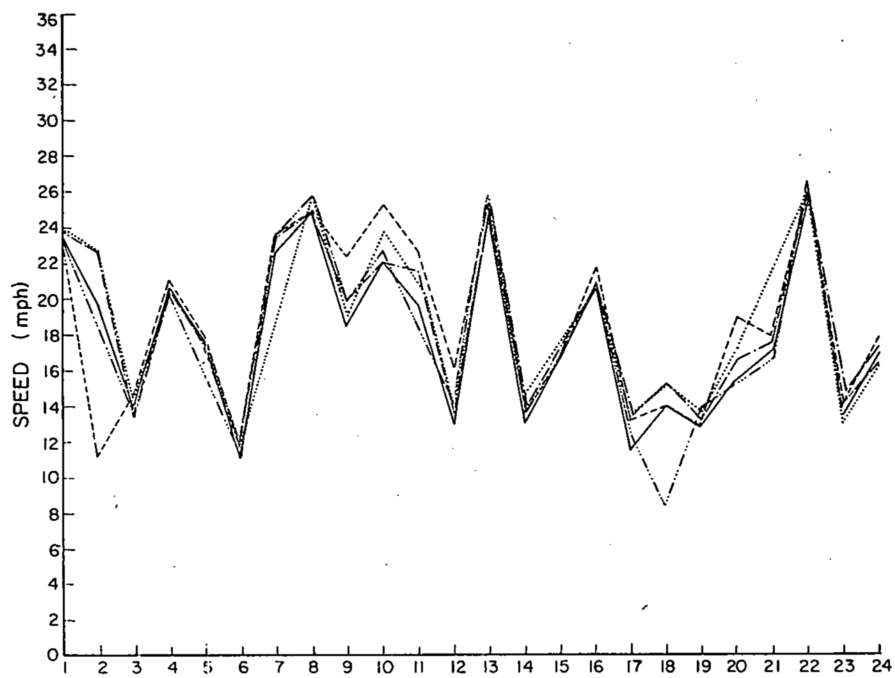



**Figure 3. Section speeds predicted by UTCS-1's use of simplified network and five different random number seeds.**

SENSITIVITY TO VARYING RANDOM NUMBER SEED

Simulation results are an estimate of the expected (or average) results that the model would produce with an infinite number of runs. A model will generally have some bias relative to reality. If the user can estimate these biases, the analysts can calibrate their models in an attempt to eliminate, or at least reduce, them. The expected performance of the model itself can be approached by increased replication of the simulation procedure, which is generally costly and therefore limited. In summary, a model's bias will generally be clouded by the random variation inherent in stochastic simulation. The extent to which this occurs is a function of the relative magnitudes of the bias and the random variation.

To obtain an estimate of the magnitude of the random error inherent in the results from a UTCS-1 model, the simulation of the Bloor Street network was performed five times under identical conditions, except that a different random number seed was used for each replication. The simplified Bloor Street network was used in each case and a 10-min period simulated at the aggregated hourly demand rate.

The speeds predicted by the model are plotted by link for each replication in Figure 3. A visual comparison of the various speed profiles indicates that there is little relative sensitivity to the random number seed, i.e., the intralink variation due to randomness is small compared with the interlink variation for our Bloor Street network when a simulation period of 10 min is used. The speed profiles of all five curves are quite similar. The average intralink variance is 1.9 with a corresponding standard deviation of 1.4 mph. This is small compared with the floating-vehicle variation, as might be expected, as the former represents a 10-min average, while the latter consists of only single vehicles. The results obtained from two of the five random number seeds were compared by using the UTCS-1 statistical package. The results of the statistical tests are summarized in the table below (note: FHWA no longer supports the UTCS-1 statistical package):

| Measure of Effectiveness | Statistical Test T-Test | Wilcoxon | U-Test |
|---|---|---|---|
| Vehicle trips | - | - | - |
| Travel time/vehicle | - | 1% | - |
| Delay time/vehicle | - | 1% | - |
| Average speed | - | 1% | - |
| Stops/vehicle | - | 1% | - |
| Percentage stop delay | - | 1% | - |
| Average saturation | - | 2% | - |
| Cycle failures | - | - | - |
| M/T ratio | - | 2% | - |

The Wilcoxon test consistently finds them to be significantly different while the other tests do not find a significant difference. The tests as performed by UTCS-1 are seen to be inconsistent. From a visual examination of Figure 3, it appears that the Wilcoxon test as performed by UTCS-1 may be concluding that significant differences exist where they may in fact not exist. In summary, UTCS-1's simulation results seem insensitive to the random number seed when a 10-min simulation period is used. This indicates that the random error involved in simulation with UTCS-1 is relatively small and therefore not of great importance. This is not surprising in light of the fact that UTCS-1 generated its exogenous input vehicles at regular intervals.

## CONCLUSIONS

UTCS-1 appears to predict traffic speeds quite accurately. The variation due to altering the random number seed is quite small, especially in comparison with the variation in floating-vehicle studies. UTCS-1 speed predictions are also relatively insensitive to aggregation of time slices. Therefore it is recommended that a potential user carefully study the peaking nature of the flows in the network prior to selecting a level of time aggregation. The Bloor Street study has indicated the potential cost and possible insignificant benefits due to meaningless disaggregation of flows into smaller subintervals when there is not a significant number of queued vehicles stored at the end of a subinterval.

UTCS-1 was not found to be sensitive to detailed modeling of the simulated Bloor Street network. It is therefore felt that most side streets and unsignalized intersections may not merit inclusion in a network model for UTCS-1 application.

Practical applications of the UTCS-1 model will generally require the services of a competent systems programmer, as it is felt that some modifications or additions to the program would usually be required. The model therefore seems more appropriate for application by the frequent user or a consulting UTCS-1 specialist.

A discussion of potential nonstandard applications of NETSIM and of potential pitfalls to users, based on our own experiences with UTCS-1, are noted below.

## POTENTIAL APPLICATIONS OF NETSIM

A potential application of NETSIM is in testing schemes for on-line traffic control. These would include varying the traffic signal green splits and cycle lengths. The form of the UTCS-1 model used in the Toronto study did not have provision for modeling the variation of splits and cycle length due to problems of offset transition. One of the purposes of that study was to determine what additions or alterations were required before UTCS-1 could be used to test offset-transition schemes. It was found that by making some modifications to the program the scope for application of UTCS-1 was increased. Specific modifications are discussed below.

### Altering Traffic Signal Cycles

The computer program did not allow the user to change signal control plans between two successive subintervals in a simulation run. It did not even print out an error message if one attempts to alter the signal operation. It simply ignores any such instructions.

The inability of the program to accept different signal control plans between subintervals was a drawback in the sense that it did not allow the user to study the effect on the network of signal transition from one control plan to another. Since much present-day traffic control research is geared to real-time or on-line signal control, it becomes necessary to change this aspect of this model. The first step toward real-time control strategy would be to introduce a large number of sequential fixed-time control plans, each plan lasting only for a short interval. To accomplish this another subroutine was added to the original UTCS-1 program. This new routine is almost identical to PRSIG (where signal codes are primed initially) in the original program. The only change is that the signal codes are read straight from the cards for the second and subsequent intervals instead of reading off the tape. The program is also modified to print out signal codes existing at the beginning of the second and subsequent intervals.

This feature then gave the user the option to study the effect on the network of changing from one control plan to another, and the user was then in a position to change splits, cycle length, and offsets between subintervals. Whenever a change is introduced at any one signal, it is necessary to input the signal codes for all the signals.

### Offset Transition

The computer program was further modified to study the offset transition in a network. Changes and modifications were performed on routine UPSIG. With those modifications the user then had the ability to study the effect of offset transition on network performance. The input requirements are the node at which offset has to be changed, the upstream node number of the approach link whose green phase marks the beginning of offset transition at the downstream node, the required change in offset, a code to indicate if the change is an increase or a decrease, and the step size during the offset transition. By using the above data, the program will take as many steps as possible with the given step size and one last step size if necessary. It is important to note that the program will take only one step per cycle and so the subinterval simulation time should be at least as large as the number of steps required multiplied by cycle length. Otherwise, the program will increase the simulation time to the minimum required value and a message to that effect will appear in the output.

Some of the limitations of this approach are as follows:

1. Offset transition begins only during a green phase.
2. The indicated green phase cannot have zero offset to start with. To overcome this, perpendicular approaches can be coded for transition, as their green phase is about half a cycle away.
3. Whenever there is a flashing green followed by a solid green, offset transition begins only during the solid green phase.
4. The offset transition is achieved with equal steps plus one step of different size if necessary.

The above modifications performed by a person who had not developed the original UTCS-1 model demonstrated that the model can be made to perform the types of operations required of it. These can be achieved through program modifications or the use of subroutines via the provided "windows". However, application of the model requires some intimate knowledge of the program and its routines. Therefore, the model does not seem compatible with the needs of a casual user. It is felt that a potential user should first have available a programmer who can understand and modify the program, as was the case in our study (1).

SOME POTENTIAL PITFALLS FOR NETSIM USERS TO NOTE

A few potential problems of which a prospective NETSIM user should be aware are cited here. Some of these are not outlined clearly in the available UTCS-1 documentation, while others have been learned from experience and/or trial and error.

1. Pedestrian flow levels cannot be specified on output links so that dummy internal links must be inserted to accommodate them.
2. Zero-valued exogenous flows must be specified in any time interval when it is required that they replace non-zero values. Otherwise the previous value will remain. This holds for both entry and internal links.
3. The embedded parameters are automatically assumed, if the user fails to choose one from the given set of alternatives. For example, the existing embedded parameters included a default value of 0.38 as the probability of left-turn jumps for any number of lanes at an intersection approach. For the Bloor Street network, the probability of left-turn jumps was much smaller, and a value of zero was used.
4. In order to fully use UTCS-1's vehicle dynamics capabilities the user has to add nodes and links to represent any significant midblock sources and sinks with stop signs. The mainline vehicles may be delayed by vehicles entering or leaving the roadway, especially the latter that can be particularly sensitive to pedestrian volumes.
5. Since statistics cannot be obtained on entry links, an additional link must be added in series if information is required for entering vehicles.
6. A vehicle can change lanes only when it reaches the tail of a queue or when it changes links at a node. It cannot switch lanes once it has joined a queue. This should be borne in mind when modeling a network.
7. If the data input is by cards and if the simulation run has more than one subinterval, type 88 cards are not to be used. Type 88 cards are necessary only if a data set stored on tape is used.
8. The program is not able to handle high left-turn volumes by using more than two lanes.
9. Our version of UTCS-1 did not have provision for changing splits, offsets, or cycle length from one subinterval to the next. The User's Manual was also not clear on this issue.
10. In specifying saturation flow headways at an intersection approach, the value should be obtained for a single through lane. The program calculates an appropriate value for lanes with turning movements or other friction factors.
11. The UTCS-1 assigns intersection movements at random according to the specified distribution until 80 percent of the subinterval has been processed. It then attempts some correction in the final 20 percent of the subinterval if the random procedure has overassigned or underassigned to any of the turning movements. Although this was not found to be a problem in the Bloor Street simulations, it does present a potential problem. To check this, it is recommended that a report be printed after 80 percent of each subinterval and the turning movement volumes examined at that point.
12. Since capacity can be very sensitive to the volumes of pedestrian conflict at intersections with significant turning movements, it would seem rather crude that it considers only four levels of pedestrian volumes. Furthermore, the applications manual (3) states that hourly pedestrian volume will suffice, which makes one question the model's sensitivity to pedestrian volumes, especially when these volumes were observed to vary considerably within the peak hour on the Bloor Street network. It is conceded that the collection of precise pedestrian volumes would involve a major effort if they were required.
13. Although it is stated in the Technical Report (3, p. 21) that non-constant headways can be used for input of vehicles into the network, the User's Manual (4) does not show how this can be accomplished.
14. A lane, when channelized for through movement and left turns or through movement and right turns, cannot be handled by this model.
15. A T-intersection cannot be handled directly as the model requires at least one lane in a link to be nonchannelized.

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