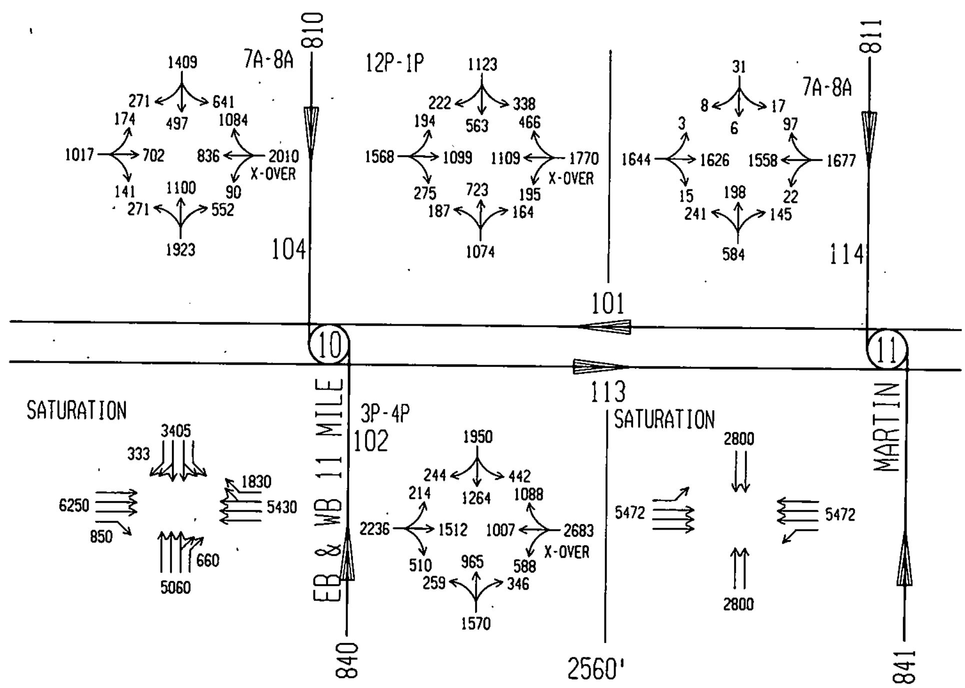


Figure 1. Example of combined NETSIM and TRANSYT computerized graphic.

3. Fixed-Time Signal Information Form
   10,11 Fixed-Time Signal Control
4. Actuated Controller Form
   15 Actuated Controller
5. Phase Information Form
   16A Actuated Phase
6. Phase Operation Form
   17 Actuated Phase Operations
7. Surveillance Information Form
   25 Surveillance Systems

The forms display program virtually eliminates the possibility of data being input into improper fields. The consolidation of many card types on one form reduces errors of omission significantly. The forms are limited to include only the most widely used card types. We are planning to expand the forms to include all card types and to allow a preprocessor program to edit the data before executing the model. The use of forms display has reduced our data entry time by 75 percent. In the long range, we hope to have the capability to interface a common data base to automatically create a coded network. This would greatly improve the data entry process.

CONCLUSION

The time for model simulation as a serious analytic tool has arrived. The growth and acceptance of NETSIM have exceeded all expectations. NETSIM was initially used as a supplement to reinforce traditional analytical methods. Today, the results from NETSIM analyses stand on their own merit.

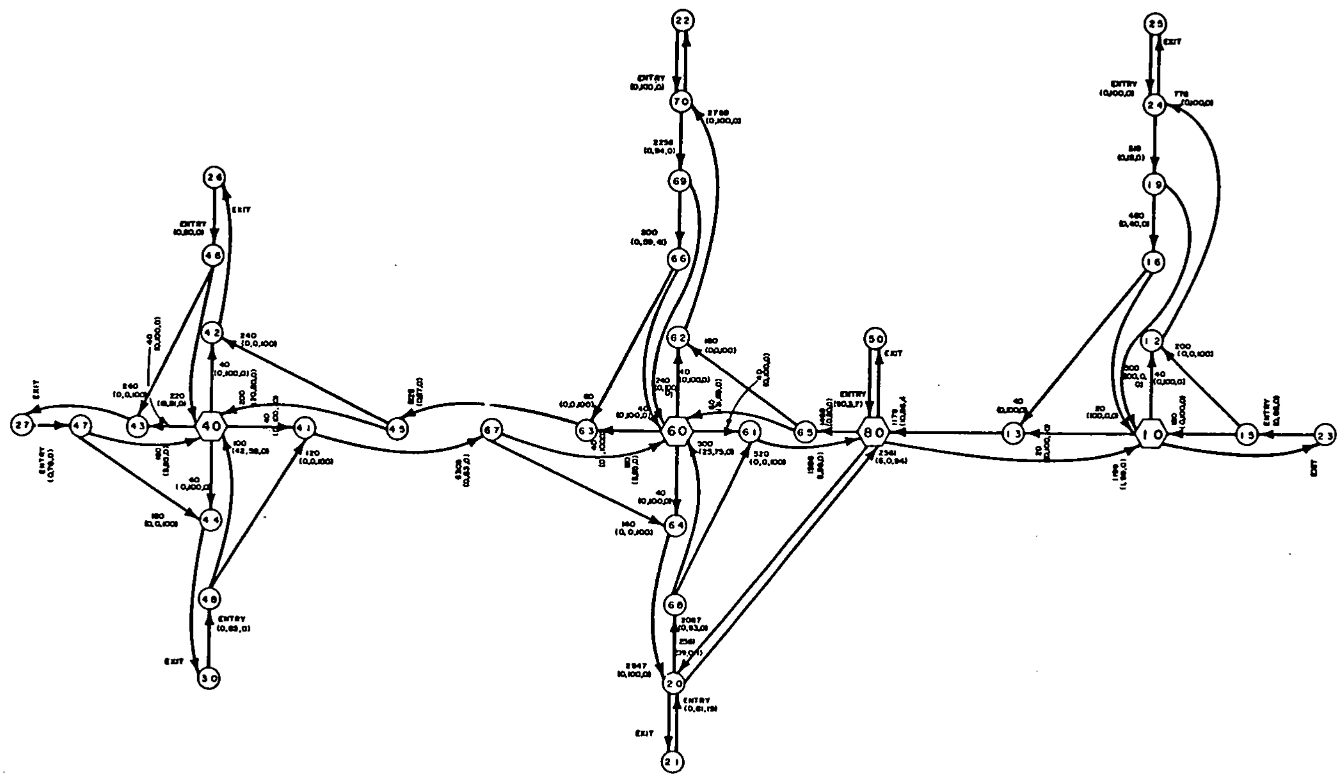
Application of NETSIM Computer Simulation Model to Traffic Control Problems

WILLARD D. LABRUM

Utah's experience with the NETSIM (then UTCS-1) model began in 1973 with a need to determine whether to use traffic-actuated intersection control or a fixed-time progressive arterial control in a small city near Salt Lake. Application was made to the National Highway Traffic Safety Administration (NHTSA) for a project to investigate the use of models to study traffic flow problems.

On receipt of project approval, the UTCS-1 (NETSIM) model was obtained from FHWA and modified for use on the University of Utah's 1108 UNIVAC computer. A network consisting of two intersecting arterials and adjoining streets in the Salt Lake suburban area was selected to test the model. All available personnel from our office simultaneously counted vehicles traveling in and out of the network through the morning and afternoon traffic peaks. The results were then compared with simulated results to determine if the model could be applied to obtain simulated results that reasonably compared with the observed traffic. A link node diagram of the network is shown in Figure 1. Statistical comparisons of vehicle volumes were made (t-test),

Figure 1. Link and node diagram for first test network.



which indicated no significant (at the 10 percent level) differences.

The model was then used to study a diamond interchange and a multiphased signalized intersection.

URBAN GRID STUDIES

The next development was a contract from FHWA to use the model on a variety of problems with an urban grid network the main focus of the study. The network selected was the downtown section of Ogden, Utah. This area was signalized with a fixed-time, single-alternative, single-dial system.

The first objective of the study was to improve the signal timing and coordination of the network. The link and node diagram for the network is given in Figure 2. SIGOP II was used to develop an alternate time plan. The alternate plan was then used in the simulation model and compared with the existing system. The results showed that the proposed plan was slightly less efficient than the one in use.

PEDESTRIAN STUDIES

A problem that arose during the Ogden study was that of pedestrian strategies proposed by city government officials reacting to pressures from the business community. Merchants desired to accommodate potential customers to the greatest extent possible. The Ogden city traffic engineer was requested to consider traffic control strategies that would facilitate pedestrian traffic as much as possible. The specific strategy requested for study was that of a "scramble" system, and the city traffic engineer was interested in the effect of signalized midblock pedestrian crossings and of pedestrian grade separations. The scramble system was simulated at six intersections on Washington Boulevard, the main arterial in the Ogden network.

In order to simulate pedestrians crossing the streets at these intersections, diagonally or in any direction they so desired, a 30-s, all-red signal phase was introduced in the network. The results indicated that excessive delay to vehicular traffic would result. (See Figure 3 and Table 1.)

Another technique that was investigated was midblock crossings with pedestrian-actuated signals. To simulate this strategy with NETSIM, it was necessary to improvise a method for input of pedestrian volumes, since the model does not provide for an input of pedestrian flow at midblock crossings or a pedestrian-actuated signal system. The technique that was developed consisted of placing an entrance and an exit link at the midblock position, thus causing the model to accept the pedestrians as vehicles. After several attempts with various strategies, it was decided to represent pedestrians as 4-ft-long trucks traveling at 4 ft/s for input to the model. The link and node diagram for this is given in Figure 4. The results are shown in Table 2.

BUS SYSTEM

The Ogden study included an analysis of the bus system's effect on traffic flow when it was proposed to improve bus service by doubling the number of bus trips into the central business district (CBD). Because of computer costs, the network was reduced in size to an abbreviated bus network (Figure 5). Table 3 compares measures of effectiveness (MOE) for the network with no buses, existing bus service, and increased bus service. Figure 6 is an enlarged drawing of the critical CBD area affected by the buses, and MOEs for these links are compared in Table 4.

OTHER STUDIES

Two other studies might be mentioned. One is an

Figure 2. Link and node diagram of Ogden, Utah.

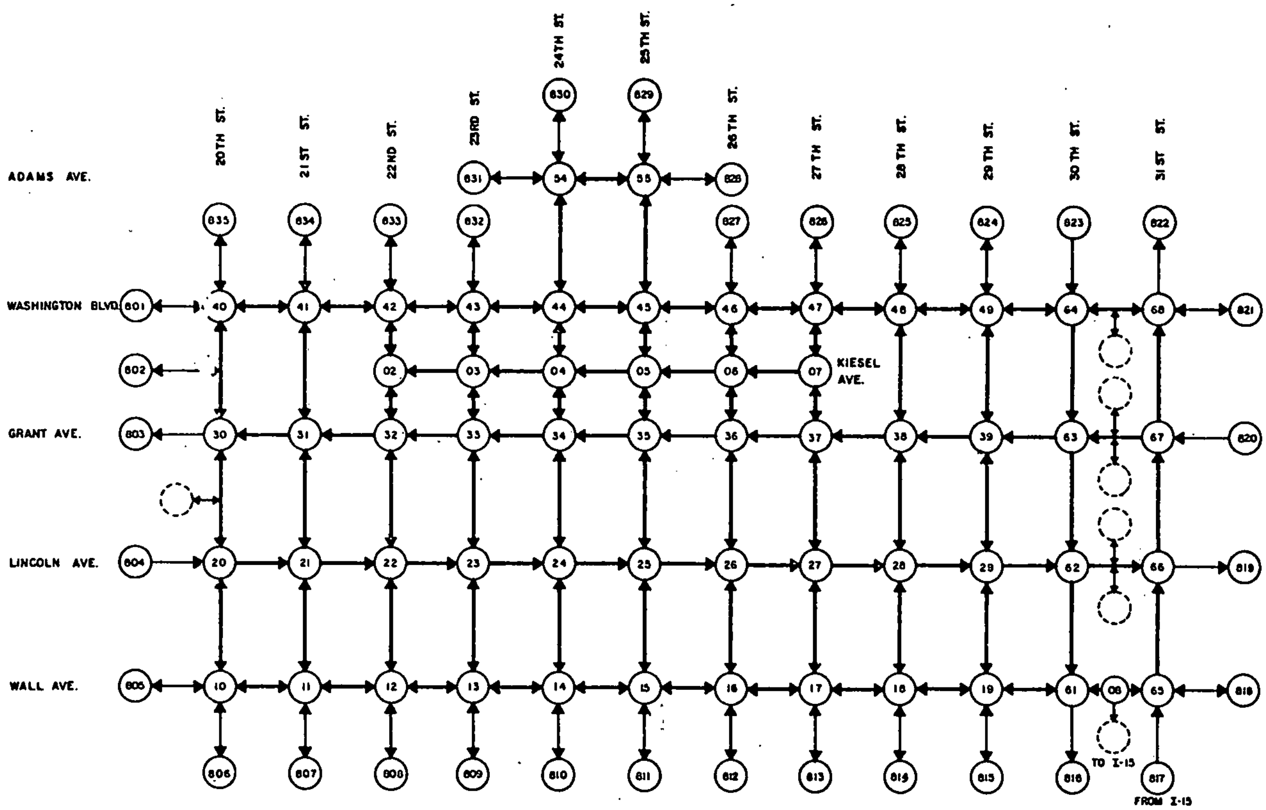


Figure 3. Link and node diagram for pedestrian scramble system.

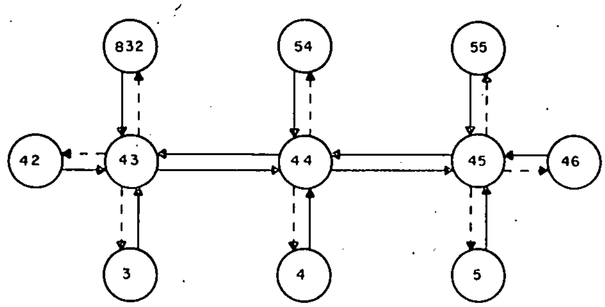


Table 1. Scramble system pedestrian phasing comparison.

Factor	Total Delay (vehicle min)	Delay per Vehicle (s)	Delay per Vehicle Minute per Vehicle Mile	Avg Speed (mph)	Stops per Vehicle
Existing	115.75	9.36	1.19	18.93	0.42
80-s double alternate	142.45	11.53	1.49	17.87	0.42
80-s scramble system	319.66	29.07	3.48	11.10	0.87

Figure 4. Link and node diagram for pedestrian crossing study, Ogden.

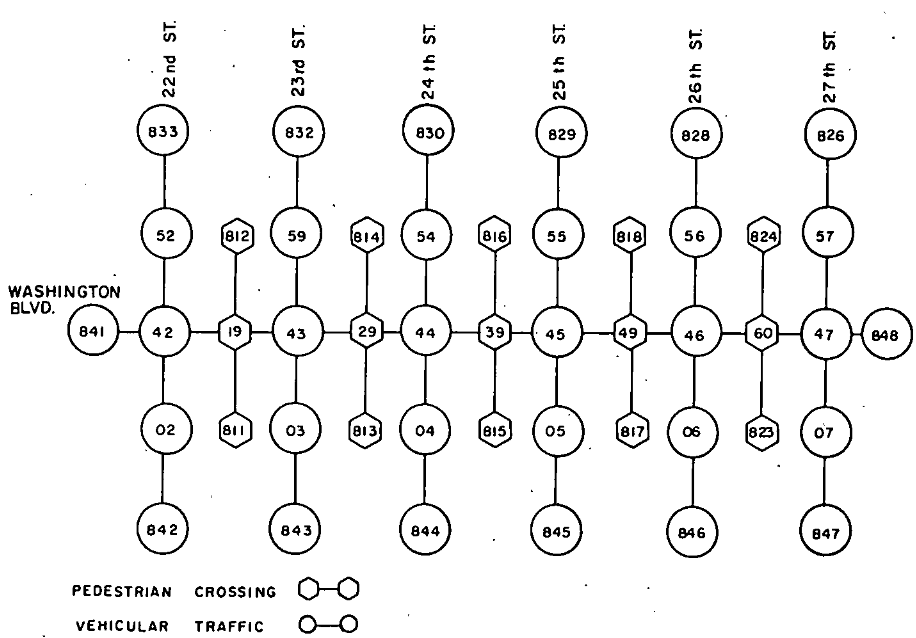


Table 2. Washington Boulevard pedestrian crossing strategy evaluation.

Factor	Total Delay (vehicle min)	Delay per Vehicle (s)	Delay per Vehicle Minute per Vehicle Mile	Avg Speed (mph)	Stops per Vehicle
Existing	735.3	27.47	1.28	18.10	1.105
Pedestrian overpasses	569.90	9.6	1.20	19.27	0.367
Signalized midblock crosswalks	1636.50	62.43	2.87	12.25	2.55

Table 3. Ogden network simulation bus-routing study.

Factor	Peak Period[a]	Total Delay (min)	Avg Speed (mph)	Delay per Vehicle (s)	Stops per Vehicle
No buses	p.m.	1214.3	18.96	42.04	1.92
	a.m.	1109.1	19.15	39.01	1.77
Buses: existing headway	p.m.	1506.6	17.51	50.78	1.87
	a.m.	1591.1	16.80	55.70	1.88
Buses: one-half headway	p.m.	1763.7	16.32	59.72	1.99
	a.m.	1848.2	15.64	65.00	1.92

[a]Peak period = 7:30-7:45 a.m.; 3:45-4:00 p.m.

Figure 5. Ogden CBD abbreviated bus network.

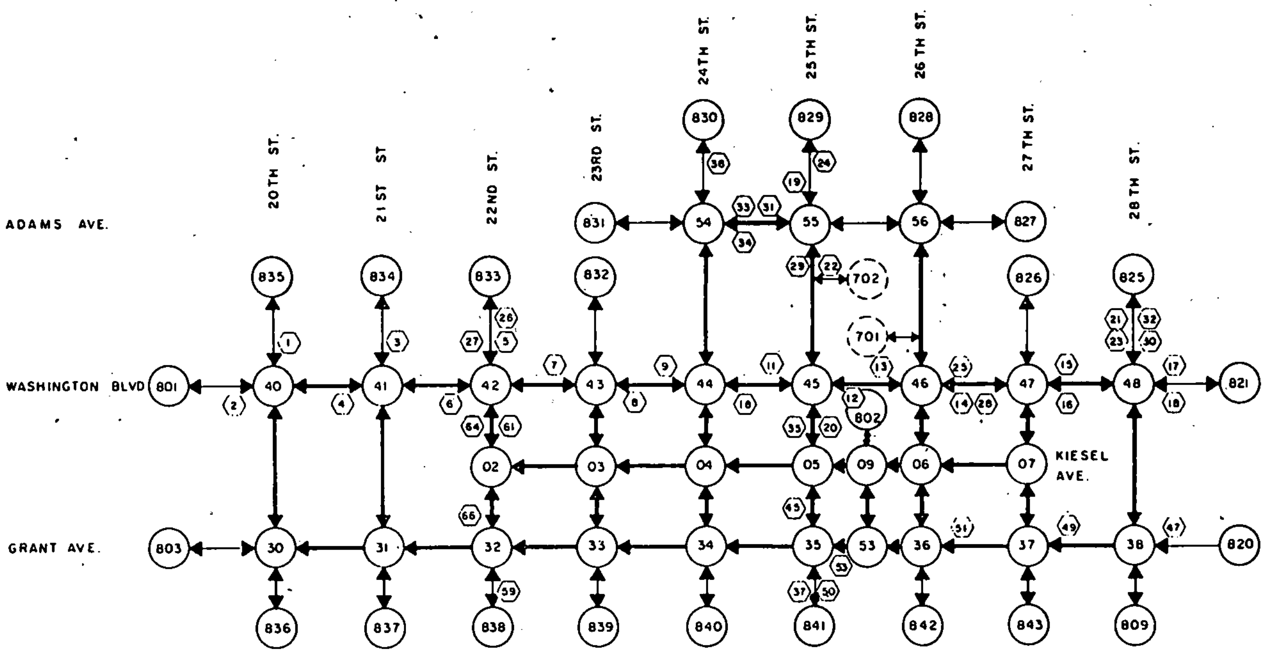


Figure 6. Link and node diagram of critical area, Ogden bus network.

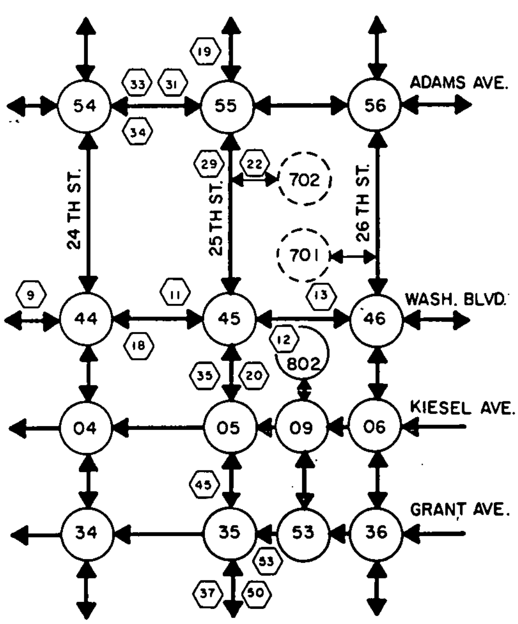


Figure 7. Link and node diagram of I-80 detour study, Salt Lake City.

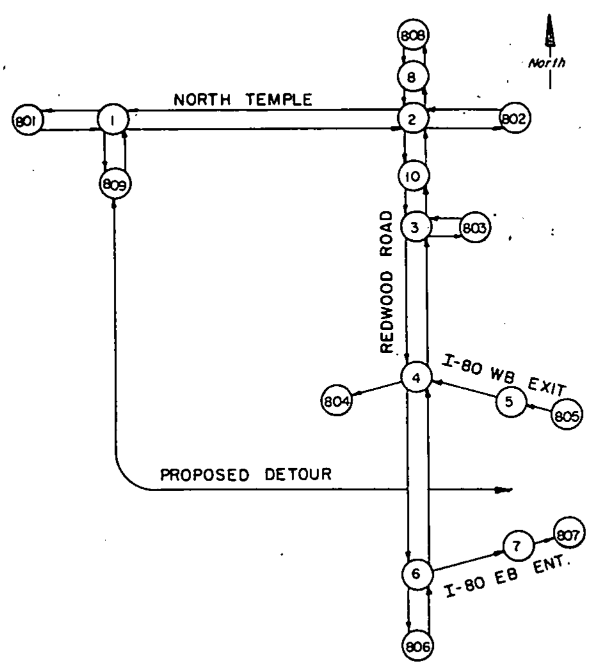


Table 4. Delay by link for Ogden bus network for 15-min simulation.

Condition	Link Identification (delay in vehicle min) 5-45	44-45	45-46	48-47	43-44	44-54	45-44	46-45
A.M. peak								
No buses	6.6	41.3	46.8	31.1	38.0	41.3	48.7	40.0
Buses: normal headway	174.5	89.5	171.0	36.6	47.5	13.8	104.7	48.4
Buses: one-half headway	205.6	139.7	142.6	46.3	57.5	11.0	176.8	92.2
P.M. peak								
No buses	18.1	43.5	32.8	39.7	47.6	49.1	39.3	30.3
Buses: normal headway	91.4	79.0	126.7	58.3	65.6	48.8	129.2	79.3
Buses: one-half headway	153.1	132.0	138.5	66.1	65.7	48.6	147.6	73.5

economic analysis to decide on construction of a detour at the termination of Interstate 80 in West Salt Lake. The proposed detour would route westbound I-80 traffic around a high-volume intersection (Redwood Road and North Temple, US-40). The link and node diagram is given in Figure 7, and the analysis is shown in Table 5. The detour was completed and has been operative for several years.

The fuel and emissions option of the NETSIM model was used in a number of studies. Table 6 illustrates comparisons for various traffic control strategies used in the Ogden study.

In 1979, FHWA authorized a project with the Utah Department of Transportation (UDOT) to revise the report of studies previously completed for use as a case studies technology transfer report. In addition, a coding handbook was prepared along with instructor materials and visual aids to conduct a pilot two-day training course. This was completed in 1980. One pilot course has been conducted, and two more are planned in 1981. One session of that course will be presented if enough interest by conference participants is indicated.

In the last two years, UDOT has applied the model to more complex problems. One use has been to apply the model's ability to simulate a dual-ring, eight-phase controller to several single intersections where three-phase signal timing strategies have been used. The link and node diagram and intersection plan for one of these are illustrated in Figures 8 and 9. Before and after phasing diagrams are illustrated in Figures 10 and 11. MOE comparisons are shown in Table 7.

Probably the most difficult application of the model is that of simulating coordinated, actuated intersections of an arterial or grid network. Riverdale Road in Ogden is an example. Time-space relationships are shown in Figure 12. MOE comparisons are given in Table 8.

When the model is applied to more complicated control systems, more caution must be exercised in using simulated results. The model is limited to semi-actuated, four-phase signalization for coordinated systems. If a more complicated system is being studied, it is necessary to make assumptions in use of the model to avoid the four-phase limitation. Drawing conclusions from simulated results should be done very carefully to prevent erroneous decisions.

A study of a southwest Salt Lake area is under

Table 5. I-80 detour economic analysis.

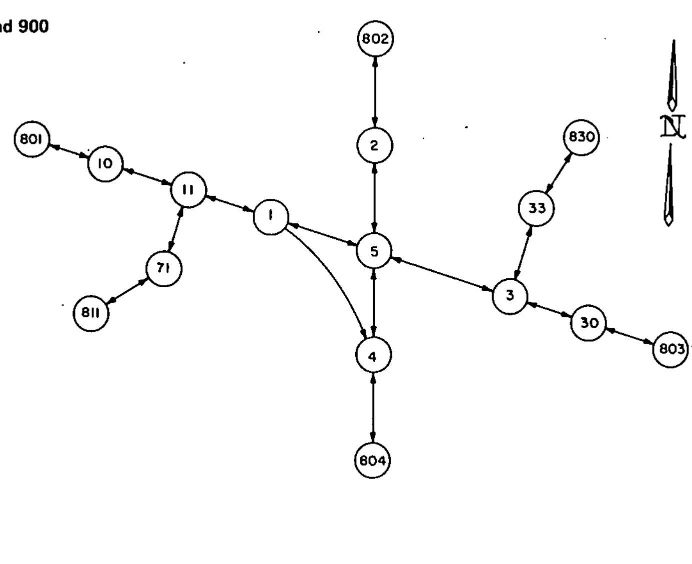
Item	Detour Closed	Detour Open	Daily Savings
Delay A.M. peak (vehicle min)	3094.4	1415.6	1678.8
Delay P.M. peak (vehicle min)	2005.2	1678.0	327.2
Total savings in delay (vehicle min)			2006.0

Savings per year = 2006 vehicle minutes x $0.06/vehicle minute x 5 days/week x 52 weeks/year = $31 295; present worth of $31 295/year for 10 years at 8 percent = $209 990; construction cost estimate = $164 000; annual maintenance cost for detour (estimated) = $610; present worth $610/year for 10 years at 8 percent = $4093; benefit/cost ratio = value of benefit/cost of project; benefit/cost ratio = $209 990/$164 000 + $4093; and benefit/cost ratio = 1.25.

Table 6. Ogden abbreviated bus network.

Item	Total Delay (vehicle min)	Delay per Vehicle (s)	Delay per Vehicle Mile (min)	Avg Speed (mph)	Stops per Vehicle
Existing: 50-s cycle	385.2	40.48	1.07	18.95	1.81
SIGOP II +: bandwidth 70-s cycle	478.83	52.17	1.34	17.22	2.13
Double alternate: 80-s cycle	516.4	53.15	1.42	16.95	2.05

Figure 8. Link and node diagram of Van Winkle Expressway and 900 East, Salt Lake City.



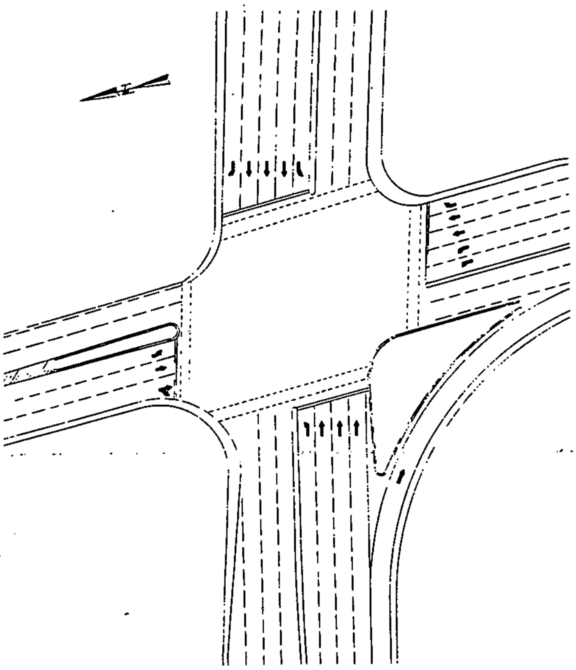


Figure 9. Van Winkle Expressway and 900 East intersection geometry.

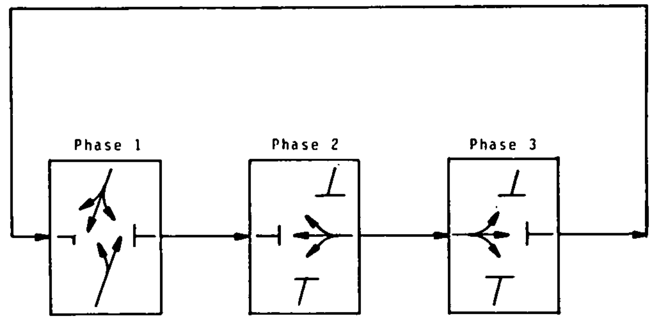


Figure 10. Van Winkle and 900 East before signal-phasing diagram.

Table 7. MOEs for Van Winkle and 900 East (Salt Lake City).

Item	Three-Phase Actuated (before)	Six-Phase Dual Ring (after)
Vehicle mile	113.66	117.78
Stops per vehicle	0.86	0.84
Vehicle trips	648	671
Delay per vehicle (s/vehicle)	80.41	73.83
Delay per vehicle mile (min/vehicle mile)	7.64	7.39
Avg speed (mph)	6.65	6.82
Total delay (min)	868.4	825.7
Gasoline (gal)	22.18	21.62

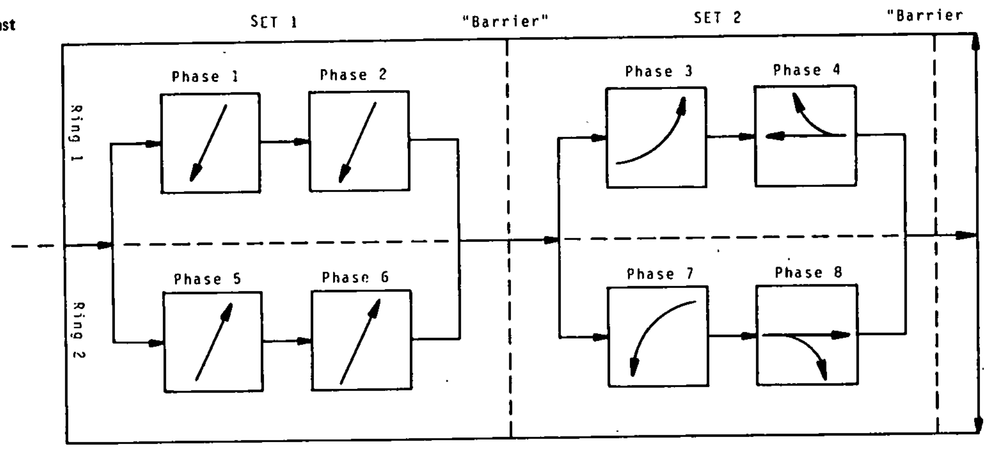


Figure 11. Van Winkle and 900 East after signal-phasing diagram.

way to determine changes in the street network to accommodate future growth expected in that and adjacent areas. This area has recently been incorporated as West Valley City. Traffic growth predictions were supplied by UDOT's Planning Division. The network is shown in Figure 13. The NETSIM model was used to simulate 2005 volumes on the existing street system. Minimal improvements, such as intersection widening and signalization, were selected for critical locations and simulated with NETSIM. Based on simulated results, user costs were estimated. The project is still under way; under consideration is the building of a new arterial facility north-south through the network. This "build" option is shown in Figure 14. By this analysis method, it is expected that staged improvements can be made to meet the most critical needs and minimize the cost of improvements. Comparison of some of the MOEs are shown in Table 9. This method of analysis has been used very effectively for this problem.

If a problem to be solved begins with an existing or before condition, the initial simulation of the problem can be compared with observations in the field. It is not difficult to determine if the simulation reasonably represents the field condition. When the problem remedy has been determined, the simulated results can be compared with the before simulation. Confidence in simulated results can only be developed through experience.

The final example is a before-and-after study required by FHWA on a signal demonstration project. Two east-west parallel arterials were put under computer control. The objective was to coordinate them to attain better traffic flow. Both systems intersect with a freeway (I-15) and two six-lane arterials (State Street and 700 East). The link and node diagram is shown in Figure 15. Because of the long cycle length at these intersections, coordination of all intersections cannot be attained by the model. These three intersections were allowed to run free with the remaining intersections coordinated by the computer. Comparing before and after results of the simulation proved inconclusive. The new coordinated system did not show any significant improvement over

Figure 12. Time-space diagram for Riverdale Road coordination study.

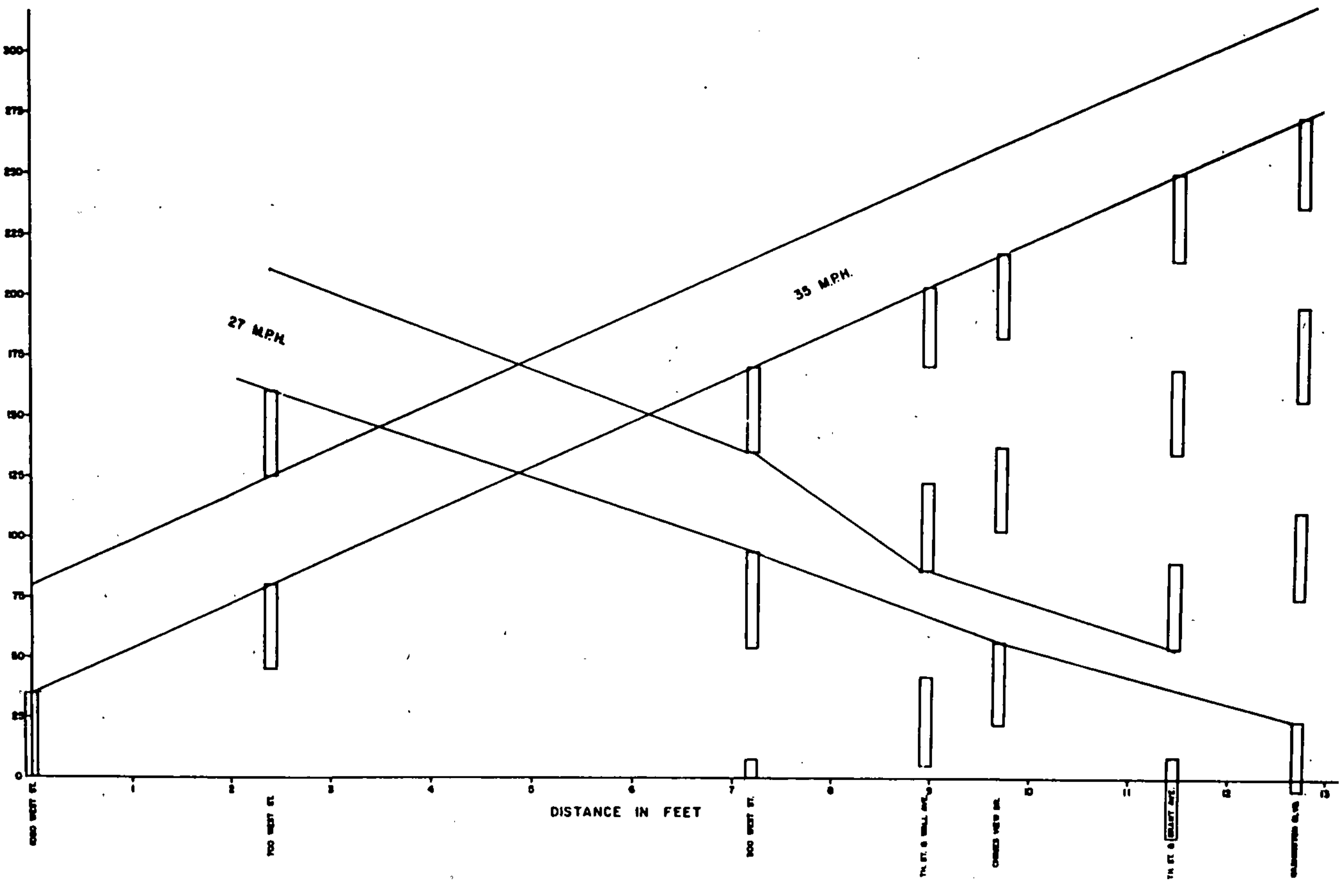


Table 8. Riverdale Road comparison of MOEs (coordination study).

Period	Vehicle Miles	Vehicle Trips	Avg Speed	Total Delay (min)	Avg Delay per Vehicle (s)	Stops per Vehicle	Stopped Delay (%)
	Comparison of MOEs (p.m. peak)						
Before	8007	7692	23.77	7 890	61.55	1.41	47.8
After	6317	6696	14.69	16 011	143.47	1.44	82.0

Figure 13. West Valley study network.

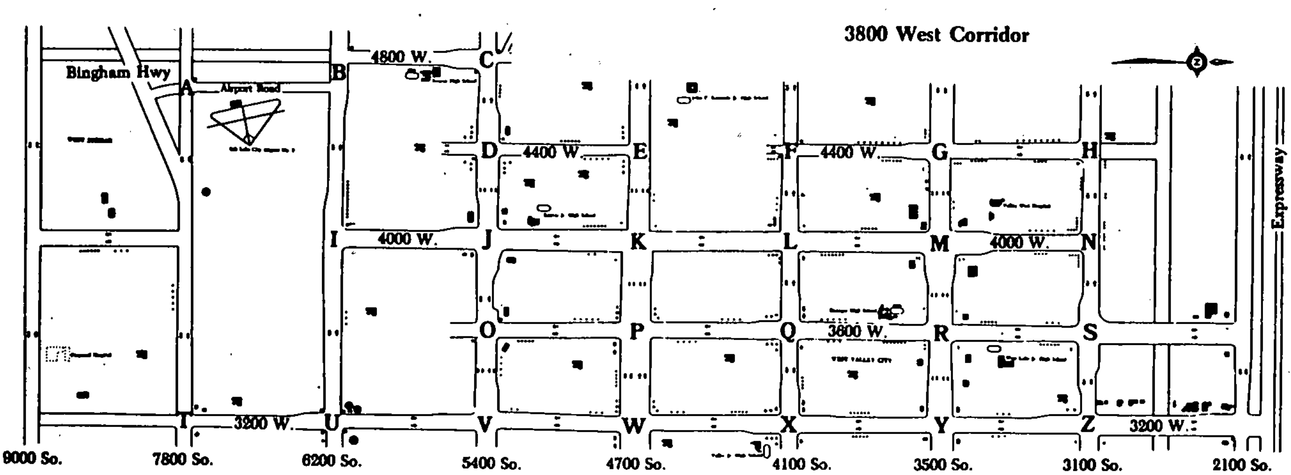


Figure 14. West Valley study build-option network.

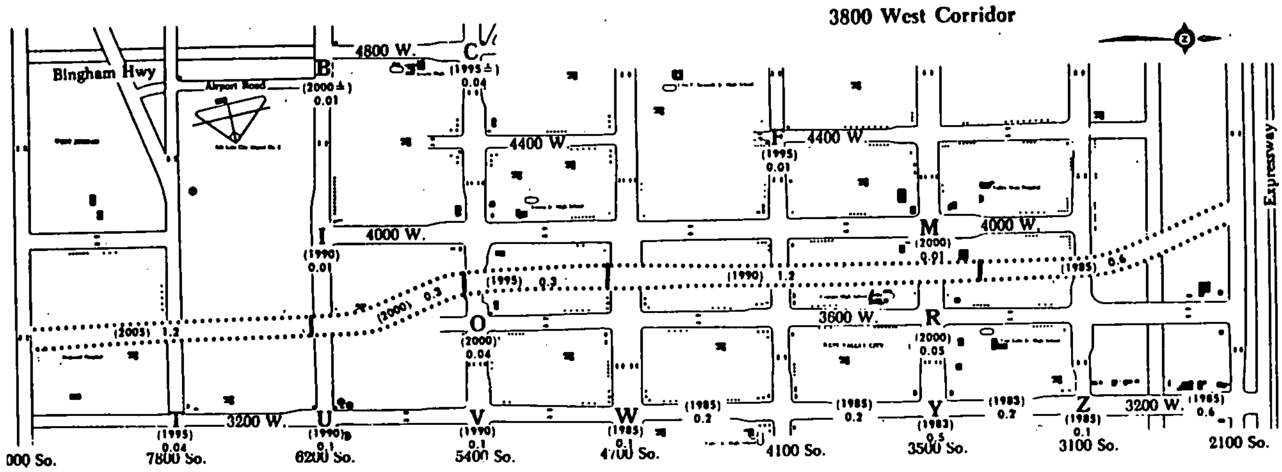


Figure 15. 3300 South (Salt Lake City) arterial computer coordination study.

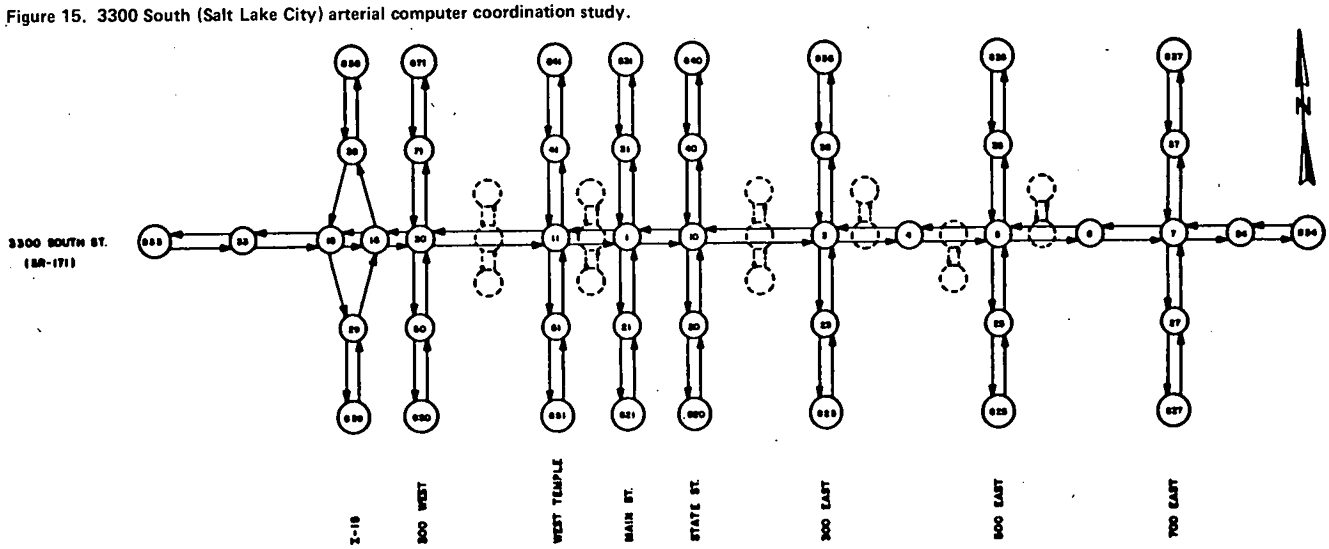


Table 9. User cost analysis for West Valley City.

Factor	3200 West Network	Total West Valley Network
MOE		
Travel (vehicle miles)	113 590	283 975[a]
	158 830	397 075[b]
Vehicle trips	151 564	378 910[a]
	170 568	426 420[b]
Moving time (vehicle hours)	3 229	8 073[a]
	4 445	11 113[b]
Total delay (vehicle hours)	2 989	7 473[a]
	3 134	7 835[b]
Avg speed (mph)	18	18.3[a]
	21	21.8[b]
Projected User Costs ($/day)		
Without TSM improvements	25 000	62 500
With TSM improvements	24 100	60 250

[a]Without transportation system management improvements.
[b]With transportation system management improvements.

the before system. This example demonstrates a present limitation of the model.

DISCUSSION OF RESULTS

The technique developed for using the model is a simple before and after comparison of alternatives. Selecting MOEs for comparison is determined by the application. There are a few precautions that must be observed:

1. Be sure the simulated system adequately represents the alternative being studied.
2. Examine simulated results in detail using link statistics. Look for queue locations.
3. Make sure simulated signal systems are operating as designed. Use the output feature of frequent printouts to check the status of signal phases.
4. When comparing before and after simulated results, use the same input volumes. There will probably be times when observed volumes may be used, but if so be cautious in making comparisons.
5. Remember simulation is not the real world. Apply all results by using good judgment that comes from experience. If results look unreasonable, do not use them.

SUMMARY AND CONCLUSIONS

The NETSIM model has been used extensively to evaluate traffic control strategies for single intersections, arterials, and grid networks. Pedestrian control problems have been analyzed, bus system plans have been studied, and fuel consumption and emissions analyses have been applied to a variety of systems. Economic analysis has proved useful in many studies as well as for decision making in design projects.

More recently, coordination of actuated signal systems on arterials has been attempted with some success. Planning studies are presently under way.

NETSIM has been applied to a fairly wide variety of problems with satisfactory results, but how accurate these results are is likely to be the most frequently asked question. It must be remembered that all the results and values (MOEs) derived from simulation are not precise field measurements. Simulation is a means of making reasonable approximations of operating control systems for comparison purposes. Our experience is that these approximations are useful and generally within accuracy limits in measuring traffic flow (daily and monthly variations, etc.). It provides a means to analyze problems that are difficult or impractical to approach by any other means. Results have been used for decision making in numerous problems, and no real failures have been experienced. NETSIM has been well supported by FHWA, and its continued support is urged. Capability to simulated, more advanced control technology is recommended. Plans are under way for some of these. Simulation of computer-controlled systems would be a desirable goal. This capability would help avoid costly and embarrassing errors in the design of those systems.

NETSIM is a very useful tool. It is highly recommended for solving a wide variety of control problems.

ACKNOWLEDGMENT

Acknowledgment of assistance in the work leading to this paper is given to David R. Gibson, FHWA HDV-21, contract manager, and to Steven L. Cohen, FHWA HRS-31, for updating and correcting computer tapes and providing valuable assistance with problems.

The assistance of Donald E. Godfrey, Ogden city traffic engineer, who provided a large amount of the field data and cooperated in the Ogden studies, is appreciated.

Thanks are also extended to UDOT personnel--Elva Anderson, Ernie Pais, Wayne Lyon, Robert Walsh, and Ralph Farr--and others for data gathering, typing, drafting, and other assistance.

Traffic Flow Simulation: User Experience in Research

Jamie W. Hurley, Jr., and Ahmed E. Radwan

Traffic simulation computer programs have long been viewed as practical and effective tools for analyzing traffic flows, especially when one considers the expense and time required to collect and analyze field data. In addition to being used for operational purposes, some of these programs, especially those based on microscopic flow simulation, have been used for research. This paper describes experiences encountered while using traffic simulation for research at Virginia Polytechnic Institute and State University (VPI). Because of its scope and considerable potential as a research tool, the experience described is confined to the NETSIM microscopic traffic simulation program (1). A brief description of the NETSIM program is presented in the following section.

NETSIM PROGRAM

The NETSIM program is a microscopic traffic simulation model developed for FHWA to evaluate traffic control strategies in urban street networks. NETSIM (formerly called UTCS-1) was designed for use by both researchers and practitioners. The basic NETSIM model enters individual vehicles into a network through source nodes and entry links. As each vehicle is generated, it is stochastically assigned a set of performance characteristics, such as vehicle type, average discharge headway, average acceptable gap, etc. Each vehicle's movement through the network is then controlled by its assigned performance characteristics and microscopic car-following, queue-discharge, and lane-switching algorithms and by the assigned link turn percentages. The basic model has the capacity to handle 99 intersections, 160 links, and 1600 vehicles at any one time. However, these limits may be increased by changing the dimensions of the arrays that define the size of these parameters.