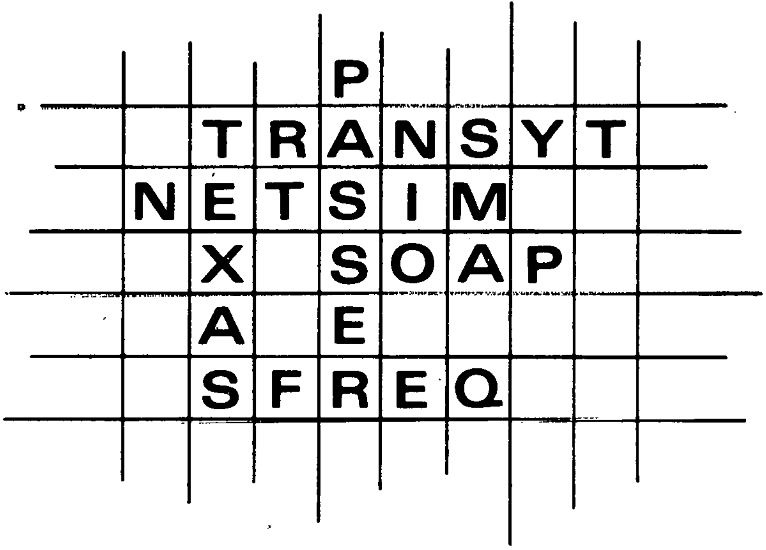
The Application of Traffic Simulation Models

Special Report 194



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The Application of Traffic Simulation Models

Special Report 194

Proceedings of a Conference on the Application of Traffic Simulation Models, June 3-5, 1981, Williamsburg, Virginia

conducted by the Transportation Research Board

and

sponsored by the Office of Development, Federal Highway Administration, U.S. Department of Transportation

NATIONAL ACADEMY OF SCIENCES
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The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competence and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

The views expressed in this report are those of the authors and do not necessarily reflect the view of the committee, the Transportation Research Board, the National Academy of Sciences, or the sponsors of the project.

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WORKSHOP SESSIONS—I: APPLICATION OF SIMULATION MODELS BY DIFFERENT USER GROUPS

WORKSHOP SESSIONS—II: TECHNICAL ISSUES IN SIMULATION MODELING AND APPLICATION

Preface

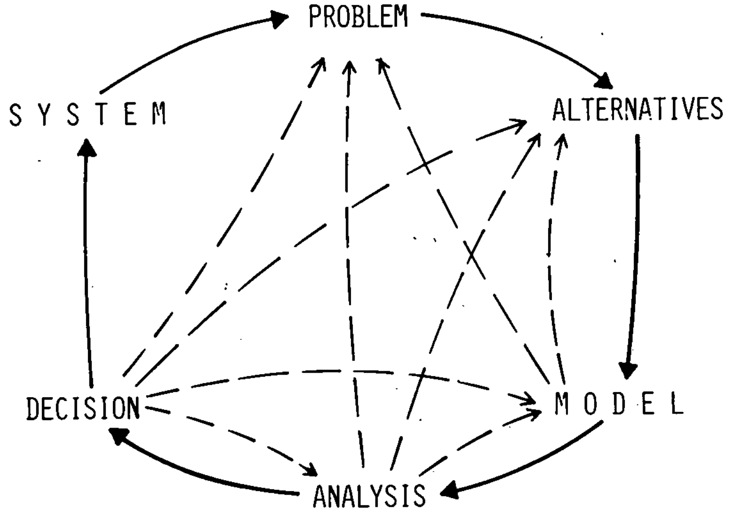
Traffic simulation models were the subject of a conference, conducted by the Transportation Research Board (TRB) on June 3-5, 1981, in Williamsburg, Virginia. Sponsored by the Implementation Division of the Federal Highway Administration (FHWA), the conference had two general objectives. The first was to inform the user community about what models are available and what is being planned in their further development. In large measure, the distribution of this report is the principal means of achieving that objective. The second was to obtain feedback from the user community on its past and present experiences in the application of simulation models and the needs that became apparent as a result of that experience.

Planning for the conference was accomplished by a steering committee, selected by TRB and chaired by Donald E. Orne. FHWA liaison members were David R.P. Gibson, H. Milton Heywood, and Gary Euler. The steering committee designed the program content, identified program participants, prepared resource papers, and led sessions during the three-day meeting. Nathan H. Gartner, a member of the steering committee, also served as conference editorial consultant.

Some 75 persons attended the Williamsburg meeting. They represented all groups with an interest in traffic simulation models: researchers, developers, and users from universities, consulting firms, and government agencies at the local, state, and federal levels.

This special report provides the edited texts of the resource papers presented at the conference, the workshop summaries, and an overall summary of the conference and its findings. These findings were approved by the steering committee (see Part 2). These proceedings also include a collection of other contributed papers generated by the conference.

Part 1
Introduction



Welcoming Remarks

Milton P. Criswell

I would like to explain briefly why FHWA sponsored this conference and what it expects to achieve by holding it. As you may be aware, the Office of Development is charged with major responsibilities for the FHWA technology-transfer function. Our job is to assure that potentially usable research results are translated into a form that accelerates their application in an operating environment. To accomplish this job successfully, technology transfer involves many factors. Three that I am going to highlight involve, first, informing the potential user community of the availability of the new technology; second, assuring that the technology has been translated into an acceptable user language; and, third, making adequate technical assistance available to help the user during initial trials.

This conference was conceived by FHWA to assess and address its experience to date on these factors in the traffic simulation area. FHWA asked TRB to organize this conference because of its well-known reputation for conducting successful transportation-related conferences.

In the past decade, a variety of traffic analysis tools has been produced from research programs in FHWA's Traffic Systems Division in the Office of Research. The TRAF family of traffic simulation models and, in particular, the NETSIM traffic network analysis model show significant real-world potential. Accordingly, the first objective of this conference is to inform you of FHWA's plans concerning these models. The second objective is to obtain feedback on FHWA's past work and planned future work with the NETSIM program so that the implementation process with the new TRAF models coming on-line, such as TRAFLO and FRESIM, can benefit. As part of this process, we should gain a better understanding of what users, such as you, assess as the most important needs and the best ways for FHWA to address these needs.

To gain a better understanding, it is important that the various user groups that utilize traffic models be involved in the process. These users include cities, states, universities, and consultants. Users can also be classified in terms of program managers, teachers, design engineers, planners, etc. The wide variety of users by both jurisdiction and functional specialty led to the by-invitation-only development of this conference so that the cross section of users could be controlled to reflect the actual user communities. To this end, the 75 participants registered at this conference represent the following groups: state and local government, 34 percent; consultants, 24 percent; academia, 22 percent; and federal (including other), 20 percent.

To get the proper balance between informing and obtaining feedback from you, we asked the conference steering committee to formulate an agenda balanced among papers on planned activities, user experience reports, and workshop discussions. The people who organized the conference have done this job. Now it's up to you to "milk it for all it's worth".

Most of you have extensive experience in the use of traffic simulation models. The opportunity is here to learn from others with equal experience; to meet the key individuals involved in a similar activity; to enhance user interchanges among people with similar experiences, needs, problems, solutions, and understanding; and to foster better communication, needs identification, and problem-solving activities. You are a nucleus of key experienced people in traffic simulation models and, I believe, have a major responsibility for making the technology go forward.

To make it happen, therefore, it is important for you to give of yourselves and share your knowledge. Questions are as important as answers. I expect that working relationships and friendships will be developed that go far beyond the limits of this conference.

In conclusion, the conference feedback will provide input into FHWA's planned program for implementation of a wide range of future traffic-simulation-model activities. I am confident that the conference will meet its objectives.

Role of Simulation in Traffic Engineering

(Thoughts on Accepting and Using New Analysis Techniques)

Donald E. Orne

This conference is aimed at advancing, perhaps even promoting, the use of simulation models as working tools in the field of traffic engineering. Because we are convinced that some models are ready for wider use, we want to bring about an expanded dialogue among traffic engineers to facilitate greater understanding of the practical value of simulation modeling and to accelerate efforts toward overcoming implementation barriers. We can improve our abilities to authoritatively and persuasively select and seek approval for traffic improvement programs if we help each other to gain additional technical capabilities both at this conference and in the profession at large.

This is a challenge. But your presence here demonstrates your commitment to this objective. Our conviction that several models are ready for wider application along with our collective action toward implementation can begin to bring about significant advancement in their use as traffic-engineering problem solvers.

I have a concern, however, that we may be somewhat presumptuous in thinking that our unsolicited help will be welcomed by the typical traffic engineer or transportation manager. This suggests to me that we need to spell out why these ultimate users will be interested in what we have to say. We must clearly identify the problem we are trying to solve.

Traffic operations improvement projects have characteristically been designed and carried out by a specialized group of engineers who have focused on pragmatic solutions to problems. These engineers, whose function evolved from street traffic enforcement, often have had only a limited theoretical background on which to base their decisions. The technical explosion of the last two decades, in many respects, has increased the difficulty of the job. We have been catapulted from an environment where cause-and-effect relationships were unknown or uncertain to one in which we are overwhelmed by what appears to be an unmanageable set of variables, constantly changing analytic tools, and continued uncertainty about cause and effect.

We can demonstrate that simulation offers a better way to comparatively evaluate alternate solutions to one problem or competing solutions to several problems. We can also enhance our abilities, through increased objectivity, to devise and recommend acceptable improvement programs.

I contend, then, that we do have a legitimate role at this conference that will receive enthusiastic support from the user. This role is to reduce to practice a framework that provides badly needed, fast, accurate, and reliable analytic tools to either solve multivariate traffic operations problems or compare complex and costly alternatives before they are executed. We can provide a reliable means of predicting the outcome of several possible courses of action in situations that involve factors so large and complex that conventional analytic methods do not offer much assistance.

This may all appear obvious, and perhaps you are wondering why we need to meet since numerous very sophisticated computerized simulation models already exist and are in limited use. Why, then, are they not running right now on every government, consultant, and university computer in the land? A managerial perspective of the answer to this question is that resistance, both to change and to perceived complexity, is very real. However, although individual and institutional barriers may exist, it must also be recognized that the suggested program may not really be perfected. Thus, a user is reluctant to initiate it.

Some of these barriers are founded on unwarranted fears of the unknown, but others relate to very real skepticism about costly commitments to unknown or operationally difficult products. Consider for a moment that some of the basic tenets of classical physics continue to be challenged, even today. We are regularly learning more about their limitations and the costly consequences of misapplication--and most of these only have three or four variables. Yet, we presume to ask a director of transportation to expend sizable amounts of money for equipment and staff and then base multimillion-dollar decisions on results obtained with very complex models that involve hundreds of variables.

Something else to consider is that researchers and developers sometimes lose sight of the real decision makers and their sales resistance. Many of today's managers and administrators were practicing engineering before commercial television or commercial jet air travel were introduced. The technical breakthrough of their day was the transistor.

These same managers and administrators now control transportation improvement programs and the money needed to construct them. The technical world has moved very rapidly, and many still retain a built-in resistance to computer applications. This resistance arises from an aversion to expending substantial time and energy to learn about computers, and a fear that printouts may be only manipulated or unreliably simplistic conclusions produced through the use of complex mathematics. The result is that a good intuitive basis on which to judge simulation output validity sometimes does not exist.

This is beginning to sound very gloomy, and one may wonder if there is any hope for overcoming the barriers to implementation. I happen to believe there is considerable hope and that progress can indeed be made.

The cliche, "Nothing succeeds like success," is very applicable. Our conference program features a number of user experience reports. These factual statements about successful practical application should go a long way toward alleviating fears about the translation of mathematical models into everyday practice.

After all, it is common among staff professionals of state transportation departments, counties, and cities to seek out and listen to show-and-tell presentations. The word is spread at meetings, through correspondence, and by telephone. This search for positive problem-solving experiences leads to new opportunities and new ideas for improvement.

Word-of-mouth enthusiasm and endorsement within the professional community probably do more toward breaking down barriers to the acceptance of new techniques than the best 12-ft shelf of technical literature in existence.

Communication is the key to breaking down barriers. This conference has two communication objectives (and I suspect that we can improve our performance in both areas):

1. Inform the user community about model availability and planned future development so that understanding of adoption implications may be increased, and
2. Obtain from the user community a statement of needs in order that developers and researchers may improve and enhance the value of simulation models.

Without proposing specific recommendations, I do suggest that substantial effort should be expended to rethink and improve the dialogue between users and model developers. The 12-ft shelf is not bad, provided it is read, understood, and accepted. But, its limitation is its inherent one-direction communication. More desirable and practical bidirectional surrogates should be used. The first step can be to identify, or affirm, the intended audiences and open up wider discourse among them. All too often one receives the impression in the field that researchers and developers talk and write trade jargon to and for each other and lose sight of their ultimate customer--the field practitioner. Conversely, I am sure that field practitioners sometimes appear unsophisticated and unable to describe their problems precisely.

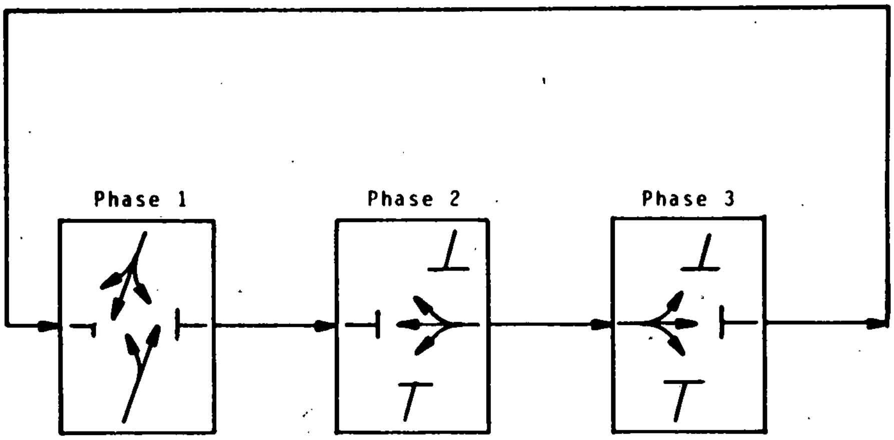
What, then, can we accomplish during this conference and in the weeks and months ahead? Obviously, a meeting has little point if experts only discuss their specialty among themselves and do not disseminate their conclusions to those less knowledgeable. Significant gain can best be made if your articulated thoughts are captured and the synergistic product of our discussions is made available to those who make the field changes. The practitioners, in turn, must continue to feed their experiences back to the researchers if the art is to be further refined.

Each of you is a catalyst who will return home with a renewed enthusiasm to enable you to overcome persuasively the barriers to the practical use of high-speed traffic problem analysis through simulation tools. I hope you will choose to become part of a nationwide communication network to inform others about this remarkable problem-solving tool.

So, my challenge to you is to think of simulation as a useful tool with a vital purpose to serve and not as a museum piece to be admired but not touched. Traffic simulation models fail to achieve their purpose until they serve usefully in that part of the world where traffic problems are real and immediate. Our task is to cause this to happen. Only then will our objectives be realized.

Part 2

Conference Overview and Findings



Conference Summary, Findings, and Recommendations

Nathan H. Gartner

System simulation is a technique of solving problems by following the changes over time of a dynamic model of the system. Simulation of vehicular traffic on highways and on street networks has been a natural application of computer modeling since the early stages of digital computation. The traffic environment is complex and stochastic in nature. Individual vehicles move along specified guideways constrained by the presence of other vehicles and restricted by control devices, while they attempt to satisfy individual objectives. Although analytical treatments such as queuing models can describe local behavior with some degree of accuracy, no such approach has been applicable for adequately describing the operational performance of traffic over street and freeway networks.

Traffic simulation models are computer programs that are designed to represent realistically the behavior of the physical system. Such models are themselves systems, in the sense that they are a collection of analytical models that describe such highly variable motorist responses as car following, lane changing, queue formation, discharge, etc. Such models are integrated into a logical structure in the form of computer software.

Traffic simulation models can be classified as either microscopic or macroscopic in design. Microscopic models describe the detailed, time-varying trajectories of individual vehicles in the traffic stream. Macroscopic models represent the traffic stream in some aggregate form (e.g., employing a fluid flow analogy or a statistical representation). Although the latter approach is usually less accurate and more limited in scope than the former, it offers the advantage of lower computational cost.

Inputs to models include known attributes of the system such as the geometrics of each link (e.g., length and number of lanes), network topology, properties of the control devices, and the time-varying traffic-demand volumes and circulation patterns. This initial preparation of the input data must be undertaken with care and represents the largest investment by the user.

All simulation models accumulate statistics in the course of representing the dynamic behavior of traffic. These statistics are output as measures of effectiveness (MOE) that describe the operational performance of traffic on each link (i.e., street or roadway segment) of the analysis network. Representative MOEs include vehicle miles, vehicle hours, speed, stops, delay, density, queue length, spillback, mass transit operations, fuel consumption, and vehicle emissions.

By exercising the simulation model and carefully analyzing the resulting statistical output, the engineer can study the operational effects of several policy and/or design alternatives rapidly and economically. Careful examination, combined with the engineering knowledge of the user, can provide the insight needed to identify the optimal design or policy. In this procedure, the simulation model is the tool that provides the necessary information; it is the engineer or analyst who must correctly interpret this information, apply his or her expertise to form the proper conclusions, and use this skill to arrive at the best solution.

The digital computer is particularly effective in providing the medium for exercising traffic simulation models and their interaction with external management and control measures. Thus, it provides the analyst with a very convenient laboratory for experimentation, evaluation, and design.

This conference was to be a signpost in the continuous process of development and application of traffic simulation models. It brought together developers, users, and prospective users of models to facilitate the accomplishment of the following objectives:

1. Demonstrate through user experience reports the availability and effectiveness of existing models for traffic simulation analysis,
2. Discuss a wide range of issues and problems encountered in using existing models in order to enhance their applicability and usage,
3. Communicate to the user community pending and future model developments, and
4. Prepare an agenda of needs for future research.

The proceedings of the conference are presented in this report. An overview of the resource and contributed papers, the main findings of the conference, and the conclusions and recommendations emerging from the workshop discussions are summarized here.

BACKGROUND MATERIAL

Available Models for Simulation Analysis

Four papers were presented on existing models for traffic simulation analysis. Gibson and May each present a comprehensive survey of existing models. Gibson provides a catalog of 104 documented computer models for traffic operations analysis that are listed in a handbook on this topic being prepared by FHWA. The models are classified according to the geometrics of the application--that is, intersections, arterials, networks, freeways, and corridors. Ten of these models are considered practical in the sense that they produce practical and useful results. The models are

SOAP--intersection optimization
TEXAS--detailed intersection simulation
PASSER II--arterial optimization
PASSER III--diamond interchange optimization
SUB--arterial bus simulation
TRANSYT-7F--network optimization
SIGOP III--network optimization
NETSIM--network simulation
PRIFRE--freeway optimization
FREQ3CP--freeway simulation

Most of these models are being made available by FHWA; SOAP, PASSER II, and TRANSYT are included in the Arterial Analysis Package (AAP). NETSIM is currently available and an enhanced version will be included in the TRAF family. TRANSYT-7F and SIGOP III are undergoing extended testing before their planned release. The FREQ family (including PRIFRE) is available from the University of California at Berkeley.

The FHWA implementation support is directed toward making effective use of these models. In order to get traffic engineers to use simulation and optimization models they have to be made easy to use and have to be proven reliable and valid. The first of these objectives is addressed through training and implementation support, while the other objectives involve demonstration and testing.

May provides a comprehensive survey of models for freeway corridor analysis, including their historical development and applications. An extensive bibliography of the model descriptions and their application reports is also given. May argues the need for integration of research, education, and implementation activities as keys to the enhancement of simulation modeling practice.

Lieberman describes a variety of enhancements recently incorporated into NETSIM as part of the development of the Integrated Traffic Simulation Software System, which has been given the name TRAF. These enhancements include (a) modifications to facilitate user access, (b) minimization of computer resource requirements, (c) new model features, and (d) extended input-output capabilities.

Courage and Wallace describe and compare the computational characteristics of five traffic signal optimization and evaluation models with which they had extensive experience. These are SOAP, PASSER II, PASSER III, TRANSYT, and SIGOP II.

User Experience

Three papers report user experience with the most widely used traffic network simulation model--NETSIM. The first two reports are by members of state departments of transportation and the third by university researchers. Hagerty and Maleck demonstrate the extent to which a computer simulation model (NETSIM) can be effectively used in a wide range of traffic engineering and transportation planning applications. In the course of three years, more than 15 000 simulation runs were made at the Michigan Department of Transportation (MDOT) using about 500 networks. The major use has been in analyzing geometric and signal system alternatives. It is also used to evaluate corridors at the transportation planning level and to evaluate signal installation requests. This model has become a very effective tool to aid decision making at MDOT. While listing a number of problems and limitations of the model, Hagerty and Maleck nevertheless conclude that the "growth and acceptance of NETSIM have exceeded all expectations."

Labrum describes the experience with NETSIM studies at the Utah Department of Transportation. The NETSIM model has been used extensively to evaluate traffic control strategies for single intersections, arterials, and grid networks, as well as to analyze pedestrian control problems, bus system plans, and fuel consumption and emission rates. It has also been used for economic analysis in many studies as well as for decision making in design projects. The NETSIM model has been found to be a very useful tool in solving a wide variety of traffic control problems.

Hurley and Radwan describe the experiences of using NETSIM for research in a university environment. Most of the research described analyzes the effects of traffic signal timing on fuel consumption and delay. Recommendations are made for improvements in internal program logic, program output, and program documentation.

Current and Future Developments

Two papers examine current and future development. Radelat points out that the development of traffic simulation models requires two distinct skills: modeling and computer programming. Modeling is the representation of a real-life system by a simplified logic. Programming is the translation of the modeling logic into computer language. In general, six types of traffic simulation activities can be defined:

1. New model development,
2. Testing,
3. Implementation,
4. Enhancement,
5. Application, and
6. Maintenance and support.

For continuous successful application of a simulation model it is necessary to pursue all of these activities in concert.

Radelat then proceeds to describe the new TRAF system. This system is being developed in light of these principles and will consist of both microscopic and macroscopic model components for urban networks and freeways and a microscopic component only for two-lane rural roads.

Ross speculates on possible long-range futures of traffic simulation modeling in view of current trends and projected developments in computational hardware and software. He foresees major developments in graphic displaying capabilities, interactive computations, and, ultimately, on-line simulations.

Contributed Papers

Part 5 of this report contains papers that were presented at workshop sessions and papers submitted by conference participants for the proceedings. The first five contributed papers (Maki and Branch, Maki and Saller, Slee, Schaffer, and Greyson) briefly describe user experiences in evaluating traffic control alternatives by using simulation modeling analysis (NETSIM and TEXAS). The next three papers address the evaluative capabilities of simulation models. Davis and Ryan compare NETSIM results with field observations and Webster discusses model predictions for isolated intersections. Yagar and Case present a summary evaluation of NETSIM's forerunner (UTCS-1) on an arterial street in Toronto. Model predictions of travel times are compared with floating car field measurements. In a second paper, Yagar and Case assess the evaluative capability of the TRANSYT model for the same Toronto arterial. Chin reviews some of the recent developments in interactive computer graphics user interface with existing traffic simulation packages. He concludes that such user interface is an invaluable aid to the understanding of traffic simulation models, preparation of input data, detection of errors, and interpretation of outputs.

WORKSHOP RECOMMENDATIONS

Twelve workshops were conducted. Their themes were divided into two categories--the application of simulation models by different user groups and the technical issues in simulation modeling and application--and were held on two different days. Consequently, each participant had the opportunity to attend one workshop in each category. Discussions reflected views from different organizational entities making use of the models as well as issues relating to the technical performance of the models in a variety of applications. It was no surprise that many of the viewpoints expressed and issues raised were common to several of the discussion groups.

Because many of the conference participants were primarily NETSIM users and because this simulation model seems to have found wide applicability in traffic operations analysis, most of the discussion items refer to this model specifically. The workshop discussions and recommendations followed along four main lines:

1. Promotion and implementation,
2. Maintenance and support,
3. Computer-user interface, and
4. Technical issues in modeling.

Promotion and Implementation

While it is widely recognized that analytical models are invaluable tools for use by traffic engineers in their analysis and design functions, it is also clear that these models have not yet found the widespread implementation they deserve and have not yet been used to the fullest. One of the principal objectives of this conference was to address this problem and to make recommendations for its alleviation. The following items were seen as keys to the achievement of this goal:

1. Management Support. The decision makers are the ultimate users--the implementors of the model outputs. They need to be aware of the availability of these tools and must be convinced of their utility relative to their needs.

2. Education and Training. A majority of practicing traffic engineers, at all levels of the profession, are not sufficiently knowledgeable concerning the use of computer models and their potential benefits. Expanded education and training materials will help improve this situation and provide a basis for informed judgment in model use.

3. Facilitation of Model Use. Both current and potential users would be encouraged to make better use of available models through improvements in their applicability--namely, centralized maintenance and support, improved documentation, development of user guidelines and case studies, and improvements in data management, input-output processing, and computer-user interface.

Maintenance and Support

Various needs in the maintenance and support area were also discussed. The following summarizes these needs and the views of the conference participants on the proper role of FHWA in providing maintenance and support services.

1. Program Distribution. FHWA should be responsible for both the initial and continuing distribution of the programs. After development of a program, FHWA should release it to a limited number of "expert" users for use on a test basis. The programs should be revised based on the users' experience, and then general release should follow. Conference participants expressed concern that this process currently consumes too much time and needs to be accelerated.

FHWA should also periodically distribute updated versions of the programs. After a number of minor revisions have been made, the new version of the program should be distributed to all users. This should occur no more frequently than annually.

2. Program Documentation. The need for improved documentation was universally viewed as a critical element in the support of all other activities. This need was expressed in a number of forms: (a) overview and promotion materials for managers; (b) text on general principles of traffic simulation and optimization; (c) minitexts for training purposes on all aspects of model implementation; (d) handbook of case studies and typical applications, including guidelines on when to use various models; and (e) user guidelines on such issues as parameter values, data-collection procedures, input-output procedures, etc. It was stressed, in particular, that there is a need for appropriate documentation to accompany updated and newly released program versions.

3. Training. FHWA should provide training courses for potential users of the programs. Specific suggestions in this area include (a) mailing materials for precourse study; (b) a course session on model theory; (c) hands-on experience during the course through structured laboratory sessions; and (d) preparation of adequate materials to accompany the aforementioned program, e.g., guidebooks, slides, etc.

4. Technical Assistance. FHWA should keep all models operational and have experts available to provide technical assistance to users of these programs. This service could be provided by telephone (a hot-line concept was discussed) or through electronic mail. State highway departments should be encouraged to develop this capability at their level so as to decentralize and improve the timeliness of the technical support function. Realizing, however, that not all states will be able to develop this capability, FHWA should maintain a strong centralized role and serve the clearinghouse function.

5. User Communication Network. Conference participants expressed interest in the formation of a users' group to allow for exchange of ideas, problems, and solutions. This communication could be facilitated through a newsletter, technical committees of the Institute of Traffic Engineers or TRB, and sessions at national meetings and future conferences like this one. In this context, a nationally representative technical advisory committee should be formed to review needs and program objectives.

Computer-User Interface

Suggestions noted here on computer-user interface could be applied to any simulation-optimization model. Included are potential improvements in the model's data-handling capabilities and user interfaces.

For the short-term, the most promising improvement appears to be the development of interactive input forms displays (such as those used by the Michigan Department of Transportation for NETSIM). The development and use of these displays would simplify greatly the burdensom task of keypunching or otherwise entering data in specified formats via a terminal.

For the long term, the development of a traffic-engineering data base system would enable a user to run any simulation-optimization program from a centralized pool of data used in common by these programs. The system would automatically produce an input data deck from the data pool in the appropriate format for the program to be run. The development of such a system would further simplify the input data process.

Another promising improvement is the use of computer graphics to display program outputs. Research still needs to be conducted on what is the most useful form of graphics display. The problem of portability among different terminals of graphics display presents a potential problem.

Finally, the use of microcomputers is inherent throughout all the above suggestions. Micros could be programmed for forms displays, as well as to interact with a data base system, to display computer graphics, and to provide a wide variety of diagnostics. Since they are affordable, the traffic engineer could have these capabilities available at his or her desk.

Issues in Modeling

As evidenced in the workshop discussion reports and, in fact, throughout the conference proceedings, most users had considerable experience with the NETSIM model. Therefore, most of the modeling issues raised and problems discussed concerned this model. The long list of suggestions for improvements should not be taken as an indication of weakness. Quite to the contrary, it is an indication of vigorousness and of the wide range of possible applications to which the model was subjected. It is also an indication of the usefulness of communication among users, developers, and nonusers that this conference has afforded.

Among the most pressing needs mentioned were the following:

1. Improving and validating the traffic-actuated signal control logic,
2. Providing capabilities to model traffic-responsive system controls and coordinated operation of semi-actuated and actuated traffic signal controllers,
3. Inputting a specified headway distribution or field-collected arrival patterns,
4. Updating the fuel consumption and emission tables to reflect current vehicle population,
5. Modeling a four-way-stop controlled intersection,
6. Providing for left turns and lane discipline (i.e., a lane containing both left-turning and through traffic as well as a lane facing opposing left turners),
7. Modeling a center dual-left turning lane,
8. Handling railroad crossing,
9. Handling pedestrian traffic, and
10. Seed random numbers (the dependence of NETSIM on a single random number string was considered a weakness that may compromise the validity of pairwise comparisons).

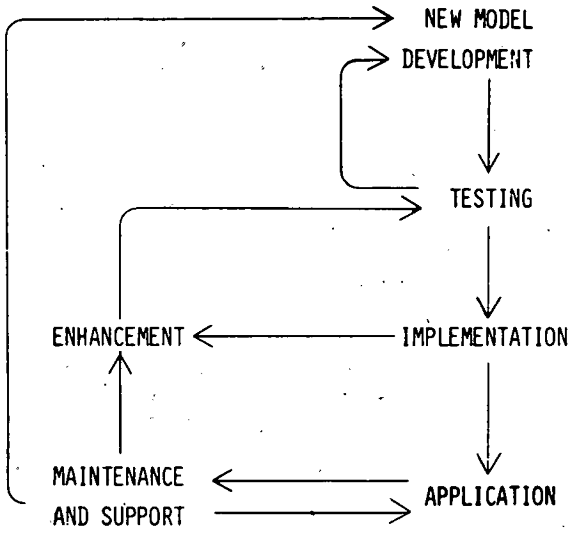
Another category of modeling issues concerned the interface of traffic simulation software with transportation planning software. Traffic simulation models, NETSIM in particular, are already used for several types of planning and transit analyses and it would seem worthwhile, in the longer range, to strengthen this interface through integratory measures, such as sharing of data bases, and through the formalization of the traffic system design process. The latter, eventually, would involve the addition of automated optimization capabilities to the descriptive simulation models. In this way, the models would expand their existing predictive capabilities to include also normative functions.

CONCLUSION

Realizing and agreeing that the use of computer simulation and optimization models is strong today and will continue to gain strength in the future, the conference participants and steering committee recommend that FHWA take a strong role and lead in the continuing development, promotion, and implementation of such models for improving traffic operations and management throughout the country.

[Editor's note: Since the conference, a TRAF support service has been set up. It can be reached at 516-549-9829.]

Part 3
Resource Papers



Available Computer Models for Traffic Operations Analysis

David R.P. Gibson

The purpose of this report is to make the user aware of the availability of computer models for analyzing traffic operations problems. It will show their use in both proposing solutions and analyzing problems in detail. The use of these models is one of the newest areas of traffic engineering. Practicing traffic engineers may only be slightly aware that these tools are available to assist in reducing the considerable amount of time spent in developing and evaluating alternative improvements to traffic systems. Traffic signal systems in particular could take advantage of the currently available models.

The outline of what is available in this report is based on previous work done in developing the outline and intended contents for a handbook on computer models for traffic operations analysis, an FHWA project.

In order to put what is available in perspective, it will be necessary to also portray what and how FHWA is making computer models available. Present and future work in the implementation process will be described. (Work in progress and needed future work are described in separate reports by Radelat and Ross in these proceedings.)

WHAT IS AVAILABLE?

In the review of models for the handbook, a total of 104 distinct computer models were located that could be applied to traffic engineering problems. The technical appendix gives a one-page summary of "all significant models".

Types of Models

The major goal in describing what is available in computer models for traffic operations analysis is to describe the models in terms of typical problems that need to be analyzed. After looking at various methods of problem classification (such as signal phasing, ramp metering, lane operations, etc.), it was felt that the simplest classification would be by the geometrics that the model analyzes.

Intersection Models

There are more than 250 million signalized intersections in the United States. Most drivers regard these as a major problem on their way to their destination. Inefficient operation of an intersection can lead to excessive fuel consumption.

Manual design procedures for intersection signal timing does not permit comprehensive evaluation due to the trial-and-error nature of the process. As a result, many phasing patterns cannot be considered and the traffic engineer must use his or her experience in deciding which patterns and traffic conditions to analyze in detail.

Many solutions to intersection problems require geometric changes. Adding lanes or widening them can be very expensive and the traffic engineer will need an extremely strong case before funds will be allocated.

Considerable effort was expended in trying to develop models that would provide accurate and quantifiable estimates for assessing proposed improvements at intersections. A total of 26 models were identified that could be used to optimize and analyze traffic at intersections. Table 1 summarizes the models reviewed for possible inclusion in the handbook. Most of these were found to be inappropriate. They were old and had not been maintained. Thus they became outdated. Two of the models are relatively new and potentially useful. These are the SOAP and the TEXAS models.

SOAP (see Figure 1) was developed for FHWA and the Florida Department of Transportation by the University of Florida. It provides a tool for examining and evaluating a wide range of intersection signal design alternatives. It is an optimization, not a simulation, model. Solutions are found for cycle length, phasing, and left-turn analysis. It also has a theoretical capability for analyzing coordination effects; however, other models are more appropriate for this purpose. (See a more detailed description of this model in a paper by Courage and Wallace in this report.)

TEXAS (see Figure 2), the Traffic Experimental and Analytical Simulations model, was developed by the University of Texas for the Texas State Department of Highways and Public Transportation. TEXAS allows the user to evaluate the effects of roadway changes, driver and vehicle characteristic changes, intersection control, lane control, and signal-timing plan effects on single intersection operations. It is perhaps the most microscopic traffic simulation program in existence. It does have some problems in being brought up on new computer systems and is recommended only for those cases where its supermicroscopicity is needed.

Both SOAP and TEXAS are maintained by public agencies. Future enhancements of both models are expected.

Arterial Models

Many arterial highways are now congested. This severely restricts the flow of traffic to and from work and major shopping areas. In this era, new highway construction is coming to an end due to environmental, right-of-way, and construction cost problems. Engineers have a wide range of improvements that can be applied to reduce congestion. Usually, the first to be looked at are traffic control techniques such as improved coordination and parking restriction. These are the lowest-cost measures. Minor geometric improvements such as adding turn lanes and bus pullouts are the next level of improvements to be considered. Arterial computer control systems can now be implemented economically. Table 2 summarizes the models reviewed for possible inclusion in the handbook.

A variety of arterial signal coordination programs has been developed. The most widely used of these are PASSER II, PASSER III, SIGPROG, SIGART, and the LITTLE/MORGAN model. Of these, PASSER II and PASSER III are the best maintained. Of the remaining models, the SUB model provides a unique capability for simulating urban buses. It is hoped that SUB's capabilities will be integrated into the TRAF model.

PASSER II (see Figure 3) was developed to determine optimum progression along arterials while considering phasing sequences. The model developer combined Little's optimized unequal bandwidth equations with methods for handling multiphase signals. Inputs include turning movements, saturation capacity flow rates, minimum green times, distances be-

Table 1. Summary of models reviewed for FHWA handbook project.

Number	Name	Date	Application	Modeling Approach	Program Language	Computer
1-1	TEXAS	1978	Traffic Performance	Mic., Stoc., TS, Sim.	Fortran IV	CDC 6600 IBM 370
1-2	SOAP	1977	Signal Timing (Cycle, splits & phasing)	Mac., Det., TS, Opt.	Fortran IV	IBM 360/ 370
1-3	SPLIT	1976	Signal Timing (Splits only)	Mac., Det., TS, Opt.	Fortran	IBM 360
1-4	CYCLE	1976	Signal Timing (Cycle only)	Mac., Det., TS, Opt.	Fortran	IBM 360
1-5	HARPST	1975	Pedestrian Effects	Mac., Det., TS, Sim.	GPSS	IBM
1-6	SIGCAP	1975	Signal Timing (Splits only)	Mac., Det., TS, Opt.	Fortran	
1-7	UTCS-IS	1973	Traffic Performance	Mic., Stoc., TS, Sim.	Fortran IV	IBM 360
1-8	BLY	1973	Bus Priority Lanes	Mic., Sim.	Fortran	Unknown
1-9	SIGSET	1971	Signal Timing (Cycle & Splits)	Mac., Det., TS, Opt.	Fortran	IBM 360
1-10	BRADFORD	1968	Gap Acceptance	Mic., Stoc., TS, Opt.	ALGOL	ICL 1909
1-11	TEC	1968	Traffic Performance	Sim.	GPSS	IBM 7094 IBM 360
1-12	JONES	1968	Left Turn Storage	Mic., Stoc., TS, Sim.	Fortran	IBM 1130
1-13	DARE	1966	Advisory Speed Signals	Sim.	GPSS	IBM 360
1-14	WRIGHT	1967	Stop Control Delays	Mic., Stoc., TS, Sim.	ALGOL (Ext.)	Unknown
1-15	BOTTGER	1965	Four Way Stop	Mic., TS, Sim.	Unknown	Unknown
1-16	MILLER	1965	Effect of Turns	Mic., Stoc., Sim.	Unknown	Unknown
1-17	NCHRP	1964	Traffic Performance	Mic., Stoc., TS, Sim.	Fortran II, FAP	IBM 1094
1-18	AUSTRAL-IAN	1964	Capacity and Controls	Mic., Stoc., TS, Sim.	Fortran	IBM 7090
1-19	BLEYL	1964	Traffic Performance	Mic., Stoc., TS, Sim.	Fortran II	IBM 7094
1-20	EVANS	1963	Queueing at Stop Signs	Mic., Stoc., TS, Sim.		IBM 7090
1-21	AITKEN	1963	Queueing at "Tee" Junction	Sim.	Unknown	Ferranti Sirius
1-22	KELL	1962	Vehicular Delay	Mic., Stoc., TS, Sim.	FAP	IBM 701& 7094
1-23	LEWIS	1962	Traffic Control	Mic., Stoc., TS, Sim.	Fortran II/FAP	IBM 7094
1-24	NPL	1962	Traffic Performance	Mac, Det., Sim.	Unknown	Ferranti Pegasus
1-25	CHEUNG	?	Delay	Mac., Det., TS, Sim.	Fortran	ICL 1907
1-26	GOODE	1956	Delay	Mic., Det., TS, Sim.	Unknown	M10AC IBM 704

Abbreviations:
Mic. - Microscopic
Det. - Deterministic
TS - Time Scan
Sim. - Simulation
Mac. - Macroscopic
Stoc. - Stochastic
ES - Event Scan
Opt. - Optimization

Figure 1. Intersection model: SOAP.

MODEL: SOAP

DEVELOPED BY: K.G. Courage and M.R. Landmann, University of Florida Transportation Research Center

MAINTAINED BY: Florida Department of Transportation

PURPOSE: Optimal signalization of isolated intersections.

MODELING APPROACH: Macroscopic, deterministic, time-scan, optimization.

DEGREE OF DOCUMENTATION:
Model Development - Yes
Program Description - Yes
User Manual - Yes

GENERAL DESCRIPTION:

SOAP is a design and analysis tool which enables the user to design the signalization for any two to four legged intersection. Either fixed or actuated control and multiple phasing may be specified. Multiple runs may be included in one job to obtain comparisons of alternative design configurations. SOAP uses a search and find optimization procedure to find the optimum cycle length, splits and dial assignments. Measures of effectiveness are delays, stops, excess fuel consumption due to stops and delay, degree of saturation and left-turn conflicts. SOAP may be used to analyze existing or pre-determined timing. Inputs consist of a wide variety of options and control parameters. Volumes, headways, capacities and special parameters are input. The latter permits SOAP to consider coordination of the signal with an adjacent intersection and the effect of platoon arrivals.

NUMBER: 1-2

YEAR: Original: 1977

PROGRAM LANGUAGE: FORTRAN IV

PROGRAM STRUCTURE: Structured

MACHINE: IBM

CORE REQUIREMENTS: 176 K

EFFICIENCY: High

DEGREE OF VALIDATION: Extensive field testing

REFERENCES:

* (1) Courage, K.G. and M.R. Landmann, "Signal Operations Analysis Package," five documents "Volume 1 - Computational Methodology,""Volume 2 - Users Manual," Volume 3 - Programmer's Manual," and "Volume 4 - Portable Calculator Routines," University of Florida, Transportation Research Center, FHWA Implementation Package 79-9, July, 1979.

Figure 2. Intersection model: TEXAS.

MODEL: TEXAS

DEVELOPED BY: T.W. Rioux and C.E. Lee
Center for Highway Research
University of Texas at Austin

MAINTAINED BY: Texas Departemnt of Highways
and Public Transportation

PURPOSE: Evaluation of traffic performance

MODELING APPROACH: Microscopic, stochastic, time scan, simulation.

DEGREE OF DOCUMENTATION:
Model Development - Yes
Program Description - Yes
User Manual - Yes

GENERAL DESCRIPTION:

The TEXAS package is designed to perform detailed evaluations of traffic performance at isolated intersections. The geometry processor, GEOPRO, translates the user input data into the required geometry information. These geometry input data are straightforward and comprehensive. The driver-vehicle processor, DVPRO, randomly generates the individual driver-vehicle units based on a variety of user data and program default values. The particular driver characteristics and the vehicle generation are treated stochastically. The simulation processor, SIMPRO, microscopically processes each driver-vehicle unit through the intersection in a fixed, discrete-time increment, and accumulates data on the vehicle performance and traffic interaction. This model is useful in developing and evaluating alternative geometric or control improvements and appears to be an efficient, well-developed tool.

NUMBER: I-1

YEAR: Original: 1977

PROGRAM LANGUAGE: FORTRAN IV

PROGRAM STRUCTURE: Structured

MACHINE: CDC 6600 & IBM 370

CORE REQUIREMENTS: Est. 205K

EFFICIENCY: 1:48 to 1:8

DEGREE OF VALIDATION: Computational & Field

REFERENCES:

*(1) T.W. Rioux and C.E. Lee, "TEXAS - Microscopic Traffic Simulation Package for Isolated Intersections", presented at the 56th annual meeting of the Transportation Research Board, Washington, D.C., 1977.

*(2) C.E. Lee, et al., "The TEXAS Model for Intersection Traffic - Development", Research Report No. 184-1, Center for Highway Research, University of Texas, Austin.

*(3) C.E. Lee, et al., "The TEXAS Model for Intersection Traffic - Programmer's Guide", Research Report No. 184-2, Center for Highway Research, University of Texas, Austin.

*(4) C.E. Lee, et al., "The TEXAS Model for Intersection Traffic - User's Guide", Research Report No. 184-3, Center for Highway Research, University of Texas, Austin, July, 1977, 82 kpp.

*(5) C.E. Lee, et al., "The TEXAS Model for Intersection Traffic - Analysis of Signal Warrants and Intersection Capacity", Research Report No. 184-4, Center for Highway Research, University of Texas, Austin.

Table 2. Summary of arterial models.

Number	Name	Date	Application	Modeling Approach	Program Language	Computer
A-1	SIMTOL	1976	Grades & Trucks	Mic., Stoc., TS, Sim.	Fortran IV	CDC 6400
A-2	NC STOP 1	1975	Signal Progression	Mac., Det., TS, Opt.	Fortran IV	Unknown
A-3	PASSER III	1974/ 1976	Signal Timing Diamond Ramps	Mac., Det., TS, Opt.	ANSI/ Fortran IV	IBM 360/ 370
A-4	PASSER II	1974/ 1978	Signal Progression	Mac., Det., TS, Opt.	Fortran IV	IBM 360/ 370
A-5	SUB	1973	Urban Bus Operations	Mic., Stoc., ES, Sim. (for buses) Mac., Stoc., TS, Sim. (for others)	Fortran IV	IBM 360/ 370
A-6	NCSU	1973	Passing Sight Distance Requirements	Mac., Det., TS, Opt.	Fortran IV	Unknown
A-7	YU	1973	Parking Effects on Capacity	Mic., Det., Sim.	Unknown	Unknown
A-8	VECELLIO	1973	Platoon Dispersion	Mac., Det., Sim.	GPSS	IBM 360/ 165
A-9	TSUMB	1971	Intersection Operations	Mic., Stoc., Sim.	Machine Code	Elliott 920 NB
A-10	MRI	1970	Traffic Flow in Mtns.	Mic., Stoc., TS, Opt.	Fortran IV /Assembly	CDC 6900
A-11	MACCLEN- AHAN	1969	Vehicle Lengths	Mic., Det., TS, Sim.	Fortran IV	Unknown
A-12	DELAY/ DIFFERENCE	1969	Signal Progression	Mac., Det., TS, Sim.	Fortran IV	IBM 7094
A-13	SIGPROG	1967	Signal Progression	Mac., Det., TS, Opt.	Fortran	IBM 360
A-14	FIRL	1967	Passing Maneuvers	Mic., Det., TS, Sim.	Fortran IV	Unknown
A-15	WARNSHIUS	1967	Traffic Flow - Rural Roads	Mic., Det., TS, Sim.	Fortran IV	IBM 7094
A-16	CRAFT/ SMITH	1967	Traffic Flow	Sim.	Unknown	Unknown
A-17	SIGART	1967	Signal Progression	Mac., Det., TS, Opt.	Fortran IV	IBM 360/ 510
A-18	NEWARK	1965	Car Following Mdn.	Mic., Stoc., Sim.	Unknown	Unknown
A-19	LITTLE	1965	Signal Progression	Mac., Det., TS, Opt.	Fortran IV	IBM 7094 & 1620
A-20	YARDENI	1964	Signal Progression	Mac., Det., TS, Opt.	Fortran IV	IBM 7090 & 7040
A-21	FISHER	1964	Lateral Restrictions	Mic., Stoc., TS, Sim.	Unknown	IBM 650
A-22	PRETTY	1964	Traffic Flow Signalized Arterial	Sim.	Unknown	Unknown
A-23	ARNOLD/ RESZ	1964	Traffic Flow on Two-Lane Roads	Sim.	Unknown	Unknown
A-24	MANCHESTER	1963	Traffic Performance	Mac, Stoc., TS, Sim.	Atlas Autocode	Atlas ICT
A-25	RHREE	1963	Traffic Control Pol.	Mac., Det., TS, Sim.	Unknown	Unknown
A-26	NBS	1961	Traffic Flow	Mac., Sim.	Assembly	IBM 704

Figure 3. Arterial model: PASSER II.

MODEL: PASSER II

DEVELOPED BY: C.J.MESSER, et al
Texas Transportation Institute

MAINTAINED BY: Texas Depårtment of Highways and Public Transportation

PURPOSE: Maximization of Bandwidth along signalized arterial

MODELING APPROACH: Macroscopic, deterministic, time scan, optimization.

DEGREE OF DOCUMENTATION:
- Model Development - Unknown
- Program Description - Yes
- User Manual - Yes

GENERAL DESCRIPTION:

This model, Progression Analysis and Signal System Evaluation Routine, was developed to analyze individual signalized intersection operations or to determine optimum progression along an arterial street considering varied multi-phase sequences. The model developer's have combined Brook's interference algorithm with Little's optimized unequal bandwidth equations and expanded them to include multi-phase signal operation. Basic inputs include turning movements, saturation capacity flow rates and minimum green times for each movment that must be provided for at each intersection. For progression analysis distance between intersections, average link speed, queue clearance intervals and permissable phasing sequences are provided. Standard outputs include an echo copy, progression values (optimum cycle length, and bandwidth in seconds) and average speed in both directions as well as two measures of effectiveness, bandwidth efficiency and percent of minimum arterial green time included in the band. Also included is signal timing information on phase sequence, offset and v/c ratios. As an option a printer or digital plotted time space diagram can be provided.

NUMBER: A-4

YEAR: Original: 1974
Revised: 1978

PROGRAM LANGUAGE: FORTRAN IV

PROGRAM STRUCTURE: Single Routine, 1600 Statements

MACHINE: IBM 360/370

CORE REQUIREMENTS: Unknown

EFFICIENCY: High

DEGREE OF VALIDATION: and Field Verification Computational

REFERENCES:

*(1) Messer, C.J., et al, "A Variable-Sequence Multiphase Progression Optimization Program," TRB, Highway Research Record 445, 1973, pp. 24-33.

*(2) Messer, C.J., Haenel, H.E. and Koeppo, E.A., "A Report on the User's Manual for Progressive Analysis and Signal System Evaluation Routine - PASSER II," Texas Trans. Institute, Research Report 165-14, August, 1974 (NTIS-PB-241-582)

*(3) Messer, C.J. and Fambro, D.C., "A Guide for Designing and Operating Signalized Intersections in Texas," Texas Transportation Institute Research Report 203-1, August, 1974.

tween intersections, average link speeds, queue clearance intervals, and permissible phasing sequences. Outputs include an echo of input, progression values, signal timing, and information on phase sequence, offset, and V/C ratios. A printer plot of a time spacing diagram is optional. PASSER II-80 has just been released by Texas and will be included in the handbook if time permits. PASSER-80 is an example of graceful model improvement. It uses input formats almost identical to PASSER II but has improved processing algorithms and measures of effectiveness. PASSER II is written in FORTRAN IV and was developed on IBM computers.

PASSER III (see Figure 4) provides optimal offset relationships for diamond interchanges. The objective is to minimize total delay for the interchange for a given cycle length and phasing pattern. Four phasing patterns are permitted, including all combinations of leading and lagging greens plus the four-phase, two-overlap sequence. Inputs to the model include an interchange description, phasing pattern, cycle length, overlaps, movement volumes, and capacities. A progressive mode is available that determines the optimal cycle length and progressive phasing for progression along frontage roads for a series of diamond interchanges. Time space diagrams are available as an output for this use of the model. PASSER III was written in FORTRAN 66 and requires approximately 168k-bytes of memory. The Texas transportation department has extensively field tested the model.

The SUB model is a special-purpose program for simulating bus operations on arterials. It provides a number of performance measures. Vehicular traffic is treated macroscopically, while buses are treated microscopically. Twenty arterial blocks may be modeled with either protected or unprotected bus stops. The detailed logic for bus stop operation requires input of bus descriptions, discharge headways, passenger service time, traffic volumes, bus routes, link, and signal data. Outputs include arrival and departure time for each bus, passenger statistics, and travel speeds. SUB was written in 1973 in FORTRAN 66 and requires approximately 90k of memory. Many of SUB's capabilities will be placed into the TRAF model currently under development by FHWA.

In addition to the arterial models selected for inclusion in the handbook, there is another model of interest. It is the MRI Mountainous Terrain Model (see Figure 5). It provides for simulation of directional flow on a four-lane, divided roadway up to 131 000 ft in length with intermittent hill-climbing lanes. Speed and acceleration characteristics are controlled by grade and horizontal curvature. Driver-vehicle characteristics and maximum speed on downgrades can be specified. The model has been extensively validated and appears to be realistic. The MRI Mountainous Terrain Model is written primarily in FORTRAN 66 but does have some CDC assembly code. It requires only 32k of memory.

Network Models

In most urban areas, there are one or more central business districts (CBDs) that have extremely dense road networks. These areas have been undergoing a resurgence of construction and development as rising fuel costs have reestablished their value. During the next decade, this growth may be expected to tax the transportation system. The modernization of the infrastructure of the CBD area has not extended to the physical street systems. In some areas it has been accompanied by the establishment of computerized UTCS systems. In most areas, however, traffic slows to around 20 mph when it enters the downtown area.

Efforts to improve traffic flow, such as signal interconnection, parking prohibition, one-way streets, reversible lane operations, and other changes, frequently meet with opposition from local businesses. Improvements also meet opposition from residents on the fringes of the central areas who want to restrict the flow of traffic.

Developments in computer technology provide the traffic engineer with a rather inexpensive method of developing and evaluating different techniques of improving traffic flow and persuading council, business, and residents of the potential benefits. Table 3 summarizes the models that were considered for possible inclusion in the handbook.

NETSIM and TRANSYT are the two most widely used network models, each in its own category. TRANSYT has several variations. TRANSYT-6 served as the basis for the TRANSYT-6N and TRANSYT-6C models (see Figure 6). The TRANSYT-7 model reduced input requirements from TRANSYT-6 and speeded up the optimization. An anglicized version of TRANSYT, called TRANSYT-7F, has a preprocessor to provide simplified input and a postprocessor to provide a time-space diagram and improved output. The TRANSYT traffic model also provided the basis for much of the SIGOP III traffic model. SIGOP III provides a form of in-

Figure 4. Arterial model: PASSER III.

MODEL: PASSER III

DEVELOPED BY: C.J. Messer and D.B. Fambro, Texas Transportation Institute

MAINTAINED BY: Texas Department of Highways and Public Transportation

PURPOSE: Optimizes signalization of diamond interchanges both isolated or along frontage road systems.

MODELING APPROACH: Macroscopic, deterministic, time-scan, optimization.

DEGREE OF DOCUMENTATION:
Model Development - No
Program Description - Yes
User Manual - Yes

GENERAL DESCRIPTION:

PASSER III is a design tool which enables engineers to determine the optimal offset between the two signals of a diamond interchange which minimizes total interchange delay for a given cycle length and phasing pattern. Four phasing patterns are permitted including all combinations of "leading" and "lagging" greens, plus the so-called "4-phase with overlap" pattern. Inputs to this isolated mode include interchange descriptions, desired phasing pattern(s), cycle length, overlap, queue capacities, movement volumes, and capacities (expressed as equivalent number of lanes and minimum greens). The progressive mode determines the optimal cycle length and priority phasing for progression on a system of interconnected interchanges with continuous frontage roads. The above data (or constants for patterns) plus progression speeds are input (cycle length may vary over a range). Outputs are optimal designs, measures of effectiveness and time-space diagrams.

NUMBER: A-3

YEAR: Original: 1974
Revised: 1976

PROGRAM LANGUAGE: ANSI FORTRAN

PROGRAM STRUCTURE: Modular

CORE REQUIREMENTS: 168 K

EFFICIENCY: High

DEGREE OF VALIDATION: Extensive field testing in Texas

REFERENCES:

*(1) Fambro, D.B., et.al., "A Report on the User's Manual for Diamond Interchange Signalization - PASSER III," Texas Transportation Institute Research Report No. 178-1, August, 1976.

*(2) Messer, D.J., D.B. Fambro and J.M. Turner, "Analysis of Diamond Interchange Operation and Development of a Frontage Road Level of Service Evaluation Program - PASSER III - Final Report," Texas Transportation Institute Research Report No. 178-2F, August, 1976.

Figure 5. Arterial model: MRI Mountainous Terrain.

MODEL: MRI Mountainous Terrain

DEVELOPED BY: Midwest Research Institute

MAINTAINED BY: Unknown

PURPOSE: Evaluation of traffic characteristics of roadways in mountainous areas.

MODELING APPROACH: Microscopic, stochastic, simulation.

DEGREE OF DOCUMENTATION:
Model Development - Yes
Program Description - Yes
User Manual - Yes

GENERAL DESCRIPTION:

The geometric configuration of this model allows simulation of directional flow on a four-lane, divided roadway up to 131,000 feet long with intermittent hill-climbing lanes. The simulation dynamics are parallel to those in the MRI Freeway model, except that desired speeds and acceleration characteristics are controlled by grades and horizontal curvature. Different driver/vehicle characteristics are also defined and maximum speeds for downgrades can be specified. Extensive validation has been performed and realistic results have been reported.

NUMBER: A-10

YEAR: Original: 1970
Revised: Unknown

PROGRAM LANGUAGE: FORTRAN IV/ASSEMBLY

PROGRAM STRUCTURE: Modular

MACHINE: CDC 6400

CORE REQUIREMENTS: 32K

EFFICIENCY: 20:1 to 10:1

DEGREE OF VALIDATION: Field Verification

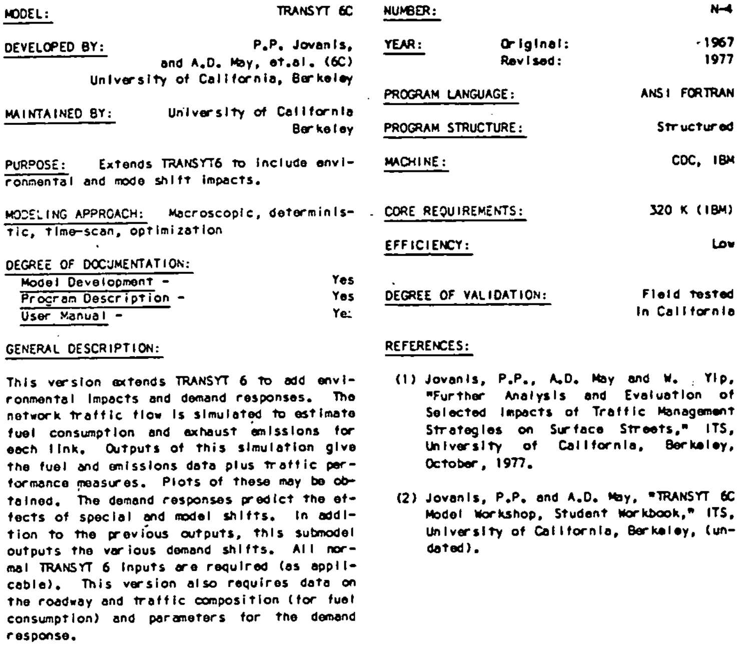
REFERENCES:

*(1) A.D. St. John, D.R. Kobett, Sommerville, and W.D. Colanz, "Traffic Simulation for the Design of Uniform Service Roads in Mountanous Terrain", 4 Volumes, Final Report, Midwest Research Institute, Contract No. CPR-11-6093 for FHWA, 1970.

Table 3. Summary of arterial network models.

Number	Name	Date	Application	Modeling Approach	Program Language	Computer
N-1	SIGOP II	1979	Opt. Signal Timing	Mac., Det., TS, Opt.	Fortran	CDC 660 IBM 360/370
N-2	TRANSYT7	1978	Opt. Signal Timing	Mac., Det., TS, Opt.	Fortran IV	ICL 4-70 IBM 360/370
N-3	NETSIM	1977	Evalute Signal Control Systems	Mic., Stoc, TS, Sim.	Fortran IV	IBM 360/370 CDC 6600
N-4	TRANSYT6C	1977	Opt. Signal Timing	Mac., Det., TS, Opt.	Fortran	CDC 6600 IBM 360/370
N-5	TRASOM	1976	Opt. Signal Timing	Mac., Det., TS, Opt.	Fortran IV	Unknown
N-6	MITROP	1974	Opt. Signal Timing	Mac., Det., TS, Opt.	MPSX/MIP	IBM 370/165
N-7	SIGOP I	1974	Opt. Signal Timing	Mac., Det., TS, Opt.	Fortran IV	IBM 370/165
N-8	ROONEY	1974	Eva. Vehicle Perform.	Mic., Sim.	Unknown	Unknown
N-9	ERIKSEN	1973	Eva. Bus Movement	Mic., Stoc., ES, Sim.	Unknown	Unknown
N-10	SIGNET	1972	Eva. Signal Timing	Mic., Stoc., TS, Opt.	Fortran IV	CDC 6500
N-11	UTS-1	1971	Evaluate Traffic Flow	Mis., Stoc., TS, Sim.	Unknown	Unknown
N-12	BIRMING-HAM	1970	Evaluate Signal Timing	Mic., Det., TS, Sim.	Egtran 3	Atlas ICL
N-13	DYNET	1969	Evaluate Traffic Flow	Mic., Stoc., TS, Sim.	Fortran	Unknown
N-14	SAKAI/ NAGAO	1969	Evaluate Traffic Flow	Mac. Stoc., TS, Sim.	Unknown	Unknown
N-15	SCHALK-WIJK	1968	Evaluate Traffic Flow	Mac., Sim.	SimScript	CDC
N-16	BRITISH COMBIN.	1967	Opt. Signal Timing	Mac., Det., TS, Opt.	Fortran IV	IBM 360/50
N-17	MIT	1966	Eval. Signal Timing	Mac., Sim.	Unknown	Unknown
N-18	VETRAS	1966	Evaluate Traffic Flow	Mic., Stoc., TS, Sim.	GPSS	IBM 360
N-19	TRRL	1965	Eval. Signal Timing	Mac., Stoc., TS, Sim.	Unknown	Ferranti Pegasus
N-20	UTS	1964	Evaluate Traffic Flow	Mic., Stoc., TS, Sim.	GPSS/FAP	IBM 7090
N-21	SIGRID	1964	Opt. Signal Timing	Mac., Det., TS, Opt.	Fortran	Unknown
N-22	TRANS	1963	Evaluate Signal Timing	Mac., Stoc., TS, Sim.	SAP/FAP	IBM 709
N-23	LONGLEY	1954	Evaluate Traffic Flow	Mic., Det., TS, Sim.	Fortran	Elliott 4100
N-24	TRAUTMAN	UNK	Evaluate Traffic Flow	Mac., Stoc., TS, Sim.	Unknown	SWAC

Figure 6. Arterial network model: TRANSYT 6C.



MODEL: TRANSYT 6C

DEVELOPED BY: P.P. Jovanis, and A.D. May, et.al. (6C) University of California, Berkeley

MAINTAINED BY: University of California Berkeley

PURPOSE: Extends TRANSYT6 to include environmental and mode shift impacts.

MODELING APPROACH: Macroscopic, deterministic, time-scan, optimization

DEGREE OF DOCUMENTATION:
Model Development - Yes
Program Description - Yes
User Manual - Ye:

GENERAL DESCRIPTION:

This version extends TRANSYT 6 to add environmental impacts and demand responses. The network traffic flow is simulated to estimate fuel consumption and exhaust emissions for each link. Outputs of this simulation give the fuel and emissions data plus traffic performance measures. Plots of these may be obtained. The demand responses predict the effects of special and model shifts. In addition to the previous outputs, this submodel outputs the various demand shifts. All normal TRANSYT 6 inputs are required (as applicable). This version also requires data on the roadway and traffic composition (for fuel consumption) and parameters for the demand response.

NUMBER: N-4

YEAR: Original: 1967
Revised: 1977

PROGRAM LANGUAGE: ANSI FORTRAN

PROGRAM STRUCTURE: Structured

MACHINE: CDC, IBM

CORE REQUIREMENTS: 320 K (IBM)

EFFICIENCY: Low

DEGREE OF VALIDATION: Field tested in California

REFERENCES:

(1) Jovanis, P.P., A.D. May and W. Yip, "Further Analysis and Evaluation of Selected Impacts of Traffic Management Strategies on Surface Streets," ITS, University of California, Berkeley, October, 1977.

(2) Jovanis, P.P. and A.D. May, "TRANSYT 6C Model Workshop, Student Workbook," ITS, University of California, Berkeley, (undated).

put that is very similar to the type of traffic data traffic engineers typically collect whereas data required for TRANSYT are somewhat different. SIGOP III provides for a comprehensive evaluation, including cycle lengths, with measures of effectiveness for both individual links (one direction of each block) and the network as a whole. Neither SIGOP III nor TRANSYT-7F are available to the public; both are undergoing comprehensive field trials and final development. Both models represent the latest state of the art and should provide the traffic engineer with useful tools.

NETSIM (see Figure 7) is the most widely used network simulation model. It is a microscopic, stochastic model based on the UTCS-1 model that in turn was based on the DYNET model and the TRANS model. It treats individual vehicles rather than platoons and is the main reason this conference is being held. Plans for improvements and refinements to this model as part of the TRAF family are described later in this paper as well as in other papers in this conference (see, for example, the paper by Lieberman in this proceedings).

NETSIM, TRANSYT, and SIGOP III are all written in standard FORTRAN 66. Due to their wide use, they are perhaps the most portable of the models for traffic operations analysis. The data required for input are similar. The SIGOP III input data set is a proper subset of the NETSIM data set although it is formatted slightly differently. On one occasion, we were able to code an arterial network in NETSIM directly from the SIGOP III input data. These three

Figure 7. Arterial network model: NETSIM.

MODEL: NETSIM

DEVELOPED BY: E.B Lieberman & W. Rosenfield, KLD Associates, Inc., and J.J Bruggeman and R.D. Worral, Peat, Marwick, Mitchell & Co.

MAINTAINED BY: FHWA

PURPOSE: Evaluation of alternative urban arterial network control strategies, with particular emphasis on sophisticated signal control systems.

MODELING APPROACH: Microscopic, stochastic, time scan, simulcation.

DEGREE OF DOCUMENTATION:

Model Development -	Yes
Program Description -	Yes
User Manual -	Yes

GENERAL DESCRIPTION:

The NETSIM model is a microscopic, stochastic network simulation model extensive of the UTCS-1 model which incorporated and expanded on the TRANS and DYNET models. It treats the street network as a series of interconnected links and nodes, along which vehicles are processed in a time-scan format subject to the imposition of traffic control systems. THis refined model can treat most major forms of urban traffic controls and was primarily designed as a tool for testing alternative control strategies under conditions of heavy demand. It is particularly applicable to evaluation of dynamically controlled signal systems which use real-time traffic surveillance information. A wide variety of simpler problems can also be addressed. In addition to the normal data on vehicle performance (speed, delay, vehicle-miles, etc.) output data incudes estimates of fuel consumption and vehicle emissions.

NUMBER: N-3

YEAR: Original: 1971
Revised: 1977

PROGRAM LANGUAGE: FORTRAN IV

PROGRAM STRUCTURE: Modular, consisting of a (1) pre-processor, (2) simulator, (3) fuel consumption and emissions and (4) post-processor.

MACHINE: IBM 370, CDC 6600 and UNIVAC

CORE REQUIREMENTS: 256 K

EFFICIENCY: Approx. 1:2 (IBM 360/370)
1:5 (CDC 6600)

DEGREE OF VALIDATION: The model has been subjected to an extensive program of field testing and validation.

REFERENCES:

*(1) E. Lieberman and W. Rosenfield, "Network Flow Simulation for Urban Traffic Control System - Phae II", Extension of NETSIM Simulation Model (formerly UTCS-1) to Incorporated Vehicle Fuel Consumption and Emissions", Vols. 1-5, KLD Associates, Inc., 1977, 53 pages.

*(2) E. B. Lieberman and R.D. Worrall, "Network Flow Simulation for Urban Traffic Control System - Phase II, Vols. 1-5, Peat, Marwick, Mitchel and Co., and KLD Associates, Inc., 1973-74.

*(3) E.B. Lieberman et al., "Logical Design and Demonstration of UTCS-1 Network Simulation Model:, HRR 409, Transportation Research Board, Washington, D.C., 1972, pp. 45-56.

*(4) J.J Bruggeman, E.B. Lieberman and R.D. Worrall, "Network Flow Simulation for Urban Traffic Control System", Peat, Marwick, and Co., 1971.

models are also among the most extensively validated. TRANSYT and SIGOP are based on field studies of platoon dispersion by Denis Robertson in Great Britain. The NETSIM model was validated through film-recorded data of a traffic network in Washington, D.C., and to a lesser extent by traffic studies by various users.

FHWA is making available the computer models selected for inclusion in the handbook. The tape library will include the source listing for each model and the sample problems used in the handbook. These problems will be useful in testing compatibility with the user's computer.

Freeway Models

Strong emphasis has been placed on increasing the capacity, safety, and efficiency of the nation's freeways in recent years due to the unavailability of new construction funds. These limited-access highways were built generally during the last 25 years to serve existing and future traffic for years to come. However, due to the attractiveness of these facilities, design volumes were often exceeded within several years.

Today, the nation's freeways operate during portions of the day with stop-and-go traffic and low speeds, much as the arterials they were designed to relieve. This congestion is due to demand in excess of capacity and frequently to traffic accidents and incidents. Because most of the congested freeways are within the urbanized areas, the typical solutions of adding lanes are not feasible, due to right-of-way and construction costs. Land use and environmental impacts also restrict new construction. The more economical solutions to these problems have concentrated on providing higher vehicle occupancy, controlling the rate of access to the freeway, relieving bottlenecks caused by weaving and inadequate merging lanes, and detection of incidents to permit improved response through traffic control measures.

In the last decade, a considerable number of computer models have been developed to aid the transportation engineer and planner in evaluating alternative traffic control strategies for these facilities. Table 4 summarizes the freeway models reviewed for the handbook.

The most common method of encouraging higher vehicle occupancy has been through the designation of a priority lane reserved exclusively for high-occupancy vehicles. The earliest reliable model, which has been used extensively in the past to evaluate the effectiveness of this technique, is the PRIFRE model. PRIFRE is an acronym for FReeway PRIority lane model (see Figure 8). PRIFRE can be used to evaluate existing conditions without priority-lane treatments and various types of priority treatments.

Another method of improving the level of service of freeways is the use of ramp metering to either control the flow of entering vehicles or provide priority treatment for high-occupancy vehicles. The FREQ3CP model (see Figure 9) has been used extensively to evaluate alternative priority entry control strategies for freeways. This model can be used to determine the entry control strategy such as metering rates and priority cut-off levels that maximize the objective function (passenger or miles of travel).

Both of these models are included in the FHWA Transportation Planning Back Pack library. They have proved to be a valuable tool in evaluating freeway operations. They were developed by Adolph D. May and his associates at the Institute of Transportation Studies (ITS) at Berkeley. In recent years May and his associates have extended FREQ3CP to include fuel consumption, vehicle emissions, and demand-response impacts (see Figure 10). They have integrated the extended model with PRIFRE to provide a more comprehensive model, FREQ6PL (see Figure 11). However, these models are still being modified to reflect operational characteristics of the motor vehicle fleet (e.g., more strictly regulated fuel and emissions control) and other enhancements that promote a more comprehensive approach to freeway operations such as the effect of ramp control on parallel arterial streets. The handbook includes the more widely used versions, PRIFRE and FREQ3CP.

Corridor Models

During the last decade, transportation engineers

Table 4. Summary of freeway models.

Number	Name	Date	Application	Modeling Approach	Program Language	Computer
F-1	FREQ6PL	1978	Evaluate HOV Lanes	Mac., Det., TS, Opt.	ANSI Fortran	CDC/IBM
F-2	FREQ4CP	1976	Develop Optimal Ramp Metering	Mac., Det., TS, Opt.	ANSI Fortran	CDC/IBM
F-3	FREQ3CP	1975	Develop Optimal Rampa Metering	Mac., Det., TS, Opt.	Fortran IV	IBM 360 CDC 6900
F-4	TRAFFIC	1975	Evaluate Incident Detection Strategies	Mic., Stoc., TS, Sim.	Fortran IV	CDC 6400
F-5	MACK	1974	Evalate Traffic Flow	Mac., Det., TS, Sim.	Fortran	CDC 6400
F-6	PRIFRE	1973	Evaluate HOV Lanes	Mac., Det., TS, Sim.	Fortran IV	CDC 6400 IBM 360
F-7	RAMPCON	1973	Develop Opt. Metering Rates	Mac., Det., TS, Sim.	Fortran	Unknown
F-8	SDC	1972	Evaluate Traffic Flow	Mic., Stoc., TS, Sim.	Fortran IV	IBM 360/67 UNIVAC 1108
F-9	GEORGIA	1971	Eva. Affects of Trucks	Mic., Stoc., TS, Sim.	Fortran IV /Assembly	IBM 360/30 & 50
F-10	CONNECTI-CUT	1970	Evalaute Traffic Flow	Mic., Stoc., TS, Sim.	Fortran IV	UNIVAC 1106
F-11	MIKHALKIN	1970	Eva. Sensor Locations	Mic., Stoc., TS, Sim.	Fortran IV	IBM 360
F-12	SINHA	1969	Evaluate Traffic Flow	Mic., Stoc., TS, Sim.	Fortran IV /Assembly	IBM 360/65
F-13	NORTH-WESTERN	1969	Evaluate Lane Changing	Mic., Stoc., TS, Sim.	Fortran IV /SPURT	CDC 6400
F-14	TTI - MERGING	1969	Evaluate Ramp Controls	Mic., Stoc., TS, Sim.	Fortran IV	IBM 7094
F-15	MRI	1968	Evaluate Traffic Flow	Mic., Stoc., TS, Sim.	Fortran IV /Assembly	IBM 360/50
F-16	MIESSE	1966	Evaluate Ramp Closures	Mic., Stoc., TS, Sim.	Unknown	Unknown
F-17	ARIZONA	1964	Evalaute Ramp Design	Mic., Stoc., TS, Sim.	Fortran & Autocoder	IBM 7072 or 1401
F-18	GERLOUGH	1965	Evaluate Traffic Flow	Mic., Stoc., TS, Sim.	Unknown	SWAC

Figure 8. Freeway model: PRIFRE.

MODEL: PRIFRE

DEVELOPED BY: R.D. Minister, P.E. Low, K. Ovaici, and A.D. May
ITTE, University of California, Berkely

MAINTAINED BY: FHWA

PURPOSE: Evaluation of HOV lanes on freeway.

MODELING APPROACH: Macroscopic, deterministic, time scan, simulation.

DEGREE OF DOCUMENTATION:
Model Development - Yes
Program Description - Yes
User Manual - Yes

GENERAL DESCRIPTION:

The PRIFRE model was developed to simulate the operation of a directional freeway section with a concurrent-flow priority lane for high-occupancy vehicles. Its structure and modeling approach is based on two earlier models, FREEQ and EXBUS. The simulation approach employed is macroscopic and deterministic, in which vehicular flow is modeled as a compressible fluid and queueing is idealized. In operation, PRIFRE calculates the total travel time expended under normal freeway operations and total travel time expended under any number of different priority operation strategies, and compares the two. Any travel time difference (savings or losses) is noted in the final output. Similarly, PRIFRE also calculates total vehicle miles accumulated under normal and priority operations, and compares the two. A variety of occupancy shifts, number of priority lanes, model splits, and growth periods can be input to the program and results are calculated and compared. With manual interfacing, PRIFRE can also be used to evaluate wrong-way reversible lanes, separate bus roadways, freeway design improvement strategies, and ramp cotnrol schemes affording priority entry to high-occupancy vehicles.

NUMBER: F-6

YEAR: Original: 1973
Revised:

PROGRAM LANGUAGE: FORTRAN IV

PROGRAM STRUCTURE: Modular

MACHINE: CDC 6400 & IBM 360

CORE REQUIREMENTS: 80 K (Est.)

EFFICIENCY: Unknown

DEGREE OF VALIDATION: Computational & Field

REFERENCES:

*(1) R.D. Minister, L.P. Lew, K. Ovaici and A.D. May, "A Computer Simulation Model for Evaluating Priority Operations on Freeways", ITTE, University of California, Berkley, 1973, 315 pages.

*(2) R.D. Minister, L.P. Lew, K. Ovaici and A.D. May, "A Computer Simulation Model for Evaluating Priority Operationson Freeways", HR 461, Transportation Research Board, Washington, D.C., 19873, pp. 35-44.

Figure 9. Freeway model: FREQ3CP.

MODEL: FREQ3CP

DEVELOPED BY: K. Ovaici, A.D. May, R.F. Teal and J.K. Ray, University of California

MAINTAINED BY: University of California

PURPOSE: Design and operational evaluation of freeway entry control systems, with or without HOV priority treatment.

MODELING APPROACH: Macroscopic, deterministic, time scan, optimization.

DEGREE OF DOCUMENTATION:

Model Development -	Yes
Program Description -	Yes
User Manual -	Yes

GENERAL DESCRIPTION:

The FREQ3CP model was developed to evaluate alternative priority entry control strategies for freeways and to select the best strategy for a given system. The model consists of a simulation submodel, FREQ3, and an optimization submodel, PREFO. The simulation submodel is a macroscopic, deterministic model that predicts traffic performance as a function of freeway design and demand O-D patterns. The optimization submodel has a linear programming formulation designed to determine the entry control strategy (metering rates and priority cut-off level) that maximizes an objective function such as passenger input or miles of travel. The optimization process is constrained such that no freeway congestion will occur and the selected metering rates will be within reasonable limits.

NUMBER: F-3

YEAR: Original: 1975

PROGRAM LANGUAGE: FORTRAN IV

PROGRAM STRUCTURE: Modular

MACHINE: CDC 6400 and IBM 360

CORE REQUIREMENTS: 150 K (Est.)

EFFICIENCY: Unknown

DEGREE OF VALIDATION: Limited

REFERENCES:

*(1) K. Ovaici, A.D. May, R.F. Teal and J.K. Ray, "Simulation of Freeway Priority Strategies (FREQ3CP)", ITTE, Univeristy of California, Berkeley, Contract DOT-GH-11-8083 for FHWA, 1975, 471 pages.

*(2) K. Ovaici, A.D. May, R.F. Teal and J.K. Ray, "Developing Freeway Priority Entry Control Strategies", TRR 533, Transportation Research Board, Washington, D.C., 1975, pp. 122-137.

Figure 10. Freeway model: FREQ4CP.

MODEL: FREQ4CP

DEVELOPED BY: A.S.Kruger, A.D. May & others, Univiversity of California Berkley

MAINTAINED BY: University of California Berkley

PURPOSE: Develop optimal ramp metering strategy for a freeway.

MODELING APPROACH: Macroscopic, deterministic, time-scan, optimization

DEGREE OF DOCUMENTATION:

Model Development -	Yes
Program Description -	Yes
User Manual -	Yes

GENERAL DESCRIPTION:

This version in the FREQ-series extends FREQ-3CP to include fuel consumption, vehicle emissions and demand response impacts. During the simulation the model estimates the amount of fuel consumed in the study area and the amounts of effluents of HC, CO and NO_x. The demand response sub-model estimates the shift of vehicles in space due to metering and estimates the change in model choice based on travel time savings and an input elasticity after optimization. In addition to the FREQ3CP inputs, data on the geometrics and vehicle mix are reuqired. Extended output include measures of effectiveness and plots of the added functions.

NUMBER: F-2

YEAR: Original: 1972
Revised: 1976

PROGRAM LANGUAGE: ANSI FORTRAN

PROGRAM STRUCTURE: Structured

MACHINE: CDC, IBM

CORE REQUIREMENTS: 280 K

EFFICIENCY: Medium

DEGREE OF VALIDATION: Field tested at a number of locations

REFERENCES:

(1) Kruger, A.J. and A.D. May, "The Analysis and Evaluation of Selected Impacts of Traffic Management Strategies on Freeways," ITS, University of California, Berkely, October, 1976.

*(2) Feldman, M., R. Cooper and A.D. May, "Development of Priority Strategies on Freeways (FREQ4CP) - Student Workbook," ITS, University of California, Berkely, March, 1977.

have realized that the problems on arterials, central urban grids, and freeways interweave. As a result, they have begun to look to solutions that considered the entire system of arterials, freeways, and feeder streets comprising transportation corridors. These efforts have focused not only on increasing freeway capacities and vehicle occupancies but also on fuller use of the existing capacity available on parallel facilities, as well as efforts to minimize the travel time and delay for the system as a whole. Efforts toward accomplishing this purpose have included the same elements of treatment that were covered in the arterial, grid, and freeway model analysis: preferential treatment for high-occupancy vehicles, priority entry, and improved signal timing. In addition, such elements as traffic diversion to parallel facilities and systemwide surveillance have been studied.

Most of the computer models available for developing and evaluating transportation corridor strategies are recent and are still in the process of development, testing, and refinement. Table 5 summarizes those corridor models identified and reviewed for the handbook project.

While not a single model, the TRAF family of simulation models will be capable of transportation corridor analysis when completed. In addition, two models of the TRAF family, FREFLO (freeway flow) and

Figure 11. Freeway model: FREQ6CP.

MODEL: FREQ6PL

DEVELOPED BY: T. Cilirs, A.D. May, et. al.
University of California
Berkeley

MAINTAINED BY: University of California
Berkeley

PURPOSE: Evaluate priority lanes on freeways.

MODELING APPROACH: Macroscopic, deterministic, time-scan, optimization.

DEGREE OF DOCUMENTATION:
Model Development - Yes
Program Description - Yes
User Manual - Yes

GENERAL DESCRIPTION:

This model combines the functions of PRIFRE and FREQ5CP. It is used to evaluate priority lanes for buses and car pools on a directional freeway with or without entry ramp control. The model estimates traffic impacts, fuel consumption, exhaust emissions and facility costs. Special and model shifts are included similar to FREQ6PE.

NUMBER: F-1

YEAR: Original: 1972
Revised: 1978

PROGRAM LANGUAGE: ANSI FORTRAN

PROGRAM STRUCTURE: Structured

MACHINE: CDC, IBM

CORE REQUIREMENTS: 165 K

EFFICIENCY: Low

DEGREE OF VALIDATION: Field tested
In California

REFERENCES:

(1) Cilliers, T., A.D. May and R. Cooper, "FREQ6PL - A Freeway Priority Lane Simulation Model," California Department of Transportation, Final Report and Volume II, September, 1978.

Table 5. Summary of transportation corridor models.

Number	Name	Date	Application	Modeling Approach	Program Language	Computer
T-1	FREQ6PE	1978	Develop Optimal Metering Strategy and Corridor Analysis	Mac., Det., TS, Opt.	ANSI Fortran	CDC/IBM
T-2	INTRAS	1977	Eva. Freeway Incidents On Corridor Operations	Mic., Stoc., TS, Sim.	Fortran IV	IBM 370 CDC 7600
T-3	CORQIC	1975	Develop Optimal Controls for Corridor Operations	Mac., Det., TS, Opt.	Fortran IV	CDC 6400
T-4	CORQ	1974	Eva. Traffic Control Strategies within Corridor	Mic., Det., TS, Sim.	Fortran IV	Unknown
T-5	VPT	1974	Evaluation of Traffic Flow in Freeway Network	Mic., Stoc., TS, Sim.	Fortran IV /COMPASS	CDC 7600
T-6	LIEW	1974	Evaluate Optimal Ramp Control Strategies	Mac., Stoc., TS, Sim.	Unknown	Unknown
T-7	STAR	1974	Evaluate Surveillance and Control Strategies for Route Diversions	Mac., Det., TS, Sim.	Unknown	Unknown
T-8	SCCT	1975	Evaluate Traffic Control Strategies within Corridor	Mic., Stoc., TS, Sim.	Fortran IV	CDC 660 IBM 370 UNIVAC
T-9	FRICP	1972	Develop Optimal Inter-Change Configuration	Mac., Det., TS, Opt.	Fortran IV /Assembly	IBM 360
T-10	DAFT	1970	Evaluate Traffic Control Strategies within Corridor	Mac., Stoc., TS, Sim.	Unknown	Unknown
T-11	SDC	1966	Evaluation of Alternative Diamond Inter-Change Configurations	Mac., Stoc., TS, Sim.	Unknown	Unknown
T-12	TRANSIM	1966	Evaluation of Traffic Performance in System	Mic./Mac., Stoc./Det. TS, Sim.	Fortran IV	IBM 7090, 7094,1401

NETFLO (street NETwork FLOw) have been developed as the TRAFLO (TRAffic FLOw) model, which macroscopically simulates large transportation areas. Testing of this model is under way.

A number of corridor models were developed at the University of California at Berkeley. Models such as PRIFRE, FREQ, CORQUIC, and TRANSYT6C were specifically developed to examine transportation system management type improvements. (See the paper by May in this proceedings.)

Due to the relatively new status of the transportation corridor models and the limited space available in the handbook, it was decided not to include corridor models. Instead, potential users are referred to the University of California or to FHWA's Office of Research and Development.

WHAT FHWA IS MAKING AVAILABLE

FHWA is sponsoring and making available a variety of models. The Arterial Analysis Package (AAP) family of models includes SOAP, PASSER II, PASSER III, and TRANSYT. The AAP is currently under development for the Traffic Systems Division of the Office of Research and Development and will be made available when successfully completed.

The TRAF family of models is still under development. However, the NETSIM program is available from FHWA. TRAFLO is available for testing and experimental use, but only under tightly restricted conditions, and is not yet operational.

The TRANSYT-7F and SIGOP III programs are undergoing extended pilot-city testing and will not be made available until after completion of the testing. They are included in the handbook with the expectation that they will be available for use by the time the handbook is printed and distributed.

The FREQ family of models is technically in the public domain. However, the University of California charges a nominal fee for copying, which includes limited consultation on setup and use of the models. Since FHWA does not have the staff or expertise to do this for cities and states, it is recommended that copies be obtained from the University of California.

PROBLEM TO BE ADDRESSED

Considering all these seemingly wonderful traffic simulation and optimization models and the long lists of users that FHWA, ITS, and the British Transportation and Road Research Laboratory can point to, the question is, Why aren't computer models being used more widely in traffic engineering practice? This was the basic problem considered by FHWA as it was planning its implementation support efforts.

The objectives of this implementation effort were quite simple: to improve safety, reduce delay and fuel consumption, reduce air pollution, and generally make traffic flow better. However, to accomplish these goals, real-world changes in the behavior of traffic engineers were needed. To get traffic engineers to use traffic simulation and optimization models, they would have to be made both easy and less expensive to use. The models would also have to be reliable and valid. Of course, the results produced by the models would have to be useful to the engineer in achieving traffic improvements.

The approach taken to establish the credibility of the models and their validity was through demonstration and testing. Making the models easier to use was the goal of the training course and the implementation support effort. Information dissemination was planned to get the results of these efforts to engineers in order to convince them to use the models. These efforts were quite successful. As a result, many engineers are now using the NETSIM model but many problems and limitations were identified. FHWA research and development now has several short-term activities planned to make NETSIM easier and cheaper to use and several long-term concepts under discussion to address the input/output problem.

DEMONSTRATION AND TESTING

FHWA contracted with the states of Utah and California to conduct real-world uses of the UTCS-1 model (the predecessor to NETSIM). These field uses identified limitations in the model that require several minor changes and one major change. The use of annotated coding forms was invented to overcome limitations in input of data. Several of the most successful applications of the model involved identifying do-nothing alternatives as the most reasonable alternatives. These efforts proved that the concept of applying traffic models to real-world traffic engineering problems could prove quite fruitful. A variety of desired enhancements was identified by Utah, California, and Michigan engineers that are part of the current FHWA recoding of NETSIM.

IMPLEMENTATION SUPPORT

A major problem found in the demonstration and testing and subsequent distribution of UTCS-1 and NETSIM codes to various users was the need for assistance to users in setup and use of the model. As a result, severe demands are made on the time of several engineers who are supposed to be conducting research activities. The FHWA Office of Traffic Operations, which is normally responsible for such activities, will not be able to conduct them until its TRANSYT-7F project is completed. Therefore, a contract effort for what might be typified as debugging, problem-solving, and program maintenance has been conceived. This effort will last from one to three years and will assist users in bringing up NETSIM on their computers, understanding its data requirements, and answering the inevitable questions that arise.

SHORT-TERM PLANS

For the next year, FHWA will be concentrating on providing basic user support through the support contract. We will also be arranging for the state of Michigan to make its forms display input program available for wider use by converting it to FORTRAN 77 and transporting it to one or more new types of computers. IBM, CDC, and UNIVAC computers are the primary candidates. Next year a test and demonstration effort of the TRAFLO program will begin. This program consists of a macroscopic version of NETSIM and a macroscopic freeway model. Before this effort begins, it is hoped that Michigan will be able to test the prototype version of the program.

FUTURE PLANS AND CONCEPTS

For the long term, FHWA plans to get involved in graphics. There is now some movement toward standards in the graphics area. The Association for Computing Machinery and the IEEE have supported a core-graphics standard and the U.S. Army Corps of Engineers has created a public-domain portable graphics software package.

Interactive input in a truly intelligent sense will require the creation of a very sophisticated input processor. FHWA hopes that the experienced gained with the Michigan forms display processor and the RPI graphics input system will provide the foundation for any easy-to-use input system. Such a system will allow the integration of simulation and optimization models.

This integration will also provide an excellent training tool. It could revolutionize the process of educating traffic engineers by providing hands-on experience. How this should be done may be the topic of some future conference.

ACKNOWLEDGMENT

Alexander Byrne of Diaz, Seckinger, and Associates compiled the tables and figures used in this paper as part of a project to develop a Handbook of Computer Models for Traffic Operations Analysis. Paul Ross of FHWA's Traffic Systems Division participated in the design of the handbook study and assisted in the identification of many of the models reviewed in it. The WYLBUR editing system of the National Institutes of Health was used in the preparation of the text.

Models for Freeway Corridor Analysis

ADOLF D. MAY

This paper has two major themes: (a) to describe existing traffic simulation models and their applications in freeway corridor analysis and (b) to demonstrate the need for integration of research, education, and implementation activities as a key for the enhancement of simulation modeling practice. The overall objective of this paper is to provide a state-of-the-art document on freeway corridor models and to encourage researchers and practitioners to work closer together in simulation modeling. The paper also includes an extensive bibliography, which is an attempt to include all published papers that describe the development and application of available freeway corridor models.

FREEWAY CORRIDOR MODELS

After a brief review of earlier models for freeway corridor analysis, five families of currently available models are described. Particular emphasis is given to the historical development of the models and to real-life applications. The five families of models are CORQ, FREQ, INTRAS, MACK, and SCOT.

Early Models

Hsu and Munjal provide a good starting point for this paper with their paper on freeway digital simulation models (1). Their paper identified and reviewed 15 simulation models associated with various aspects of freeway vehicular traffic, and the models are compared against a baseline of eight desirable model features. Space here does not permit a description of these 15 models and the reader is referred to the Hsu-Munjal paper. The identified models were

1. Arizona Transportation and Traffic Institute Traffic Simulation Model (2),
2. Midwest Research Institute Freeway Simulation Model (3,4),
3. Midwest Research Institute Mountainous Terrain Model (5),
4. Northwestern University Lane-Changing Model (6),
5. Sinha Freeway Simulation Model (7,8),
6. Connecticut Department of Transportation Expressway Simulation Model (9),
7. Texas Transportation Institute Freeway Merging Model (10),
8. System Development Corporation Diamond Interchange Model (11),
9. System Development Corporation Freeway Simulation Model (12),
10. Mikhalkin Freeway Simulation Model (13),
11. Georgia Model (15),
12. SCOT Corridor Model (14,16-18),
13. Priority Lane Model (19,20),
14. Aggregate Variable Models (21), and
15. Aerospace Corporation Freeway Simulation Model (22).

These earlier models in many cases were forerunners of later models described in the following sections. For example, Lieberman and Bullen used model 4 in the development of the INTRAS model, while model 12 was the early version in the SCOT model family. Model 13 was an early priority-lane version in the FREQ model family, and model 14 was the early version in the MACK model family.

The CORQ-CORCON Model Family

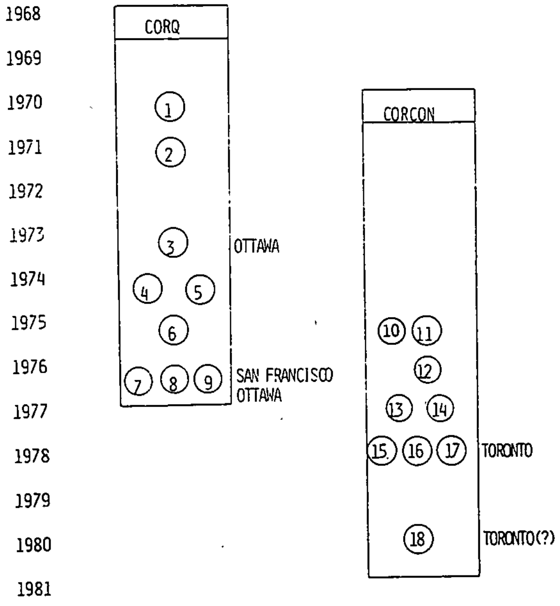
The CORQ model developed by Yagar during the period 1969-1976 and the related CORCON model developed by Easa and Allen during the period 1971-1978 are the two models in this model family. In addition to their development, these models have been applied in Ottawa, San Francisco, and Toronto by the developers. An illustration of the chronological development of the CORQ-CORCON family of models is shown in Figure 1.

Yagar began work on the CORQ model as part of his dissertation at the University of California (23). He incorporated dynamic traffic assignment and queuing in order to model the time-varying nature of peak demands (24). By 1972, the CORQ model was completed. Incorporated in it were a number of traffic-specific factors such as the sharing of capacity at the merge of an on-ramp and freeway. In 1972-1973, it was applied to the eastbound corridor serving Ottawa for the morning peak period (25). The most comprehensive description of the current CORQ model is contained in Yagar (26). Descriptions of the assignment procedure model summary (27,28) and some required theoretical modeling details have also been published.

The CORQ model predicts flows and queues in a road corridor and combines the techniques of dynamic traffic assignment, emulation of queue spillback, ramp control strategies, combines iterative and incremental assignment, and determination of mutually dependent capacities (29).

The CORQ model was applied in two geographic areas and results have been published. A number of strategies for staggered work-hour programs were tested in selected corridors in San Francisco and

Figure 1. Chronological development and application of CORQ/CORCON model family.



Ottawa (30). The effects of these staggered work-hour strategies were evaluated with the CORQ model, and potential savings in total travel time were predicted. The model was also applied to a portion of the Ottawa Queensway Corridor to predict the effects of some alternative traffic control schemes designed to relieve congested conditions (31). Strategies tested included off-ramp closures that had the greatest single effect on total network travel time.

Turning to the second model in this family, the CORCON model, Easa began work on the model as part of his thesis at McMaster University (32). During the period 1976-1978, Easa and Allen added several modifications to the model and applied the modified version to a freeway corridor (33-38).

The CORCON model is an analytical procedure for predicting traffic volumes, queuing conditions, and travel times in a freeway corridor. Traffic demand can vary over time and is assigned to a freeway and surrounding arterial street network. The minimum path algorithm can incorporate turn prohibitions. A major characteristic of the CORCON model is its link-node representation that simplifies network representation by allowing more than one directional roadway link to have common upstream and downstream nodes and automatically avoid illogical paths in the network.

The CORCON model was applied to Queen Elizabeth Way freeway corridor in southwest Toronto in order to predict traffic operating characteristics in the corridor network before and after entry control. A significant data collection-reduction and model calibration-validation effort was undertaken. The diversion parameter and the origin-destination (O-D) demand patterns were calibrated for the after-control period, and the CORCON procedure was validated by comparing the predicted and the observed conditions for the before control period. It was reported that the CORCON model would soon be used to assess the impact of a proposed freeway control project on the Highway 401 bypass route in metropolitan Toronto (38). A more detailed discussion of the use of the CORCON model for evaluating TSM-type strategies has been published (39). A 1980 report noted that a project was under way (1979-1981) to apply the CORCON model (and FREQ and FREFLO models) to problems in freeway corridor traffic management (40).

The FREQ Model Family

Demand-supply modeling efforts for freeway corridor operating environments were initiated in 1968 at the University of California when a California Department of Transportation (Caltrans) research project required the evaluation of alternatives for improving 140 miles of the existing San Francisco Bay Area freeway system. The system was too extensive and the alternative improvements too numerous to consider manual analysis. This first model called FREQ or FREQ1 was developed and was a forerunner of a family of models that now have reached a seventh-level version (41). An illustration of the chronological development of the FREQ model family is shown in Figure 2.

The FREQ2 and FREQ3 models were extensions and refinements of the earlier model, with particular attention being directed to shock-wave analysis, computer efficiency, and output format (42,43). The PRIFRE model was developed for the evaluation of priority lanes on freeways (44).

By the early 1970s, the need for decision models, those that incorporated simulation and optimization submodels, was recognized. Three models in this family were developed (FREQ3CP, FREQ3D, and FREQ3C) and incorporated priority entry control, design improvement, and normal entry control optimization submodels, respectively (45-47). An on-line version of the FREQ3C model was developed and called the FRESCOT model (48). One of the significant results of this work was the development of a technique for generating synthetic O-D tables from on-ramp and off-ramp counts.

As the modeling effort continued, greater attention was given to the surrounding street system (CORQ1C model) (49), impact assessment (FREQ4CP model) (50), and traveler demand responses (FREQ5CP and FREQ6T models) (51,52). The most recently developed FREQ models in use today are the FREQ6PE and FREQ6PL models (52,53). The FREQ7PE model is undergoing final testing and is planned for distribution in 1981 (54).

The FREQ6PE model is a macroscopic decision model of a freeway corridor and is used primarily for the evaluation of priority entry and normal entry control on a directional freeway (52). The model can also be used for evaluating design improvements with or without freeway entry control. The model predicts a time stream of impacts and traveler responses due to the interaction between ramp control strategy and traveler responses. The impact assessment includes travel time, fuel, emissions, and noise; demand forecasting includes spatial and modal traveler responses in increments during the first year of operation.

The FREQ6PL model is a macroscopic model of a freeway corridor and used primarily for the evaluation of reserving lane(s) on freeways for carpools and/or buses (53). The model can also be used for evaluating design improvements with or without priority operation. The user selects the priority lane(s), design configuration, priority cut-off level, and time duration of priority operations. The model automatically modifies the demand and supply sides of the model and predicts a time stream of impacts and traveler responses. The impact assessment includes travel time, fuel, emissions, and facility costs; demand forecasting also includes spatial and modal traveler responses in increments during the first year of operation.

Figure 2. Chronological development and applications of FREQ model family.

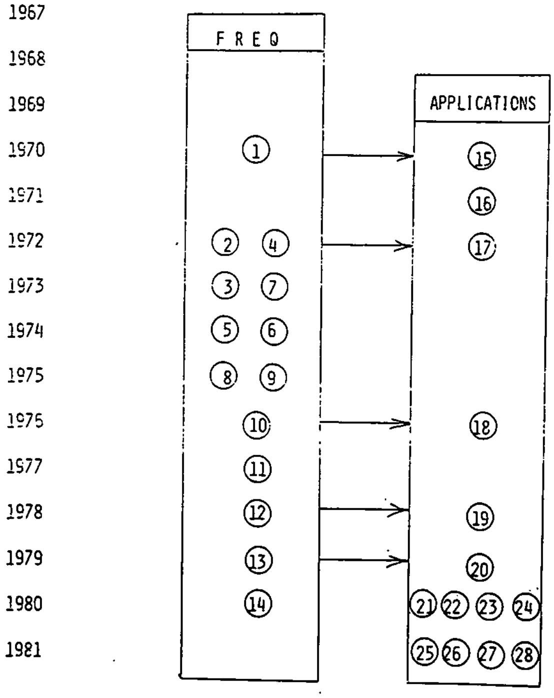
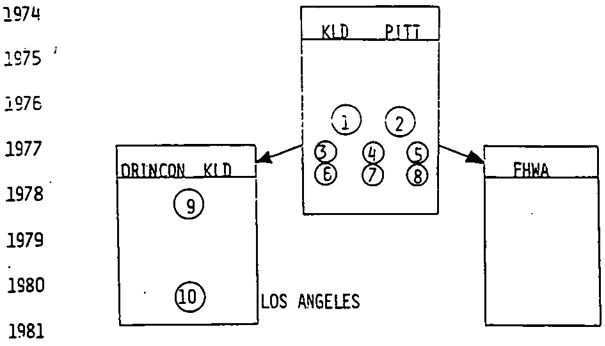


Table 1. Selected examples of FREQ model applications.

Year	Principal Investigator	Description	Site	FREQ Model	Description	Ref. No.
1970	Allen	University of California	Oakland Bay Bridge	3	Evaluate design and control alternatives	55
1971	Aidoo	University of California	I-80, Berkeley	3	Evaluate design and control alternatives	56
1972	Capelle	Voorhees	I-90, Cleveland	PRIFRE	Determine feasibility of priority lanes	57
1976	Gabard	French government	Nord RTE, Paris	3C	Evaluation of access control	58
1978	Ritch	Texas A&M	I-10, Houston	3CP	Projected future operations improvements	59
1978	English	Texas Department of Transportation	US59, Houston	3CP	Compared operations and design improvements	60
1979	Schneider	University of Washington	I-80, Berkeley	GRAF	Developed graphical output	61
1980	Michalopoulos	University of Minnesota	I-394, Minneapolis	6PE/6PL	Design and control strategy evaluation	62
1980	Immers	Delft University	A-12, Hague	4CP	Measured impacts of design and operations	63
1980	White	New Zealand government	North Freeway, Auckland	3CP	Develop and evaluate ramp control plan	64
1980	Anderson	CALTRANS	I-10, Los Angeles	6PE	Estimated metering impacts on city streets	65
1981	Torres	JFT Associates	RTE 11, Los Angeles	6PE/6PL	Evaluated fuel conservation stretegies	69
1981	Meyer	Colorado Department of Transportation	I-25, Denver	6PE	Analysis of optimized metering and geometrics	66
1981	Howard	Bartholomew	I-95, Miami	6PE/6PL	Evaluated feasibility of TSM techniques	67
1981	Deakin	Lockner	I-95, Miami	6PE	Determined feasibility of ramp metering	67
1981	Berg	Parsons	I-5, Seattle	6PE	Evaluation of TSM-type strategies	68
1981	O'Neill	Washington Department of Transportation	I-495, Seattle	6PE/6PL	Priority lane evaluation	68

Figure 3. Chronological development and applications of INTRAS model.



The FREQ models have been applied by a number of investigators analyzing freeway corridor traffic. Time and space limitations permit only the presentation of a sample of model applications and then only a brief description of highlights of selected applications. These applications are identified and described in Table 1.

The INTRAS Model

The INTRAS model is a stochastic, microscopic model especially developed for studying freeway incidents. INTRAS stands for INtegrated TRAffic Simulation and is a vehicle-specific time-stepping simulation designed to realistically represent traffic and traffic control in a freeway and surrounding surface street environment. The model development and/or applications have occurred in at least four organizations since work began in 1975. An illustration of the chronological development and application of the INTRAS model is shown in Figure 3 and the following description is keyed to this illustration.

A program of major emphasis was undertaken by FHWA that included the design, programming, calibration, validation, and demonstration of a computer simulation model for the evaluation of incident detection strategies. The project had six major tasks and included the adaptation of the UTCS-1 network simulation model for freeway applications, validation of candidate components, programming the simulation model, validation and refinement of the simulation model, validation of incident detection algorithms, and application of the simulation model.

Four interim reports were prepared (70-73). At the end of the project in mid-1977, a final report in four volumes was submitted to FHWA (74-77). The four volumes dealt with program design, parameter calibration and freeway dynamics component development (74); users manual (75); validation and application (76); and program documentation (77).

Two parallel activities have been undertaken since 1977 with the INTRAS model. FHWA staff have been reviewing the submitted project reports and have undertaken a series of investigations with the INTRAS model in anticipation that it will be released soon to operating agencies. The other activity is one undertaken by the ORINCON Corporation in which both the INTRAS and MACK models were used to evaluate freeway ramp control strategies under incident situations.

The ORINCON study for FHWA was undertaken during 1978-1980 and KLD Associates was the subcontractor responsible for production runs with the INTRAS model. ORINCON Corporation prepared an initial report (78) that compared the INTRAS and MACK models and then a final report (79) that described the project including the use of the INTRAS model.

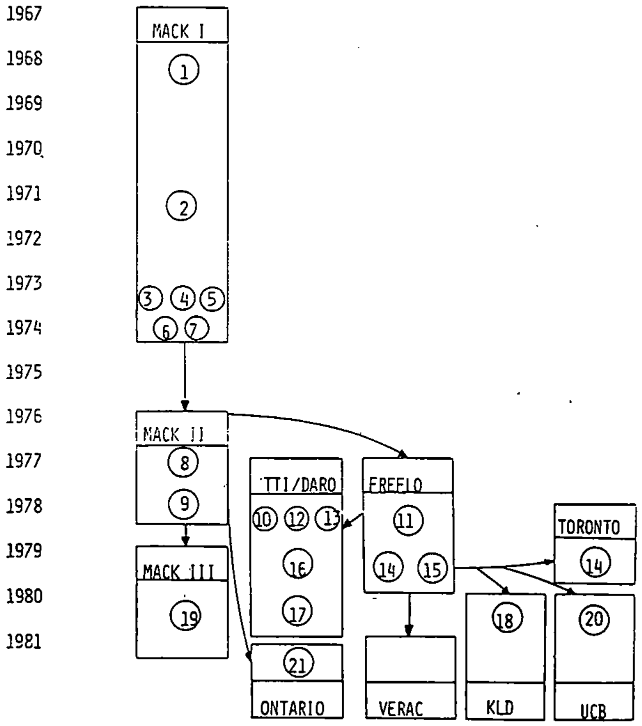
The MACK Model Family

The MACK model and its later versions are deterministic, macroscopic models that basically consist of a set of conservation equations and a corresponding set of dynamic speed-density equations. Payne and associates began work in the late 1960s and models in this family include MACK I, MACK II, MACK III, FREFLO, and TRAFLO. The model development and/or application have occurred in at least 10 organizations. An illustration of the chronological development and application of the MACK model family is shown in Figure 4 and the following description is keyed to this illustration.

The MACK I model was developed at the University of Southern California and applied to the Hollywood Freeway in Los Angeles for evaluation of ramp control under incident and recurring congestion conditions (80-85). Detailed instructions for its use and an indication of its capabilities were well documented (86).

The MACK II model was developed at ORINCON and was compared with the INTRAS model (87,88). A new equilibrium speed-density relationship and a structural change in the dynamic-speed relationship that involved the parameters were introduced. The MACK II and INTRAS models were applied to a segment of the Shirley Highway with incident-free and incident

Figure 4. Chronological development and applications of MACK model family.



scenarios. The authors recommended that MACK II be adopted for the purpose of making preliminary evaluations of control strategies for responding to incidents based on the qualitative agreement between MACK II and INTRAS results and the 100-fold cost factor between execution of the MACK and INTRAS models.

The FREFLO model was developed by Payne at ESSCOR and was a successor to the MACK II model. The FREFLO model was designed to provide a basic model, perform input data diagnostics, represent incidents, model on-ramps, control time of day, represent surveillance, represent two traffic-responsive metering schemes, provide standard measures of travel and travel time, include fuel consumption, and include pollution emissions (93). A user's guide and program documentation were prepared (90). The last published paper by Payne about the FREFLO model was a review of the model with particular attention given to critical modeling issues that significantly affect the functioning of the model or that are otherwise of interest and have yet to be explored (94). Further investigation was proposed and included the form of the continuum model, parameter values for v and T, explanation of roll waves, congestion phenomena, modeling of merge areas, and equilibrium speed-density relationships.

A continuation of an earlier NCHRP project, entitled Guidelines for Design and Operation of Ramp Control Systems, was initiated in 1977 and a final report draft was prepared in January 1980 (96). The major objective of the study was to prepare specific guidelines for determining the feasibility of ramp control and, if feasible, to identify which mode of ramp control is appropriate: pretimed, local actuated, or system. The initial research plan called for the determination of the incremented benefits of the various control models from successive field trials of each mode at selected freeway sites. After due consideration, it was determined that the use of a freeway simulation model provided the best research approach. The FREFLO model was selected and 153 simulation runs were used. Numerous technical memoranda were prepared and include plans for simulation runs (89), MACK acceptance tests (91), FREFLO acceptance tests (92), and FREFLO baseline scenarios (95).

Koble continued the work of Payne at ORINCON in using the MACK model (unofficially called MACK III) and the INTRAS model to evaluate freeway ramp control strategies under incident situations. The project was sponsored by FHWA and began in early 1978; a final report was submitted in April 1980 (98). The MACK III model was modified to handle incidents and simulate a variety of ramp control strategies. Several hundred simulation runs were made and the MACK III model was the key analytical tool employed along with the INTRAS model.

Hauer and Hurdle of the University of Toronto were selected as discussors of Payne's paper on the FREFLO model and their discussion and the author's closure were published at the end of the paper (93). The discussors applied the FREFLO model to a simple freeway example with no ramps and a bottleneck in the middle. They hypothesized expected traffic results. Computer outputs did not provide anticipated results. Hauer and Hurdle pointed out the difficulties encountered and speculated about possible explanations. Payne, in his closure, reviewed the previous successful uses of FREFLO and stressed the importance of selecting appropriate model parameters. Particular attention was drawn to the nominal capacity parameters and their relationship to the traditional concept of roadway capacity.

Lieberman and Andrews described the TRAFLO model, which is a software system, programmed in FORTRAN, and which consists of five component models that interface with one another to form an integrated system (97). The freeway traffic simulation model included in TRAFLO is an extension and refinement of the earlier MACK model. In addition to the refinements to the FREFLO model described earlier, another extension allows buses, carpools, automobiles, and trucks to be distinguishable as three vehicle types. As of 1980, the TRAFLO program had been completed and was undergoing in-house testing by FHWA personnel.

The Institute of Transportation Studies, under sponsorship of the Caltrans with the cooperation of FHWA, began an on-line freeway entry control research project in late 1979. The project consists of two phases. In phase I, selected control strategies are to be evaluated through the use of a freeway simulation model applied to a specific site. In phase II, the most promising control strategies are to be evaluated in the field at the specific site. The first working paper was directed toward the selection of site, model, and candidate strategies (99). The FREFLO model was selected for use in this project because of the dynamic nature of the model and the anticipated short control intervals. The FREFLO model has been modified to simulate more realistically congested flow conditions, to enhance user ease in interpreting model outputs, and to permit the evaluation of fixed-time, local-responsive, system-responsive control, and other control strategies. A phase I report is expected in 1981.

Derzko, Ugge, and Case prepared an informal paper in which they reported the evaluation of two dynamic freeway flow models by using field data from the Queen Elizabeth Way in Ontario, Canada (100). The MACK II model and one of Phillips kinetic models were the two dynamic models evaluated. The preliminary results of their investigation indicated the models both exhibited instabilities in their behavior and did not track their real road data correctly.

Work with the FREFLO model continues on at least

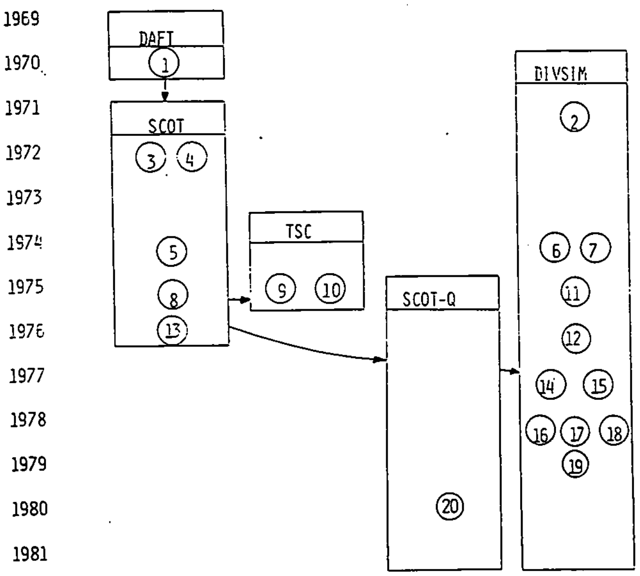


Figure 5. Chronological development and applications of SCOT model family.

three fronts. The FREFLO model will continue to be an integral part of the TRAFLO model system. The Institute of Transportation Studies continues its freeway entry control project and is using a model based on the FREFLO model. And finally, Payne at VERAC is currently under contract to FHWA to calibrate, validate, and refine as necessary the FREFLO model.

The SCOT Model Family

For purposes of this paper, the DAFT, SCOT, SCOT-Q, and DIVSIM models are classified as members of the SCOT family of models. Work began in this modeling effort in the late 1960s and continues today. The initial work on this family of models was undertaken by Lieberman and associates at KLD. Researchers at Sperry also worked on this family of models and recently integrated the more advanced SCOT-Q model into their DIVSIM model. The following highlights the development and applications of this family of models (see Figure 5).

The DAFT model was the first model developed in this family and is a macroscopic simulation of traffic along a network of freeways, ramps, and arteries. Lieberman developed this model and first applied it to a portion of the Central Expressway north of Dallas (101). In the model the vehicles are grouped into platoons and move along the freeway according to a specified speed-density relation. Along the nonfreeway links, the platoons travel at specified free-flow speed and are delayed at the downstream end of links based on g/c ratios and approach volumes. Input data include O-D demands that may vary with time. The model includes a minimum travel cost algorithm and hence produces a dynamic assignment of traffic as a by-product of the simulation.

Lieberman and associates then created the SCOT model, which represented an evolutionary development based on combining the freeway portion of the previously described DAFT model and the UTCS-1 model for urban street networks (103,104). While the freeway traffic is modeled macroscopically in essentially the same manner as the DAFT model, the urban street network is modeled microscopically in essentially the same manner as the UTCS-1 model. A key design element of the SCOT model is the interface features between the macroscopic and microscopic characteristics of the two submodels. The traffic demands may be entered into the model either in the form of turning movements at each node or O-D volumes. The model was developed as a means of testing real-time control policies for an entire corridor: freeway ramps, frontage roads, and adjoining feeder and parallel arterials.

During 1973-1976, two parallel efforts were undertaken that involved the SCOT model. The first of these two efforts was undertaken by KLD and was directed toward developing user and program documentation manuals for the SCOT model. The other effort was undertaken by the Transportation Systems Center (TSC) and was directed toward the application and evaluation of the SCOT model. KLD, under contract to TSC, prepared a plan for data acquisition, data reduction, model calibration, and model validation (105). This was followed by the preparation of user and program documentation manuals (108,113).

TSC applied the SCOT model to the central business district of Minneapolis (109) and to a 1.2-mile test network of the Dallas North Central Expressway (110). In the Minneapolis application, the SCOT model was used to predict the effect on bus service and general traffic performance of implementing candidate bus priority strategies. The SCOT model was calibrated to current peak-hour traffic conditions within an urban street grid representative of the central business district of Minneapolis. In the Dallas North Central Expressway study, the SCOT model was calibrated and validated. Tests showed no significant differences between field and simulation results for the basic parameters of traffic speed, flow, and saturation. A demonstration of the O-D traffic assignment capability of the model indicated that the minimum time-path criteria used have not been conclusively shown to be the correct criteria for traffic assignment.

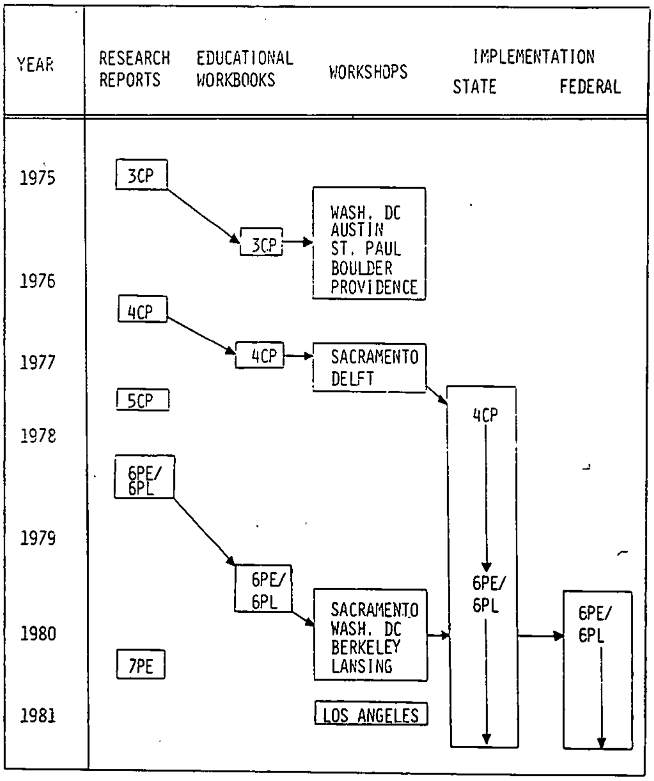
Sometime in 1976, a new effort was directed toward the development of the SCOT-Q model. The initial work on SCOT-Q was undertaken by KLD, which essentially adopted the SDC approach to the NETSIM portion of the SCOT model (120). A larger time-step was employed and, with some simplifying assumptions, the SCOT-Q model had a faster running time than the SCOT model for simulation. The SCOT-Q model was used by Sperry to aid in assessing the feasibility of an Integrated Motorist Information System (IMIS) for the Northern Long Island (N.Y.) corridor. Phase I (feasibility) of this FHWA-sponsored project, entitled Integrated Motorist Information System Feasibility and Design Study, was completed in 1977 (114). A series of more than 130 computer runs was made, and the SCOT-Q model reduced running time by 50 percent compared with the SCOT model.

In Phase II, Sperry developed a generalized IMIS feasibility methodology and, to validate the methodology, applied an enlarged version of the SCOT to a freeway corridor just east of downtown Los Angeles (118). The simulation was calibrated to the test corridor by using special data collected for that purpose. The enlarged SCOT model was used to test three scenarios: recurrent congestion situation without control, incident situation without control, and controlled response to minimize major congestion.

Phase III is planned to result in the final design for IMIS in the Northern Long Island Corridor.

In a parallel effort, Sperry researchers worked on a FHWA-sponsored project concerned with the development of traffic logic for freeway corridor control (116,119). This effort included development of DIVSIM, a corridor optimization program embedded in the SCOT simulation. The optimization portion of this program was termed DIVERT and is intended as

Figure 6. Educational and implementation activities with freeway corridor models.



the real-time version of the DIVSIM corridor optimization algorithm.

In a parallel effort, researchers at Sperry began work on another family of models in the early 1970s when they developed a simulation model of a system that balances vehicular flow between two parallel routes through the use of real-time surveillance and variable signing control (102). The model was a hydrodynamic macroscopic model, employed shock-wave analysis, and was designed considering the type of roadway and signing in use on the New Jersey Turnpike.

Sperry researchers continued the development of this model on a FHWA-sponsored project, entitled Diversion of Intercity Traffic at a Single Point, with application to the Harbor Tunnel Thruway and I-695 Bypass Route in Baltimore. A final report (106), simulation model description (107), and several technical papers (111,112) resulted from this effort. The simulation model was named the STAR model and provided a multiple roadway-freeway simulation capability. It essentially consisted of two major components: a hydrodynamic traffic flow model and a traffic diversion model. The resulting optimized policies have been incorporated into the design for a practical real-time alternate routing system applicable to the Baltimore site.

THE NEW FRONTIER--MODEL APPLICATIONS

Greater use of existing simulation models and the relevant development of future simulation models require a major educational and implementation support effort today. The developers of simulation models have an important role to play, in fact a major responsibility for such activities. As Lieberman has pointed out, "While the development of simulation models can hardly be considered an activity which has reached its full potential, we are nevertheless making a transition from a period of intensive model development to one of intensive application" (121). This section describes the educational and implementation support effort undertaken in regard to the FREQ family of models. The purpose is to demonstrate the need for such efforts and to encourage others to become involved with similar efforts with this and other freeway corridor models. Such educational and implementation activities are shown in Figure 6.

Limited educational and implementation support activities with the FREQ model were undertaken before 1975. The model had been applied by the developers and had been used by a consultant in one research effort concerned with establishing guidelines for priority lanes on freeways. Almost all effort was devoted to extending and refining the model, and there was little interest shown by others in using the model.

By 1975, the FREQ3CP model had been developed with sponsorship from FHWA. At the same time, there was a growing awareness to encourage travel by carpool and bus by preferential treatment on highway facilities. Because of this awareness, the model's capabilities, and the recognition for training, FHWA sponsored the development of a FREQ3CP instructor and student workbook (122), the conduct of five workshops, and the distribution of computer program and sample input-output listings.

The FREQ3CP model became a part of the FHWA's BACKPAC computer program system and, while formal implementation support for the model was not available, these workshops stimulated extensive model use in several cities including Houston, Minneapolis, Boston, and Denver. In late 1976, the FREQ4CP program became available and a new workbook was prepared (123).

The FREQ model developers and Caltrans recognized a need for implementation support beyond the workshop and entered into an agreement in which Caltrans professionals could continuously seek advice and assistance from the FREQ developers. The implementation support activities began in 1977 and have been in continuous operation since that time. Assistance includes a wide variety of activities such as

1. Placing FREQ model on Caltrans computer facilities and continuous update for use from district terminals;
2. Phone conversations to advise on preparation of input data, problems with unsuccessful runs, and interpretation of output results;
3. Review of input data sets and output results, initially through mail and now on-line through a terminal facility at the university;
4. Field visits to district offices for personal discussion with model users and brief presentations of current status of models;
5. Preparation of additional documentation for model users as users deem necessary;
6. Individual or team instruction at the university for model users on critically timed projects;
7. Formal workshops on basic theories incorporated in model and also on model usage; and
8. Extension and refinement of model due to user need and feedback.

By the beginning of 1979, the model had been applied in selected districts of the Marysville, San Francisco, Los Angeles, and San Diego areas.

In late 1978, the FREQ6PE and FREQ6PL models became available and, because they included many significant improvements over earlier versions, a series of workshops was proposed. The implementation activities continued with Caltrans with the FREQ6PE and FREQ6PL models replacing the FREQ4CP model.

Conversations began with FHWA representatives to work toward an educational and implementation support program at the national level patterned after the Caltrans experience.

The technical assistance phase began immediately after a series of workshops and was patterned after the Caltrans support activities. Inquiries on the order of 3-5 per week were received and responses varied from direct answer to computer runs on our computer facilities. Means for periodic communications with all model users were recognized and FREQ/TRANSYT bulletins were published in August 1980, December 1980, and April 1981. The bulletin is distributed to approximately 250 readers and includes responses to frequently asked questions, lists of model users, new and novel applications, and programming errors and improvements.

Three user exchange conferences were held: one for FREQ model users and two for TRANSYT model users. Both Caltrans and FHWA-sponsored implementation support projects are continuing.

In summary, attention has been drawn to the need for improved and extended simulation model application. For most successful applications, educational and implementation support activities are required. Such activities in regard to the FREQ family of models have been described. It is hoped that the results of such activities will encourage others to become involved in similar efforts.

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Enhanced NETSIM Program

E. Lieberman

The NETSIM traffic simulation model (1) has been applied extensively over the past seven years to a wide variety of problem areas by a large number of public and private agencies. The experience gained with NETSIM has prompted many suggestions for improving and extending the program with the view to further enhancing its value as an engineering and research tool.

In an informal survey conducted by KLD Associates a few years ago, the following suggestions were made:

1. The input preparation effort should be eased,
2. The cost of computing should be reduced,
3. Many additional features should be introduced, and
4. The output capabilities should be extended.

Interestingly, the last two suggestions conflict with the first two. Whenever additional features are introduced, some added input requirements are usually implied. Furthermore, any additional feature leads to the development of additional software that, in turn, occupies computer memory and consumes computer resources. Similarly, enhanced output capabilities imply the need to compute and to store additional data; writing output is also costly in computer time. Such conflicting user requests impose a burden on the designer to be responsive in the most cost-effective manner.

This paper describes the enhancements incorporated into the new version of NETSIM. This version constitutes the result of the first development stage of the Integrated Traffic Simulation Software System known as TRAF.

The techniques that have been applied to produce a cost-effective, enhanced version of NETSIM will also be described.

NETSIM ENHANCEMENTS

Specific NETSIM enhancements are described briefly here.

Blockers and Parkers

Blockers are defined as illegal parkers who occupy a portion of a lane dedicated to moving traffic. Such violators may be either short-term (less than 1 min) or long-term, and generally represent pickup or delivery (PUD) activities. Blockers exact a toll on the traffic stream in the form of increased travel time, reduced capacity, or both.

Unlike the previous versions of NETSIM, this enhancement explicitly models the interaction between moving vehicles and blockers. In addition, the impedance experienced by vehicles while attempting to evade such blockers through the mechanism of lane changing is also modeled. The concept of a "preferred lane" was introduced, which provided a basis for vehicles to return to a blocked lane downstream of a blocker.

Parkers are also treated as impeders, but are restricted to parking zones of specified location and length along the curb. The duration and location of parkers and of blockers are assigned by the program by using data specified by the user.

Look-Ahead Feature

When the first vehicle in a lane approaches an intersection to execute a through movement, it now responds in a car-following mode to its lead vehicle, which is on the receiving link. In the previous version, the subject vehicle did not "see" its leader if the leader was on the receiving link. Consequently, it was possible for the subject vehicle to "collide" with its leader if the latter was at the tail of a long queue.

Overflowing Turn Pockets

During periods of heavy demand, turn bays (or "pockets") of inadequate length could overflow, thus blocking the adjoining through lane. In previous versions, this overflow condition was not represented. The current version explicitly models this condition.

Bus Stops and Pockets

When a bus stop is created in the parking lane (by prohibiting parking there) or is created by a bay cut into the curb, it is called "protected". That is, a bus in dwell at a protected station will not block vehicles in a moving traffic stream.

Often, such protected nearside stations, when empty, are used by right-turning vehicles as a turn pocket. Ignoring such usage can have a pronounced effect on the validity of the simulation results. The new version of NETSIM incorporates logic that represents this behavior.

Dual Turns

When traffic on the "leg" of a T-intersection can execute both right and left turns, it is necessary to assign this turning traffic to appropriate lanes. If this "leg" approach has more than two lanes, it is necessary to assign traffic to the center lane in an appropriate, consistent manner. Additional logic was introduced to improve this feature relative to prior versions of the model.

Lane Alignment

Occasionally, the number of lanes on a link will differ from that on the downstream receiving link. Even when the number of lanes is the same, it is possible for one link to be offset relative to its receiving link. To account for such cases, a new feature was introduced to allow the user to specify the lane alignment between subject link and its receiving link.

Improve Efficiency

In previous versions of NETSIM, vehicles on entry links are treated the same way as vehicles on internal links. While there is no functional problem with this approach, it is more costly in computer resources--storage and time--than is necessary. Since no statistics are gathered on vehicles occupying entry links, it is permissible to limit the number of vehicles actually stored to those at the stop line. This approach is now incorporated into NETSIM.

Extended Range of Program

The new version permits up to 12 signal intervals to be specified instead of the previous maximum of nine intervals. Also, turn pockets may have two lanes instead of the previous limitation of one. (Each link may have seven lanes including those within turn pockets, compared with five lanes previously.)

A new feature has been introduced that permits the user to specify up to 16 vehicle types assigned to four categories. Each vehicle type is defined in terms of its length and acceleration, speed and discharge headway properties, and the categories to which it is assigned. This information allows the categorization of vehicle types as indicated in the following table:

Vehicle Type	Category				Total (%)
	Private Automobile	Carpool	Bus	Truck	
1	60	40	0	0	100
2	10	30	10	50	100
3	0	0	100	0	100

In the above table, for example, 10 percent of the vehicles of type 2 appear on the analysis network as private automobiles, 30 percent as carpools, 10 percent as buses, and 50 percent as trucks. The percentage of the vehicle fleet that is composed of type 2 vehicles--not shown in the table--is specified by the user.

The vehicle category concept permits the user to specify different treatments for each category, e.g., special lanes. Other treatments can be added in the future as the need arises. A new treatment is the addition of carpool lanes and lanes for carpool vehicles and buses.

Extended Input-Output Capabilities

With the onset of the metrication program, it became advisable to provide the user with the capability of specifying input data in either customary or metric units, and of obtaining output data expressed in either or both units. This feature is now available.

Outputs are also provided in person-specific units, based on user-specified occupancy for each vehicle type. This feature permits the user to examine the people throughput and travel time for different high-occupancy-vehicle strategies.

The operational performance of traffic on a roadway segment (i.e., link) is a function of the turning movements at the intersection. It is well known that different turning movements are serviced at different rates. Consequently, vehicles performing one maneuver may experience significantly greater delay than those performing another maneuver. In fact, it is entirely feasible for the vehicles executing a left turn, for example, to experience severe congested conditions, while those moving straight through the intersection experience little delay.

The prior versions of NETSIM did not provide the data necessary to obtain this level of detail and insight into the operational conditions. The new version does output measures of effectiveness (MOE) for each link that is stratified by movement if so requested.

Another new output feature permits the user to aggregate specified contiguous links for the purpose of obtaining statistics for that group of links. This is very useful for those who wish to examine how small sections within a larger network are operating.

A limitation on the placement of long loop detectors was removed.

Other features were also introduced. The number of lanes on a link was increased from five to seven and additional flexibility provided for the fuel consumption and vehicle emission feature. Internally, the treatment of queued vehicles was greatly improved, providing smooth vehicle trajectories regardless of queue length.

MODIFICATIONS TO EASE USER ACCESS AND MINIMIZE COST

Input Format

The input stream is designed as a collection of card types; each card type contains data that are functionally coherent. For example, data describing geometric characters are organized on separate cards from data describing traffic flow characteristics. Furthermore, data required for optional features (e.g., bus traffic, detectors, and vehicle types) are assigned to special card types that may be omitted if the feature is not used. As before, all input data items are specified as integers. With a few exceptions, all field widths are set to four columns, or digit positions, to promote a uniform format.

The input-processing software contains a wide range of diagnostic tests that are far greater in number than those of prior versions. It is our view that this extensive investment in software development is amply justified by subsequent savings in user resources. These tests are applied to the entire input data stream regardless of the number of user input errors detected. Each such error produces a diagnostic message that provides sufficient information to identify the source and cause of the error.

In addition, warning messages alert the user to examine input data that the logic determines to be suspect in some sense but that may be perfectly valid. For example, unusual network topologies are flagged by the software to prompt the user to confirm the validity of the relevant inputs. Of course, any fatal error detected by the software will terminate execution prior to any simulation processing.

Throughout the input stream, default values are provided by the software whenever feasible. While this feature relieves the user of significant effort in data preparation, the user should be cautioned to confirm that these default data items will not compromise the integrity of the study.

In our view, the best long-term solutions to minimizing user effort, in addition to the features noted above, are a file management system and automated data entry.

A file management system would consist of software that would enable the user to manipulate existing, stored input data bases so as to conduct a series of studies, with a minimum expenditure of time and effort. Ideally, this would be accomplished on-line by using a CRT terminal; an off-line system would also be cost-effective but to a lesser extent. It would work as follows:

1. The user will input the data stream for the base case. The file management software will store this data stream.
2. The program will perform its diagnostic tests and identify any and all errors.
3. The user will then correct these errors by modifying the input data stream appropriately, employing the file management software.
4. Steps 2 and 3 will be repeated until a satisfactory data stream is acceptable to NETSIM. The file management software will then store this correct data stream, properly identified for subsequent retrieval.
5. For all subsequent runs, the user will retrieve a data stream, implement necessary changes, and continue with step 2.
6. The user could purge any data stream at any time to reduce storage costs, subject to satisfying security measures designed to protect the stored files.

Automated data entry, such as the system installed by the Michigan Department of Transportation, will greatly ease the task of input data coding. This software could be integrated with the existing NETSIM software that performs card-specific diagnostic testing so that coding errors could be detected immediately, before the data are stored.

By integrating the automated data entry, diagnostic testing, and file management software into a separate preprocessing system, distinct from the main body of the NETSIM model, the appeal of NETSIM as an engineering tool will be greatly enhanced. The cost of program implementation will be greatly reduced, the input coding activity can be assigned to subprofessional personnel, and the elapsed (turnaround) time between data entry and receipt of the simulation results will narrow.

Minimize Computer Resources

The user is charged for a wide variety of computer resources, the most prominent being storage and time. The TRAF system has been designed to provide the user community with versions of the NETSIM (and other) models that are tailored to user needs:

1. The features required by the user will be provided; all others, not used, will not be included in the program. This capability will limit the computer memory required.
2. The size of the internal data base will be limited to that which is required by the user. Different versions of NETSIM will be available so that users can select the version that is most suitable for the size of the network to be studied.

Other modifications were designed to minimize input-output activity. Specifically, calculation of energy consumption and of vehicle emission for different vehicle fleet compositions may be accomplished with only a single execution of the simulation program. Also, the calculation of these environmental measures is accomplished without the need for spooling trajectory data to and from disk storage, as was done previously.

Reliability and Flexibility

The software maintenance function is an ongoing activity that must be responsive to the needs of the user community. This activity must provide for (a) reliable software (corrective maintenance) and (b) need for new or modified capabilities (constructive maintenance).

The new version of NETSIM has been designed and programmed by using the latest techniques of structured software development. As a result, the investment required to perform these needed maintenance activities should be substantially lower than that which would be required if traditional techniques had been applied.

Every effort has been made to develop software modules (i.e., routines) that are functionally independent, are of limited size, and are logically cohesive. Such software has proven to be more reliable and more amenable to change than that of the previous version whose development predated the evolution of structural techniques.

For example, the new enhancements enumerated earlier in this paper were introduced by adding new routines, with moderate changes introduced to existing routines. The additional input card types that were required were essentially plugged in to the existing input-processing software with virtually no disturbance to the existing code.

To expedite corrective maintenance, special diagnostic software was developed. This software permits the maintenance analyst to selectively and efficiently examine the software performance in the process of locating the cause of any adverse symptoms, to identify any software defect.

It must be emphasized, however, that any software system requires a continuing program of maintenance support in order to enhance the reliability of the software and to provide the responsiveness needed by the user community. It is an established fact that the use of a software product is directly related to the confidence of the user community in the performance and utility of the product and in the availability of continuing support.

Availability of New NETSIM Program

The NETSIM program is a component submodel of the current version of the TRAF software system. This current version, named TRAF I.5, combines NETSIM with TRAFLO in an integrated format. That is, one can implement NETSIM concurrently with any of the submodels in TRAFLO (2), on a single analysis network. Details are provided in the TRAF I.5 Users Guide (3).

Of course, NETSIM may be executed, as in the past, as a stand-alone program. The availability of TRAFLO within the overall structure of the TRAF software system does not burden NETSIM users in any way. Each submodel in the TRAF system resides in a separate overlay that is stored on disk; a submodel that is not used is not retrieved from disk and does not consume computer time nor storage in central memory.

As noted earlier, the input format is designed so that no additional inputs are necessary for any submodel that is not used. In summary, the additional capability provided the user community through the integrated simulation model concept implies no penalties whatever if only one submodel, such as NETSIM, is used.

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Models for Design and Evaluation of Traffic Signal Timings

Kenneth G. Courage and Charles E. Wallace

Optimization and evaluation models are valuable aids to the design of traffic signal systems. While many traffic engineers still use manual techniques for this purpose, others are finding that computer models offer substantial improvements both in the final product and in the productivity of the staff creating that product.

The product, of course, is signal timing. Its parameters are the duration and sequence of the signal phases at a given intersection and their relationship to similar parameters at neighboring intersections. The results of a good product are fewer stops, less delay and fuel consumption, and reduced accidents--all of which lead to lower operating costs for the motorist. Although the quality of the product is ultimately determined on the street, several traffic signal optimization and evaluation models have proved their ability to assist the traffic engineer in developing cost-effective operational improvements.

MODEL CLASSIFICATION

Most traffic signal models in practical use are macroscopic and deterministic. They deal with the traffic stream as a whole and not with individual vehicles. They make little or no use of probabilities or statistical distributions. Most do not use sophisticated analytical techniques; they rely instead on search techniques, simple analytical equations, or graphical approaches. On the other hand, some excellent applications of operations research techniques are also apparent (e.g., hill climbing, linear programming, etc.). The best way to classify the models to be discussed in this paper is by the following four areas of application:

1. Single intersections,
2. Arterial routes,
3. Two-dimensional networks, and
4. Diamond interchanges.

Each of these areas has unique problems and objectives, and each, therefore, has generated its own models.

The specific models discussed in this paper are shown in Table 1 and are classified by application area. This table identifies five computer programs that are frequently used for design and evaluation and summarizes the most important functions of these programs. This list is not exhaustive; other programs are also available, or under development. (See also papers by Gibson and May in this report.)

Table 1. Summary of traffic signal optimization programs.

Application	Program Name	Function
Single intersections	SOAP	Determines optimal phasing and timing for pretimed or traffic-actuated signals
Arterial routes	PASSER II	Determines optimal phasing, timing and offsets for maximal bandwidth in a coordinated multiphase arterial signal system
Traffic signal networks	TRANSYT	Determines optimal signal phase lengths and offsets to minimize a weighted sum of stops and delay in a network signal system
	SIGOP II	Same as TRANSYT; also considers queue spillover in the objective function
Diamond interchange	PASSER III (version 3)	Determines optimal signal phasing and timing to minimize internal delay within a diamond interchange and maximize progression bandwidth through a series of interchanges on frontage roads

SIGNAL OPERATIONS ANALYSIS PACKAGE--SOAP

SOAP (1) was developed by the University of Florida Transportation Research Center in 1977. The program was developed for the Florida Department of Transportation and FHWA to provide a convenient, yet powerful, intersection design tool for traffic engineers.

It exists in three forms: (a) a FORTRAN version that accommodates all intersection approaches for up to 48 contiguous (typically 15-min) time periods; (b) a microcomputer version that accommodates all intersection approaches for a single time period; and (c) a hand-held calculator version that contains the important design and analysis routines and accommodates a single approach for a single time period in a series of user steps. Because of differences in computational capability, the three versions differ somewhat in their methodology and, therefore, do not produce identical results.

Purpose

SOAP provides a computerized method of developing signal control plans at isolated intersections. A wide range of control alternatives can be evaluated, including fixed-time or actuated multiphase control plans. The typical physical condition analyzed is a two- to four-legged intersection with left turns, through traffic, and right turns. The program can evaluate the effect of a signal in an interconnected system by specifying a "platoon concentration factor" that results from signal progression.

SOAP Computational Methodology

SOAP has three computational functions: design, analysis, and evaluation. To design signal timing, it is necessary to input the appropriate data regarding the configuration of the intersection. SOAP examines all legitimate phasing schemes. It internally analyzes each scheme and selects the one that can be executed by using the minimum amount of green time. This design is returned to the user.

The next step is dial assignment and timing. A typical controller provides three dials that allow up to three timing patterns to be implemented. SOAP can handle up to six such patterns. The user must decide how many patterns are to be used at a given intersection and must assign them to the appropriate dial (control period). If any pattern is unassigned, SOAP will do so, based on the traffic demands. If actuated control is desired, no pattern assignments are made and SOAP makes its computations accordingly.

Cycle length is the most difficult element to determine. This is a particularly complex problem when several control periods are to be designed. SOAP produces these based on the appropriate volumes, capacities, and other parameters. A trial-and-error optimization procedure is used to find the cycle length that produces the minimum total delay, subject to constraints governing the amount of queuing that can be tolerated.

Allocation of green time among conflicting approaches is based on the equalization of the degree of saturation for the critical movements. This is a common traffic engineering practice; however, it frequently produces a sub-optimal solution in terms of delay, stops, and fuel consumption (2). The computation of delay is based on Webster's method for undersaturated conditions (3). A simple input-output analysis is performed on any approach that is oversaturated.

Analysis is accomplished by computing the measures of effectiveness (MOE) that are common to traffic-control systems analysis. This allows the user to quantify the effect of either the designed control strategy or any other scheme. The evaluation provides for the comparison of several alternative schemes.

SOAP Data Requirements

There are three types of input cards required by SOAP. These are

1. Instruction cards that tell SOAP what to do,
2. Parameter cards that tell SOAP how to do it, and
3. Data cards that supply the input variables for the intersection being studied.

The input formats are standardized so that all cards have an identical format. This permits the use of a standard coding form, although all fields are not always used. Each card is identified by a single word in the first field that indicates to the program the meaning of the data contained in the subsequent fields. This simplifies the preparation of inputs considerably by eliminating the need for a specific sequence of cards. With the exception of a few key instruction cards, SOAP will accept the cards in any order in which they are presented. This scheme has also been employed in the Arterial Analysis Package and the MAXBAND program, both of which will be discussed later.

SOAP Outputs

There are three primary types of outputs available from SOAP:

1. Input report--echoes the input data and prints warning and error messages as appropriate;
2. Design recommendations--includes phase sequences and lengths, cycle lengths, and dial assignments; and
3. MOE report--includes delay, degree of saturation, maximum queue length, percentage of stops, excess fuel consumption, and left-turn conflicts.

Other supplementary outputs are available in both tabular and graphical forms to aid in detailed analysis.

PROGRESSION BANDWIDTH OPTIMIZATION WITH PASSER II

While several arterial progression programs have been in use for over a decade, the state of the art in signal technology has advanced to the point that the earlier programs (such as SIGART, SIGPROG, and SIGOP) do not adequately deal with complex signal timings. PASSER II (4) was written to facilitate the design of progression systems that have multiphase signals with a variety of phasing strategies. The original program, PASSER, was developed by the Texas Transportation Institute at Texas A&M University in 1973 and was later updated to produce PASSER II.

Purpose

The Progressive Analysis and Signal System Evaluation Routine, version II (PASSER II) is a macroscopic, deterministic optimization model designed to develop the optimal signal progression on a linear arterial highway. PASSER II was written to overcome the limitations of previous progression models, which were generally restricted to fixed-time, two-phase signals, often with balanced progression speeds in the two directions. PASSER II can work with multiphase signals.

PASSER II Computational Methodology

PASSER II is a time-series search-and-find optimization routine. The model calculates phase intervals, offsets, and movement demand/capacity ratios to evaluate the level of service at each intersection. The green times are found by proportioning time according to the volumes plus lost time (subject to the minimum required greens).

PASSER II Data Requirements and Outputs

Inputs to PASSER II involve three types of data cards: (a) arterial header card that specifies the global system parameters; (b) intersection header cards, each of which specifies the operating parameters for one of the intersections in the system; and (c) intersection data cards that provide, on separate cards, the traffic volume, saturation flow, and minimum green time for each approach to every intersection.

There are three types of outputs available from PASSER II. These are (a) input data report, which gives all input data in a structured format; (b) design recommendation, which includes cycle length, offsets, phase sequences and splits, and MOE values for bandwidth efficiency and degree of saturation; and (c) time-space diagrams.

NETWORK OPTIMIZATION WITH TRANSYT

The efficient movement of traffic through a grid network of signalized intersections can improve the capacity of the system and reduce adverse effects of traffic such as annoying stops and delays. Adverse impacts on the environment and excess fuel consumption can be reduced as well. Such efficiency can only be achieved by interconnecting the signals and operating them so that delay in the system is minimized and/or other measures are optimized. Numerous computer programs have been written to assist engineers in determining how the signals should be timed, and several on-line control programs are available as well.

One of the most widely used design models is the Traffic Network Study Tool, TRANSYT (5), developed by Dennis Roberts of the Transport and Road Research Laboratory (TRRL) in England. Since the development of the original model in 1968, numerous improvements have been made and new versions issued.

Purpose

TRANSYT can determine optimum signal timing for a coordinated network of up to 50 intersections (nodes) with up to 250 directional links. Both signalized intersections and sidestreet stop-sign controlled intersections are modeled. Control is fixed-time, twoto seven-phase (including pedestrian movements) with fixed sequential phasing and offsets. Priority lanes may be designated for buses.

Since its original development, TRANSYT has been continuously enhanced. The history of its evolution is as follows:

1. TRANSYT1--the original version written in machine code in 1967;
2. TRANSYT2--a FORTRAN version of TRANSYT with provisions for more than three phases, 1968;
3. TRANSYT3--improved input and error checking, 1970;
4. TRANSYT4--added the STAR1 subroutine to calculate initial timing, flow pattern plots and provisions for buses, 1971;
5. TRANSYT5--provided multiple links at a common stopline and bus progression speed including stops, 1972;
6. TRANSYT6--improved stops model and increased efficiency, 1975 (6);
7. TRANSYT6C--added fuel and environmental measures and demand response analysis, 1977 [this version was developed at the University of California at Berkeley (7)];
8. TRANSYT7--reduced the execution time and simplified the input coding requirements, 1977 (8); and
9. TRANSYT-7F--added a fuel consumption model to TRANSYT7 and developed a preprocessor-postprocessor scheme to further simplify the preparation of inputs and interpretation of outputs by Western users [this version was developed by the University of Florida for FHWA, 1981 (9)].

TRANSYT Computational Methodology

TRANSYT is a macroscopic deterministic optimization model with periodic time scan. It has a structured organization with a master program that calls other subroutines as the analysis progresses. The TRANSYT optimization is based on a hill-climbing technique. Hill climbing is accomplished by varying offsets and splits in steps and calculating the resulting traffic effects. To accomplish the latter, it is necessary to determine the behavior of traffic within a link that is based on the manipulation of the input and output flow patterns. The inflows of one link are obtained from the outflows of the upstream link(s). These flow characterizations are computed for each link for each iteration and the resulting delays and stops are calculated.

TRANSYT Data Requirements

There are up to 20 major types of input cards for TRANSYT (depending on the version); some have single cards and others multiple cards. The inputs fall into five functional categories, namely data that

1. Are common to the entire network,
2. Control the optimization process,
3. Specify traffic data,
4. Specify signal timing, and
5. Specify plots.

Since TRANSYT is a network optimization program, the input data are based on a link-node structure. This structure is considerably more complicated conceptually than the single intersection orientation of the non-network models. User training is therefore a significant problem with TRANSYT. This problem has been addressed through a series of training courses sponsored by FHWA. TRANSYT-6C and TRANSYT-7F have both been covered in these courses.

TRANSYT Outputs

Since TRANSYT-7F contains the most useful outputs, that version is discussed in this section. There are five outputs available from TRANSYT-7F:

1. Input data report--a structured echo of input data, including any errors or warning conditions detected;
2. Performance table--a listing of significant data and MOEs including (by link) volume, saturation flow, degree of saturation, total travel and travel time, delay, stops, fuel consumption, maximum back of queue, and green times (subtotals are given by intersection and aggregated for the entire network);
3. Signal timing tables--for each intersection the offset (or yield point) is given along with the signal timing in terms of individual interval lengths;
4. Flow profiles--graphically show the arrival and departure flow patterns; and
5. Time-space diagrams--available for any number of routes desired.

The TRANSYT-7F postprocessor converts signal timing from the unfamiliar scheme originally used in TRANSYT to conventions commonly used by engineers in the Americas and Canada. Manual transformations are thus eliminated.

NETWORK OPTIMIZATION WITH SIGOP II

Another network model developed in the United States is SIGOP II (Signal Optimization Model, version II) (10). It was originally developed by KLD Associates, Incorporated, and has been revised by Honeywell. SIGOP II has been released only to a limited number of agencies and has not been used widely.

Purpose

SIGOP II extends the underlying principles of TRANSYT while reducing the effort to use the model. Furthermore, the following additional considerations are pertinent to SIGOP II:

1. A faster optimization procedure was desired,
2. Explicit representation of turning bays was desired,
3. Explicit consideration of queue buildup and prevention of spillover was desired, and
4. Production of estimates of fuel consumption and time-space diagrams was desired.

SIGOP II can optimize a network of up to 50 intersections and 130 links, and a single link can have up to three movements.

SIGOP Computational Methodology

SIGOP II is also a macroscopic deterministic optimization model with periodic time scan. It also has a structured software organization. The optimization is similar to TRANSYT; however, at each gradient search step only the intersections adjacent to the "current" intersection are reanalyzed for impact. The technique is referred to as the "method of successive approximations." Although this procedure results in significantly reduced execution time, the simplification may possibly sacrifice some confidence in the optimal solution. A major improvement over TRANSYT is the explicit inclusion of a queue length term in the optimization objective function. This term is designed to prevent spillover, which is not assured in TRANSYT. Although similar to TRANSYT, the simulation model again has been simplified. All platoons are assumed to be either "main street" or "cross street," thus differences in departure times from multiple upstream sources are not explicitly considered.

SIGOP Data Requirements

SIGOP II also requires more extensive data than arterial and single intersection models, but not as extensive as TRANSYT, because of the simplification of the optimization and simulation models.

There are 13 types of input cards available to SIGOP II, which fall into the same functional categories as discussed in the previous section of this paper. The significant differences between SIGOP II and TRANSYT inputs are as follows:

1. SIGOP II does not require link-to-link flows as does TRANSYT;
2. Signal phase sequences are coded from preset tables, which reduces the coding effort; however, this also reduces flexibility and the maximum number of phases is four, compared with TRANSYT's seven;
3. SIGOP II requires input nodes for external links, while TRANSYT does not;
4. Diagonal approaches may be coded, but their movement must be coincidental with another normal movement (in TRANSYT, all movements may be modeled explicitly and independently); and
5. SIGOP II can examine a range of cycle lengths, while TRANSYT can only consider one value in any given run.

As is the case with TRANSYT, training is more significant for SIGOP II users than with simpler models. A training course has been developed by FHWA but has not been presented widely.

SIGOP II Outputs

There are four general outputs available from SIGOP II, all of which have multiple pages:

1. Input data reports--a series of tables to report back the input data in functional categories (e.g., link data, signal timing, minimum phase lengths, plots, etc.);
2. Optimal signal timings--the optimal cycle length is reported, along with offsets, phase sequences, and splits for each approach at each intersection;
3. Performance analysis--including such data and MOE as volume, average speed, delay, stops, saturation flow, degree of saturation, and maximum queue; and
4. Time-space diagrams.

DIAMOND INTERCHANGE ANALYSIS WITH PASSER III

Since the Texas Transportation Institute (TTI) at Texas A&M University introduced the concept of overlaps in diamond interchange signal timing in 1961, much work has been devoted to methods of obtaining the design signal timing for these interchanges (11). Also, many freeways have continuous frontage roads parallel to the freeway, which can serve as alternate routes when the freeway is congested or ramp metering is in effect. Coordination of traffic signals on the frontage roads is of value to move traffic as efficiently as possible. TTI developed a progressive analysis model, PASSER II, to optimize progression on an arterial highway. This model was extended and the diamond interchange optimization was added to create PASSER III.

Purpose

PASSER III (Progressive Analysis Signal System Evaluation Routine, version III--diamond interchange) is designed to determine the optimal signalization timing of a diamond interchange and/or progression of traffic on parallel frontage roads. For a single interchange, the optimal cycle length, splits, and offsets can be computed. For a coordinated system, the program calculates green splits for each interchange in the data set and also searches for an optimal frontage road progression solution. Progression can be one-way or two-way, with or without favoring one direction.

PASSER III Computational Methodology

PASSER III is a macroscopic, deterministic optimization model. The interchange optimization is based on the fact that there can exist at each intersection of the interchange only three basic phases or allowable greens (excluding pedestrian phases). These may occur in the order of either leading left turns or lagging left turns where the off-ramp either leads or lags the left turns to the on-ramp. Similarly, there are three such phases available at the other intersection within the interchange.

Only certain movements can exist simultaneously at both intersections for any period of time. The order, duration, and time offset of these movements will determine the efficiency of the operation. PASSER III examines all possible patterns and varies the offset to find the pattern and offset that result in the minimum delay in the interchange. The frontage road progression analysis is independent of the interchange optimization, although the latter should be run to obtain the appropriate phasing and minimums for the progressive analysis. The optimal progression design is that which provides the largest bandwidth efficiency.

PASSER III Data Requirements

PASSER III uses the same general input scheme as PASSER II. Separate input cards provide a description of the facility, descriptions of each of the intersections, and, finally, the traffic data in terms of volumes, saturation flows, and minimum green times.

PASSER III Outputs

There are five output reports available from PASSER III. Not all reports are produced on each run since they vary by mode of analysis (isolated or progressive). The available reports are summarized as follows:

1. Input data report--a structured report of input data;
2. General signal information--indicates both signal timing and MOE (degree of saturation, delay, probability of queue clearance, and storage);
3. Progression design report--gives cycle length, bandwidths, efficiency, and speeds for interconnected interchanges;
4. Phasing report--gives signal phasing at each interchange; and
5. Time-space diagram--used for the frontage roads.

FUTURE DEVELOPMENTS

In this constantly evolving field, it is not surprising that new programs are continuing to appear. Most current developments represent enhanced versions of the programs already discussed in this paper. Some of the more significant developments are summarized below.

Arterial Analysis Package

The Arterial Analysis Package (AAP) (12,13) combines SOAP, PASSER II, and TRANSYT-6C into a single package that employs a common input coding scheme and output report format. This simplifies user training considerably. The AAP is currently under development by the University of Florida and PRC Voorhees. It accommodates up to 20 intersections on an arterial street and supports on-line data storage and multiple runs with successive modifications to the input data.

PASSER II-80

PASSER II-80 (13) is an enhanced version of the PASSER II program. It provides improvements in the design and evaluation tables. It also incorporates additional MOEs such as delay and probability of queue clearance. A green split routine based on minimum delay is being considered.

MAXBAND

A new arterial progression model (14) for optimizing signal offsets to maximize bandwidth is under development at the Massachusetts Institute of Technology. The Maximal Bandwidth Model will have a far more sophisticated mathematical basis than PASSER II and PASSER II-80 and will also be able to consider two or three intersecting arterials, including a triangular network. The model is being developed for FHWA and is currently in the later stages of development and testing.

TRANSYT-8

TRANSYT-8 (15) is the latest TRANSYT version from TRRL. The major enhancements include improvements to the traffic model by the addition of gap acceptance features and the implementation of a cycle search routine. This program represents a significant advance. It is only available, at present, under a license arrangement with the British government.

SIGOP III

A revised version of SIGOP II is currently being developed by FHWA. This new version will add estimates of vehicle exhaust emissions and will resolve programming problems existing in the earlier version. SIGOP III is undergoing testing as of this writing.

SOAP-82

Modifications to SOAP are also in progress. Several changes are being made to the optimization model to produce an improved design, to the evaluation model to eliminate problems caused by handling conditions, and to the input coding scheme to improve the user interface.

CONCLUSIONS

This paper has discussed the application of several computer-based models for the design and evaluation of traffic control system timing. There are abundant resources for the traffic engineer in this area, and the development of these resources has managed to stay ahead of the implementation. Current and future developments in model improvement and program documentation, together with the user training efforts of FHWA, can be expected to increase the use of the technology. It is hoped that this, in turn, will produce some real benefits--both to the traffic engineer who faces many staffing problems and to the motorist who faces many red lights.

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NETSIM: A User's Perspective

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INTRODUCTION

The Michigan Department of Transportation (MDOT) employs about 4400 people within seven bureaus: executive, administration, aeronautics, finance, highways, transportation planning, and urban and public transportation. The Bureau of Highways is the largest bureau, containing seven divisions, the smallest of which is the Traffic and Safety Division. The function of the Traffic and Safety Division includes the more traditional traffic engineering practices of signal and signing control devices and accident analysis. However, another major function is the preparation and evaluation of preliminary geometric designs. The division's traffic engineers participate in the planning, design, implementation, operation, and evaluation of all highway and some transit projects.

The practice of traffic engineering is often more of an art than a science. A good standard analytic methodology is needed to accurately predict the impacts of various geometric and traffic control alternatives on highway capacity and traffic flow. The 1965 Highway Capacity Manual, although a major improvement, often proves ineffective in weighing subtle alternatives to improve the intersection capacity and the traffic flow on arterial corridors and networks. Different conclusions are reached based on the unique assumptions of different engineers. Often, incomplete documentation leads to subsequent reanalysis. New measures of effectiveness are needed to reflect current conditions and policies. Fuel consumption and exhaust emissions have become important issues. The emphasis has also shifted from pure capacity to overall network and corridor performance.

NETSIM APPLICATION

Why use a simulation model? Why NETSIM? MDOT's implementation of NETSIM was happenstance. We were looking for a better automated means of doing capacity analyses and stumbled on the documentation of UTCS-1 (the forerunner of NETSIM). The logic of UTCS-1 resembled that of our manual headway analytic procedure. The model was implemented as a tool for analyzing geometric alternatives. At present, the model is used for a wide range of traffic engineering and transportation planning activities. Since its introduction in 1978, more than 15 000 runs have been made by using about 500 networks. The Traffic Network Study Tool (TRANSYT) is also heavily used. TRANSYT is used to optimize green time allocation and offsets, which are input into NETSIM runs to simulate the effects of the signal timing alterations.

This paper provides some insight into our experiences in implementing and using NETSIM. The following is a potpourri of experiences and comments obtained from the engineers and technicians who actually use the model.

The NETSIM model software was converted in-house to our Burroughs 7700 computer in less than two months. The source code was incompatible with our computer, since it was developed for IBM-type systems. The conversion was not labor intensive or complicated. After the conversion to the Burroughs system, the model was tested for inconsistencies. The major problem encountered while debugging the program was the outdated documentation, which was effectively solved on completion of the users guide and the supporting documentation. The development of a progressive series of published sample runs would simplify model debugging and assist in user introduction to network coding.

PROBLEMS AND LIMITATIONS

Through intensive use, problems and limitations with the use of NETSIM have surfaced. The model is expensive to operate. High computer costs are attributed to the large core memory requirements of the program. Though computer costs normally range from $30 to $50 per program execution, several have cost more than $150 and a few more than $500.

Difficulty is experienced when attempting to simulate high-volume arterials, since the model limits the input volumes on entry links at 999 vehicles per hour, allows a maximum of only five input lanes at intersections, and limits the storage in right-turn pockets to nine vehicles. The application of NETSIM does not allow for dual turns, it cannot simulate four-way stop conditions with moderate to high volumes, and right- and left-hand merges from lane drops are unrealistically simulated. The model does not adequately accommodate fully-actuated signal controllers nor correctly balance lanes of queued vehicles at signalized intersections.

Desirable enhancements would include more clearly defined input volume ranges for pedestrian traffic; allowances for railroad crossing simulation, especially for simulating the effects of a light rail transit system on traffic flow; the effective modeling of signal preemption at railroad grade crossings; updated exhaust emission and fuel consumption data; and the ability to specify vehicular speeds on input links to prevent slow loading of the network. It would be desirable to have the network name printed on the fuel consumption and emissions output page. The documentation could be improved to provide a better explanation of output parameters, and a condensed report documenting the model's logic could be prepared for use in public hearings. Also, provisions for subsystem outputs would allow for the quick analysis of specific corridors and individual intersections.

In order for NETSIM to be operationalized, potential users had to be trained to ensure proper use of the model. Both engineers and technicians were trained. Initially, the first users of the model were self-educated by using the NETSIM Users Guide. This method of training is not cost-effective on a departmentwide basis. Thus, we conducted an in-house class on network coding and model execution. Other individuals were taught in a formal training session. At MDOT, an introductory training manual was developed. It includes a small example network used to expose the trainee to NETSIM. Less than 4 h of training are now needed when using this method.

More extensive training is needed for a user to grasp the full realm of NETSIM's capability. It is important to have users who understand the theoretical methodologies of the model. The users must grasp the significance of the output parameters so that coding or model inequities can be identified and program results interpreted correctly.

Several research studies required making multiple program runs on relatively small networks. This caused problems with our computer system operation because of the large core memory requirements of NETSIM. Greater efficiency was provided when we developed a new version of NETSIM with substantially reduced core memory requirements. The program arrays for link data, vehicle information, and the number of nodes was reduced to 20 nodes, 30 links, and 600 vehicles.

On the other hand, many large networks exceeded the maximum of 1600 vehicles per link during one time step. The network would reach the saturation level and abort the execution. Therefore, we expanded the capability of the program to simultaneously track and maintain statistics on 3200 vehicles.

As a result, we now maintain three separate versions of NETSIM for small, medium, and large runs. This increases program maintenance and user confusion. In order to overcome this, the program should be revised to internally adjust the array of sizes to fit the requirements of various networks as specified by the user.

The simulation use of NETSIM and TRANSYT requires two different networks to be coded. By using our automated drafting equipment we combined both networks into one. The computerized graphic contains NETSIM node numbers and link configuration, TRANSYT link numbers, and three hourly intersection volumes and the saturation rate for each node. Figure 1 is an example of a section network used for analysis

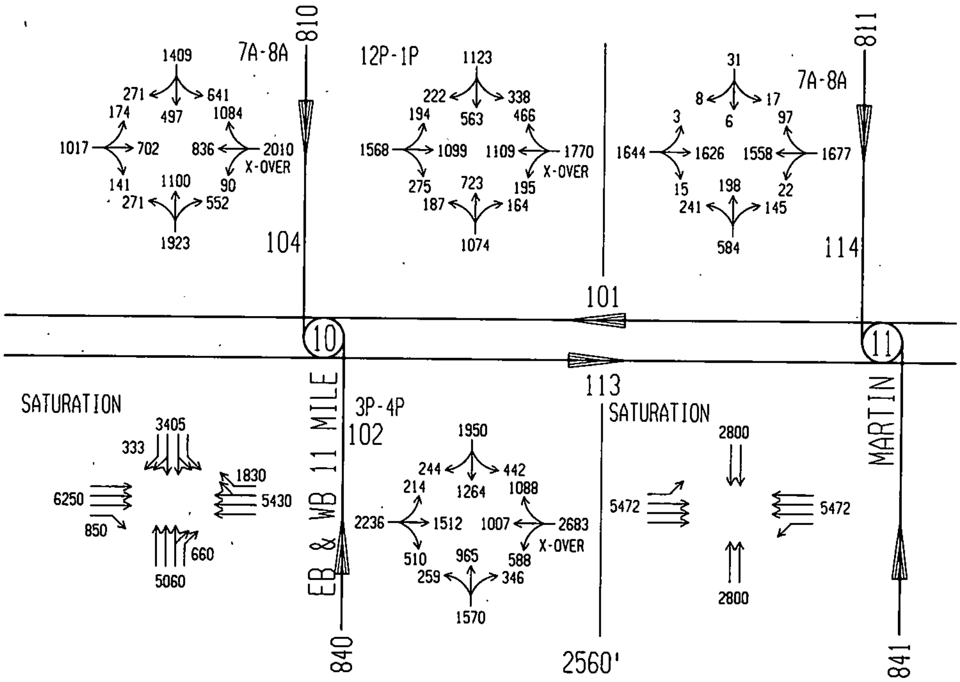
DATA ENTRY

At MDOT, more than 2000 potential computer system users share 180 CRT terminals and two card-punch machines. Instead of using punch cards, we input data on-line through CRT terminals into disk files containing card images. This method of data entry is more efficient than punching cards, but it is time-consuming and error prone. Due to the large size of many data files, errors of omission are generated.

In response to data entry problems, a forms display program was developed. It provides the user with a structured format with instructions to enter data in properly-sized data fields. The program automatically transfers the data into the proper order on disk data files. The program initially displays a menu in which the user specifies the appropriate form by depressing a function button. Below is a list of the forms and the data card types they generate.

1. Network Information Form
    - 99 Execution
    - 00 Title
    - 01 Network Name
    - 03 Network Priming
    - 60 Simulation Control
2. Link Information
    - 02 Link Name
    - 04 Link Geometry
    - 05 Link Operation
    - 07 Link Turning Movements
    - 08 Auxiliary Topology
    - 20 Volumes

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.

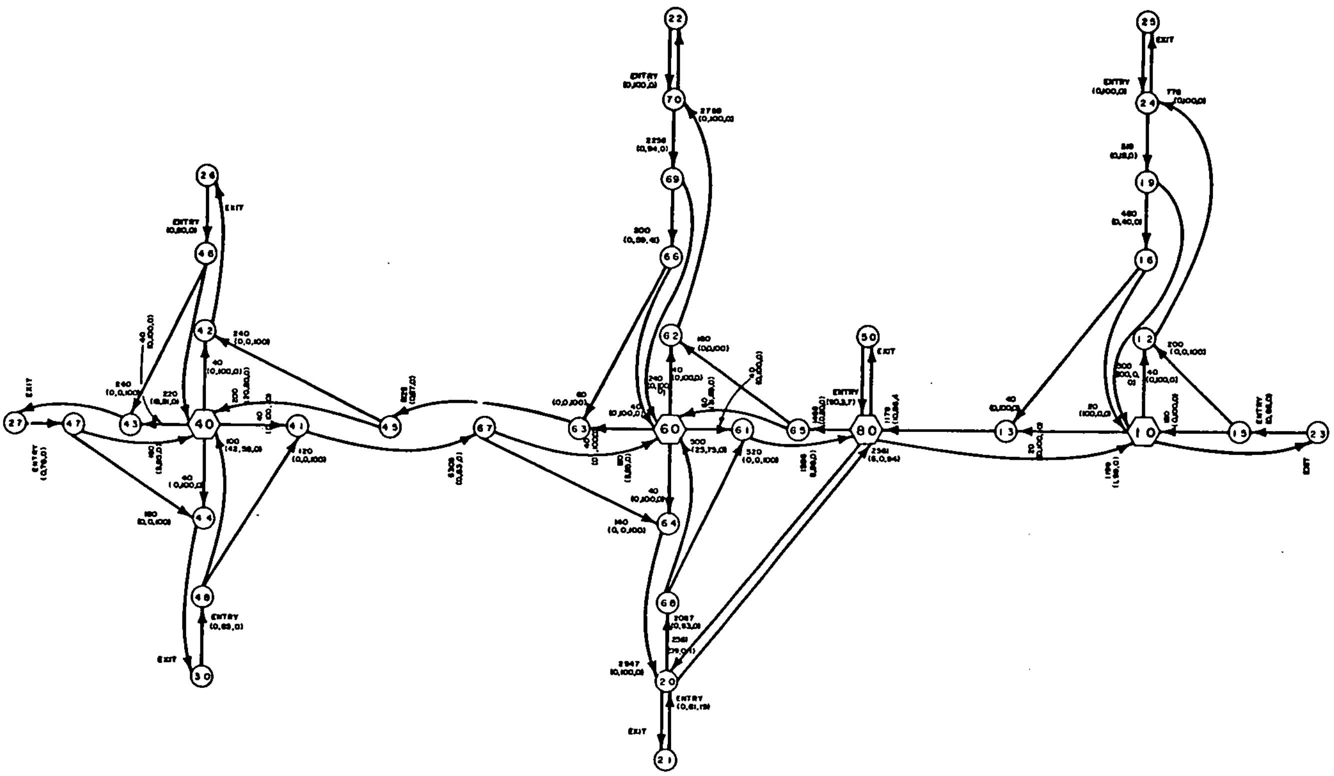
Application of NETSIM Computer Simulation Model to Traffic Control Problems

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.

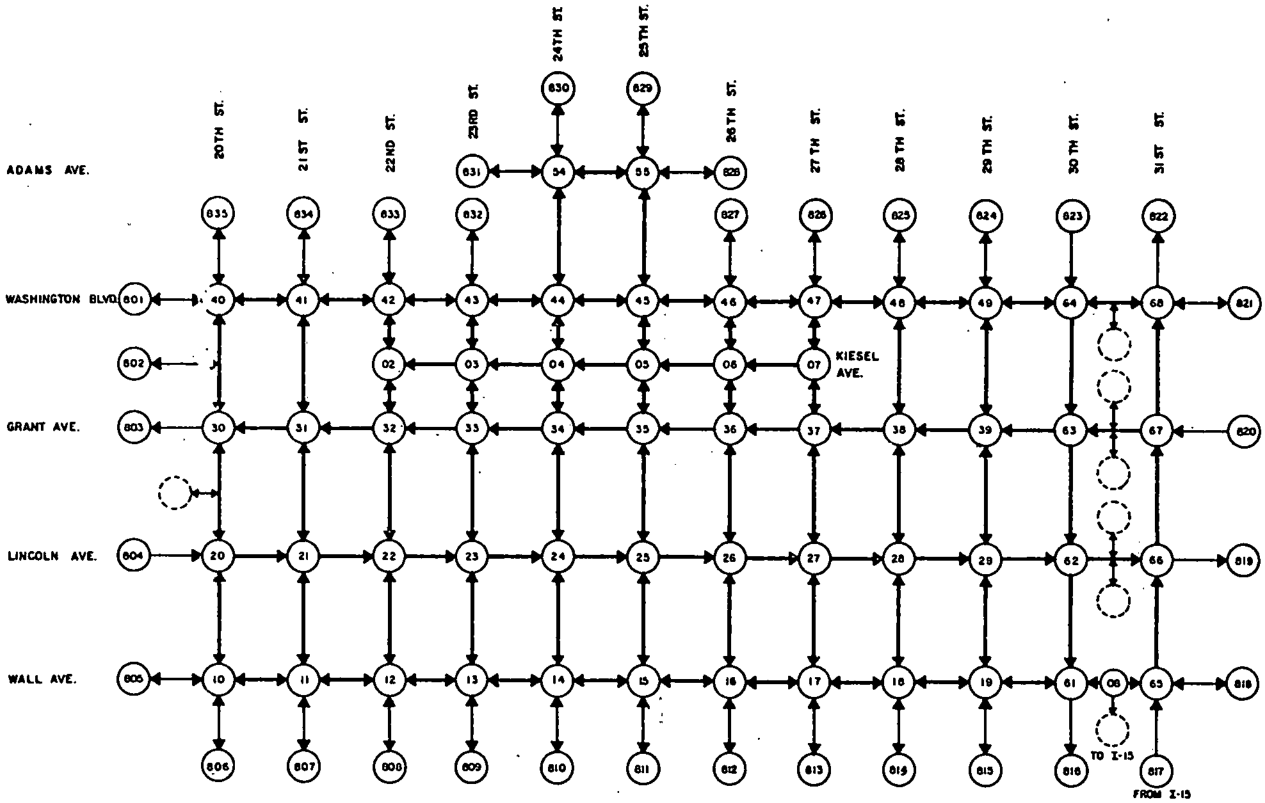


Figure 3. Link and node diagram for pedestrian scramble system.

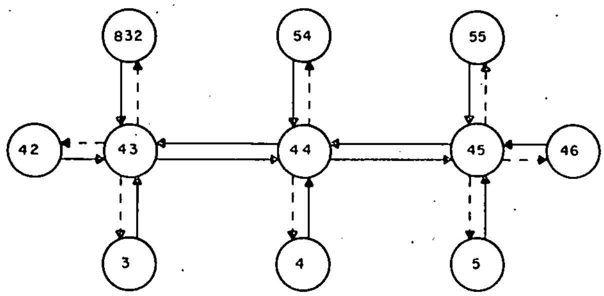


Table 1. Scramble system pedestrian phasing comparison.

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.

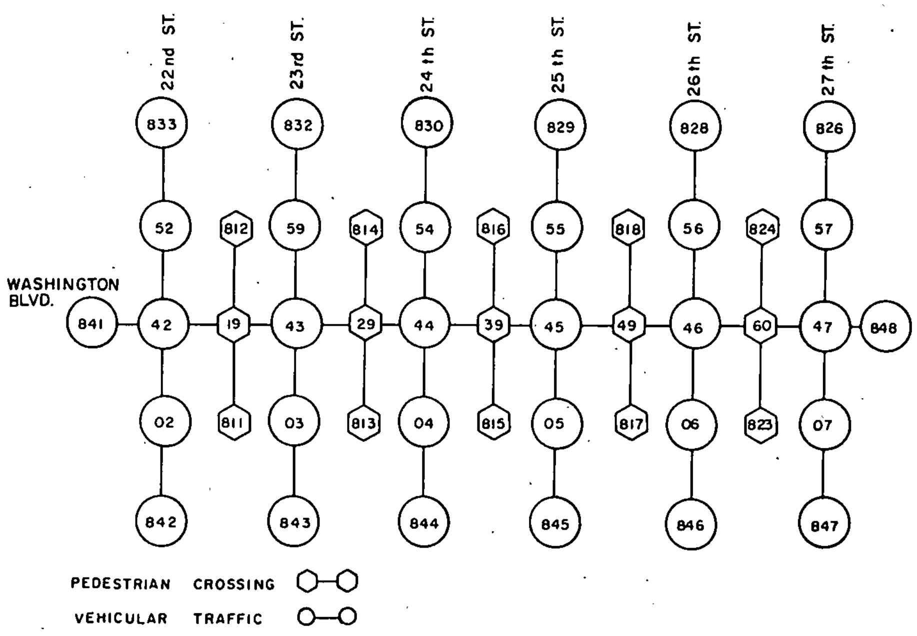


Table 2. Washington Boulevard pedestrian crossing strategy evaluation.

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.

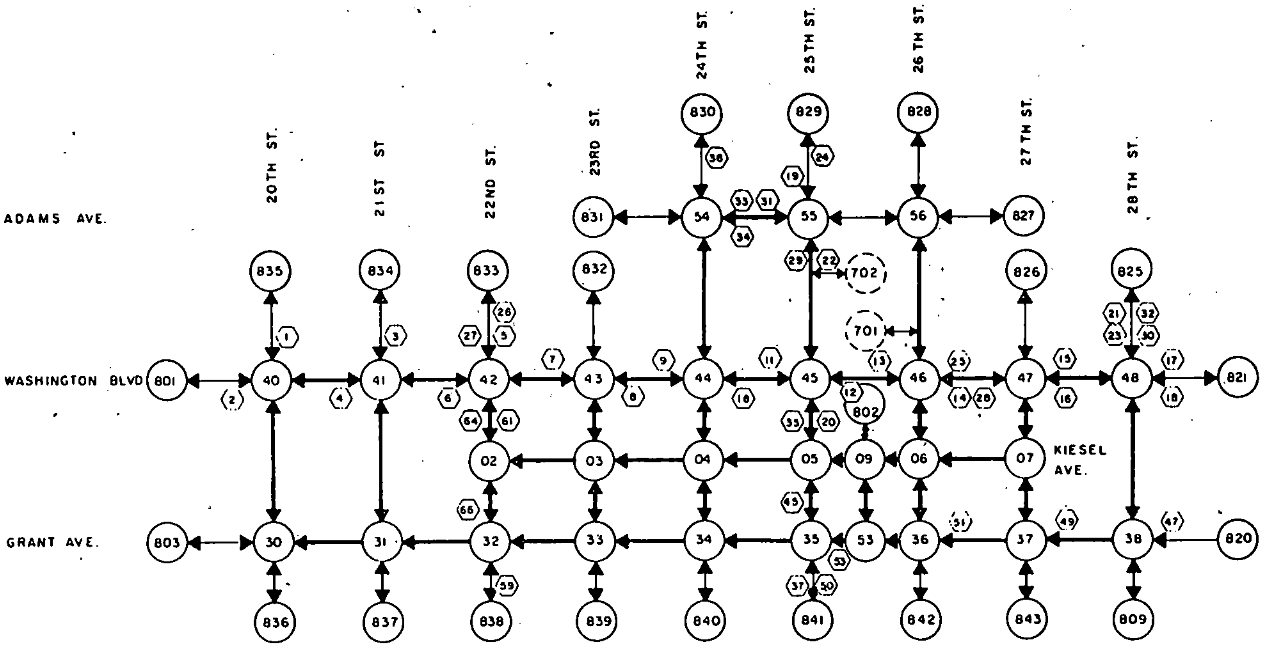


Figure 6. Link and node diagram of critical area, Ogden bus network.

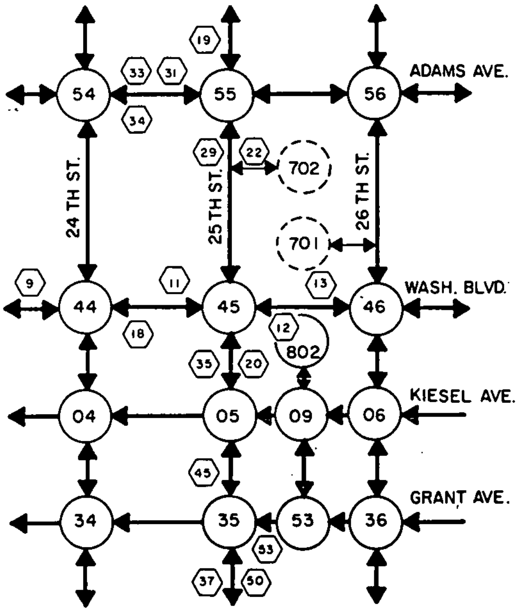


Figure 7. Link and node diagram of I-80 detour study, Salt Lake City.

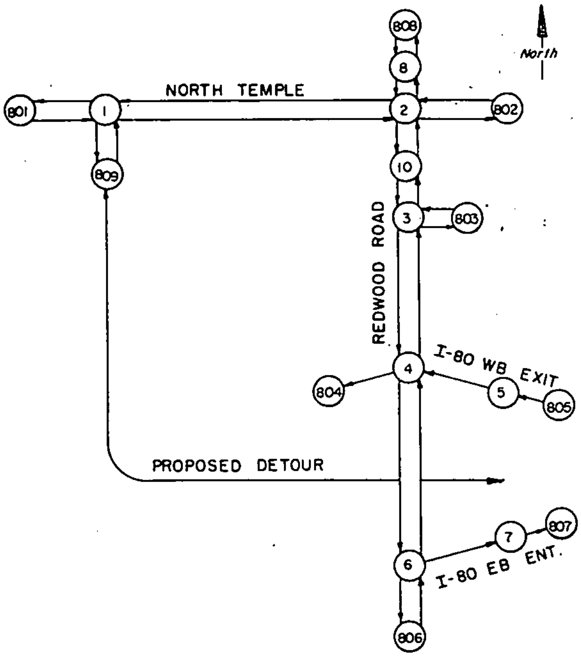


Table 4. Delay by link for Ogden bus network for 15-min simulation.

Condition	5-45	44-45	45-46	48-47	43-44	44-54	45-44	46-45
	Link Identification (delay in vehicle min)							
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.

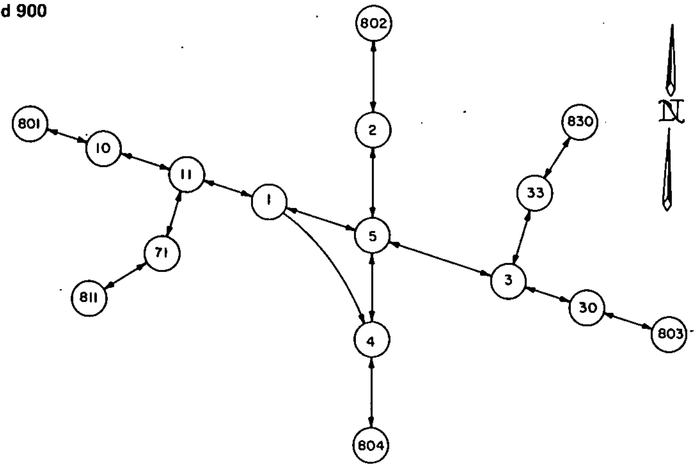


Figure 9. Van Winkle Expressway and 900 East intersection geometry.

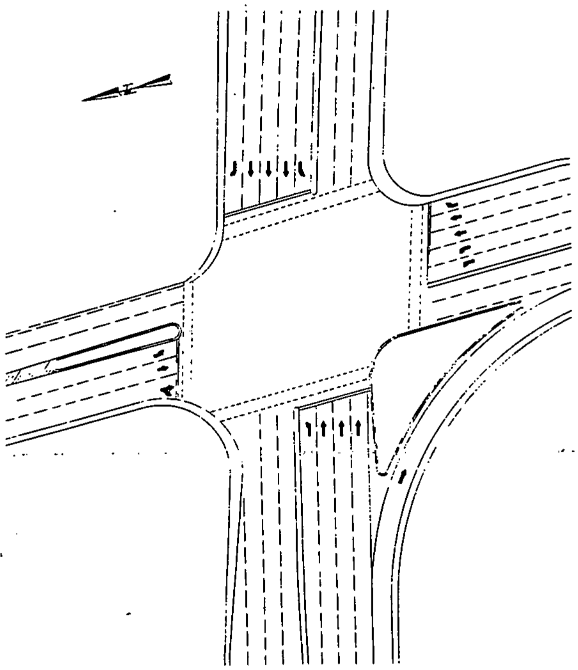


Figure 10. Van Winkle and 900 East before signal-phasing diagram.

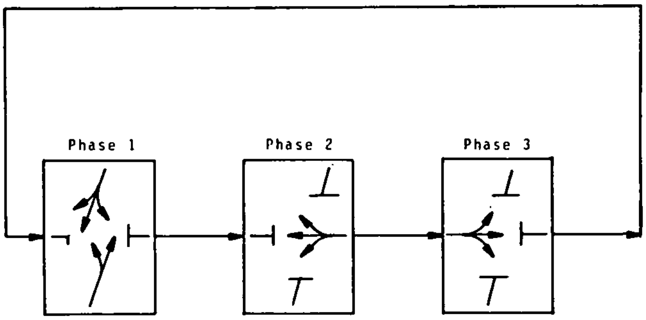
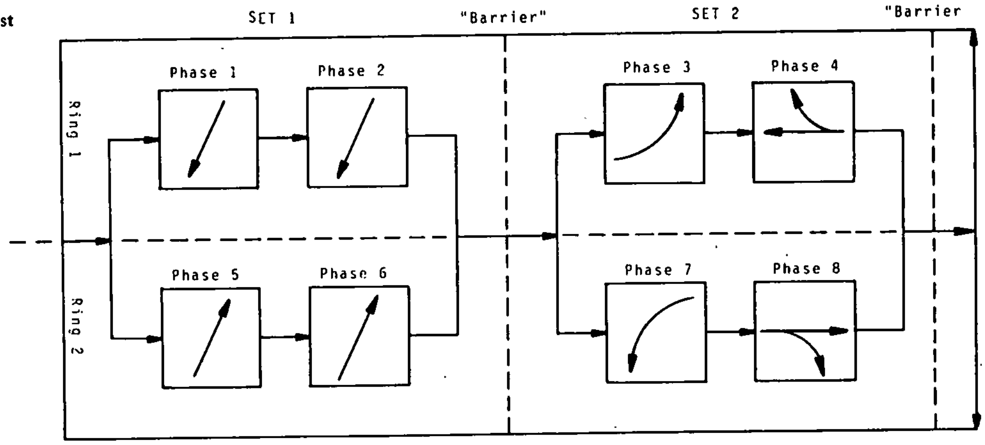


Table 7. MOEs for Van Winkle and 900 East (Salt Lake City).

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.

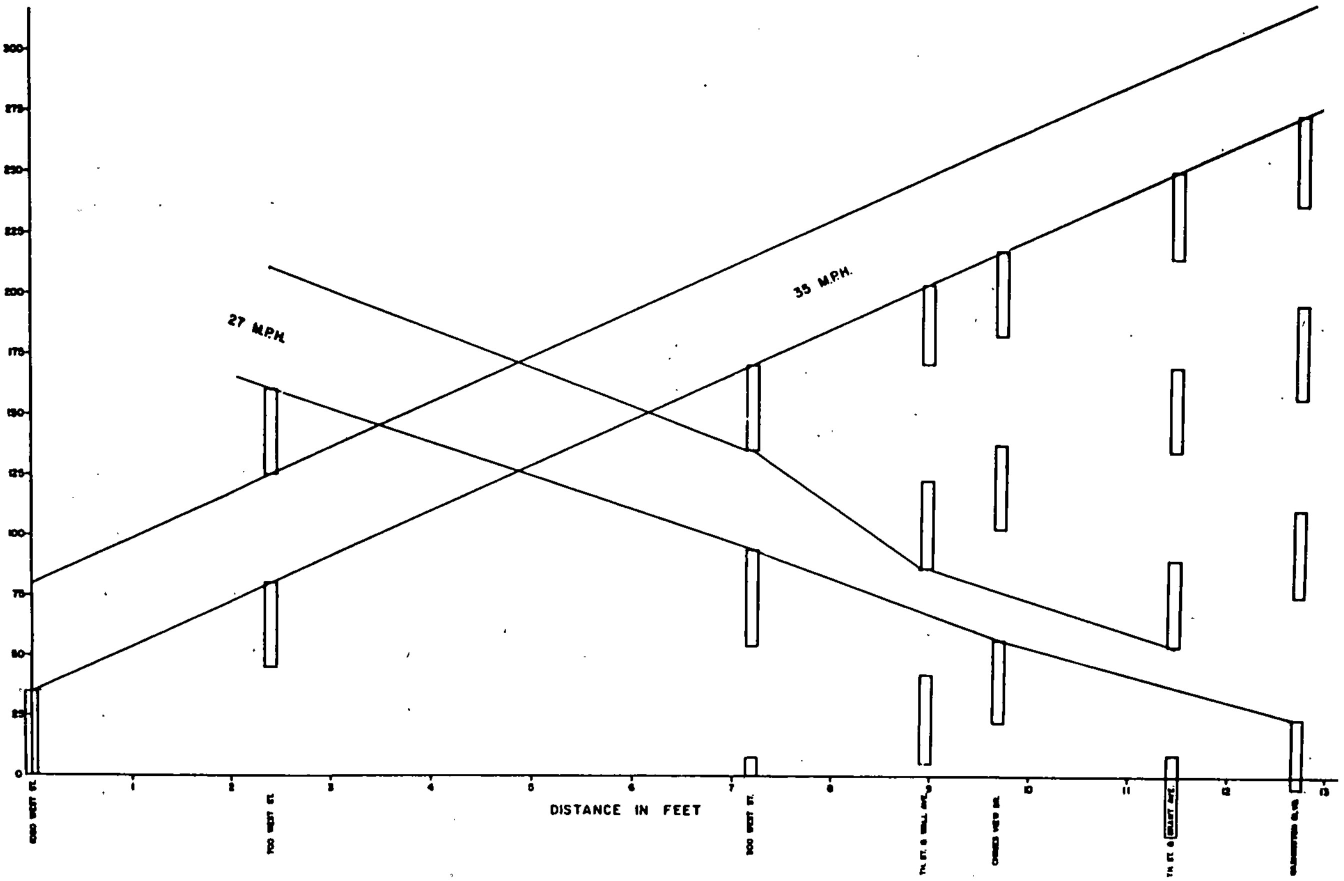


Table 8. Riverdale Road comparison of MOEs (coordination study).

	Comparison of MOEs (p.m. peak)						
Period	Vehicle Miles	Vehicle Trips	Avg Speed	Total Delay (min)	Avg Delay per Vehicle (s)	Stops per Vehicle	Stopped Delay (%)
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.

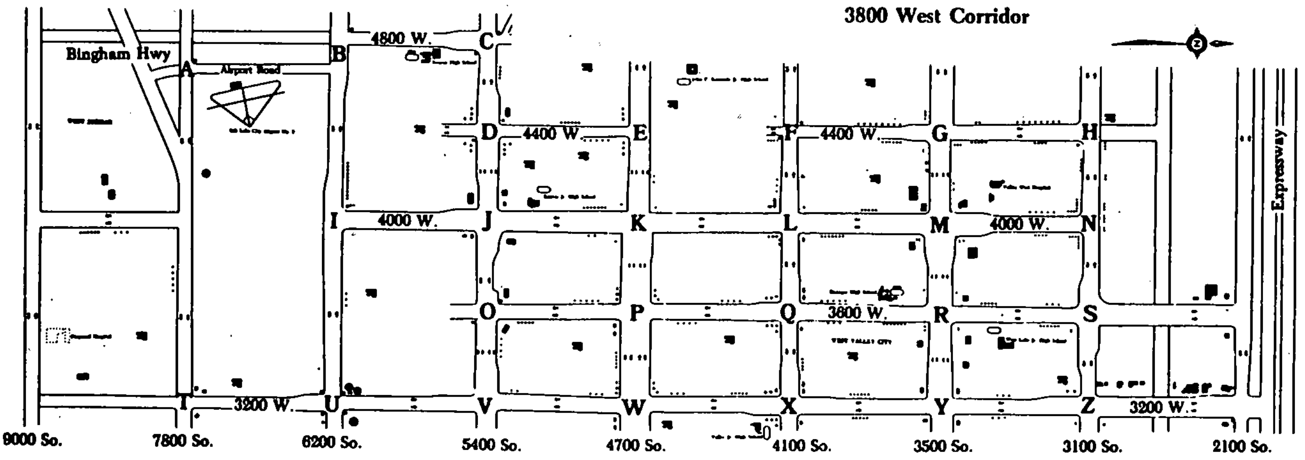


Figure 14. West Valley study build-option network.

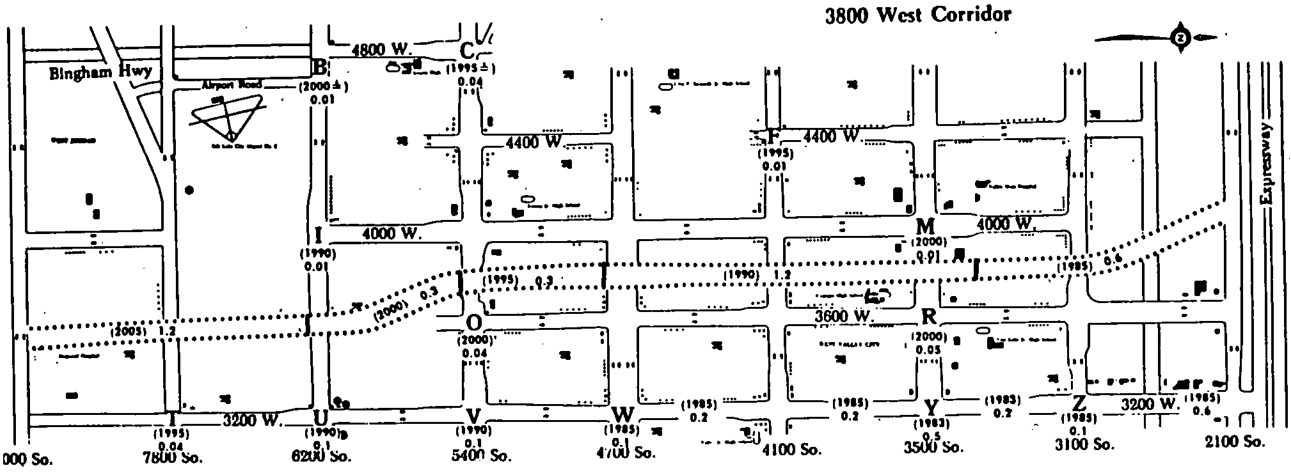


Figure 15. 3300 South (Salt Lake City) arterial computer coordination study.

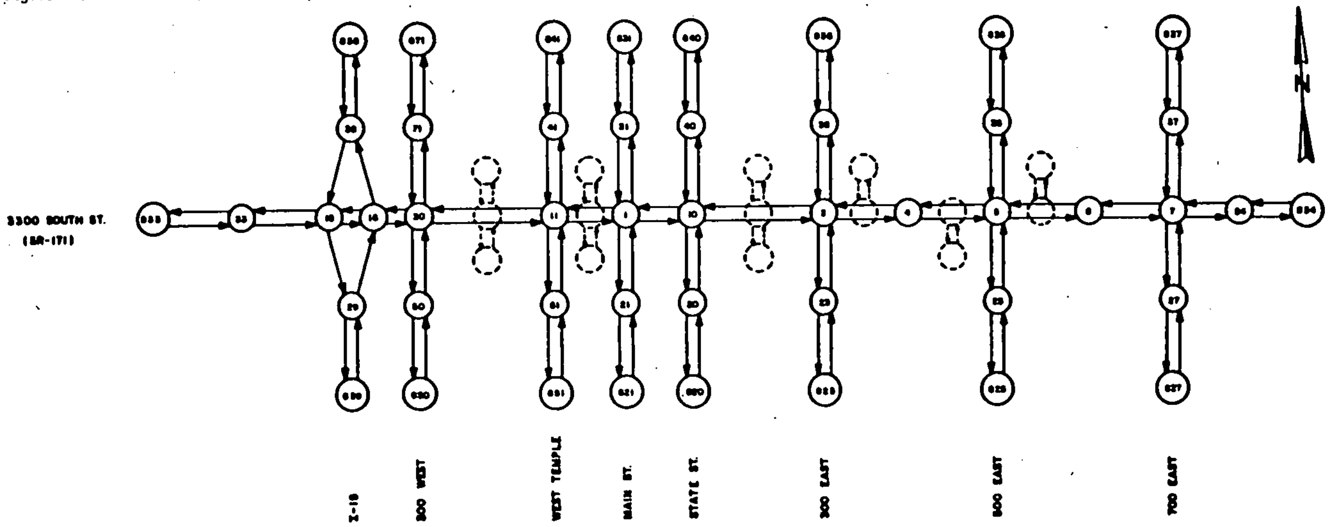


Table 9. User cost analysis for West Valley City.

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.

NETSIM has the ability to simulate the effects of traffic controls ranging from a simple "STOP" or "YIELD" sign to a dynamic, real-time traffic control system. Signal controllers may be either actuated or pretimed, and bus operations can be analyzed. A major strength of the program is its ability to consider control strategies that other programs cannot. Program output includes a variety of measures of effectiveness normally of interest to traffic engineers (speed, delay, etc.) plus estimates of fuel consumption and emissions for each vehicle type. A complete description of NETSIM's capabilities, inputs, and outputs is contained elsewhere (1).

As in any model that attempts to duplicate real-world conditions, NETSIM has its limitations. The program has been found to operate more effectively under heavy traffic conditions than in light, undisciplined flow (1). However, the model has been validated for isolated intersections (2), even though it was developed primarily for network applications.

PERSPECTIVE

The NETSIM program has been used by us and others for a variety of research purposes. Some perspectives on the type of research for which we have used the program and to some extent the frequency of its use follow.

NETSIM has been used at VPI by undergraduate and graduate students and faculty. Student use takes place in the form of independent studies, sponsored research, or thesis research, rather than as part of any regularly scheduled course. A large part of our NETSIM-related research has been concerned with determining the signal-setting requirements that minimize fuel consumption for isolated intersections and for open and closed networks, as opposed to evaluation of types of control strategies. On occasion, observations during these studies have led us to examine some aspects of the program itself, although such examinations have been performed only to ascertain accuracy of program output. In summary, then, we are occasional users of the program and should by no means be considered NETSIM "experts".

Research Applications

Most of the NETSIM-related research at VPI has dealt with the effects of signal settings on fuel consumption. The need for studies of this type first became apparent with the oil embargo of 1973, when the nation was suddenly made aware of its dependence on foreign oil. Traffic researchers began asking questions such as the following:

1. Can traffic signals be timed to minimize fuel consumption (rather than delay)?
2. If so, what are the potential fuel savings?
3. If, indeed, signals can be timed to minimize fuel consumption, what delay penalties are involved?

Most early studies addressed the problem of pretimed controls at isolated intersections. Unfortunately, the results of these studies were not consistent. Some investigators (3,4) concluded that extremely long cycle lengths were required to minimize energy consumption, while others (2,5) found that the same cycle length that produced minimum delay also minimized energy consumption. Although researchers are still not in agreement on the answer to this question, it is important that it be resolved because the impacts on both fuel consumption and motorist delay can be significant. It should be noted here that the Cohen and Euler study (2) was based on the NETSIM program.

Traffic-Actuated Control

Perhaps the first investigation of energy consumption characteristics related to traffic-actuated contol was that completed at VPI in 1979 (6). This study was concerned with net energy consumption, not only fuel consumption. Net energy analysis considers all energy used in all primary forms in vehicle operation. For example, a vehicle stop causes extra tire wear (in addition to extra fuel consumption and other items), and this extra wear has an energy cost associated with it. The study, then, was concerned with the actuated signal settings that minimized net energy consumption. The associated impact on delay was evaluated. Although NETSIM does not calculate net energy consumption, it was possible to develop a simple model that estimates net energy consumption based on NETSIM output. Since macroscopic techniques for analyzing actuated control did not exist and the necessary resources for conducting field studies were not available, NETSIM was the logical tool to use for the study. The NETSIM output data needed to determine net energy consumption were vehicle miles of travel, vehicle trips, average delay per vehicle, percentage stopped delay, and stops per vehicle.

The findings of this study will not be stated here because the results must now be considered suspect. The reasons for this are twofold. First, we discovered several months after publication of the study results that the NETSIM model generates vehicles based on a uniform statistical distribution and not according to the shifted negative exponential distribution as was done in UTCS-1. We know of no place where this change is documented. This program change should have negligible impact on simulations of large networks under high volumes, since car-following laws would govern soon after the vehicles are generated. This is hardly true, however, for isolated intersections under low-to-moderate volume conditions. The second reason is an apparent inconsistency in stops per vehicle and number of cycle failures as given in NETSIM's output.

TRANSYT Studies

NETSIM was used as a baseline program in two studies. The first study dealt with evaluating the effect of different optimization schemes on signal settings as dictated by the TRANSYT-7 program for an open network (7), and the second study investigated the effect of signal settings optimized by the same TRANSYT version on traffic operations. TRANSYT is a macroscopic simulation program that, for a given cycle length and phasing pattern, uses a performance index (PI) to optimize offsets and cycle splits in a network. The PI in the TRANSYT-7 program is a weighted sum of stops and delays. Mathematically, the performance index may be written as follows:

$$PI = \sum_{i=1}^{n} (d_i + KC_i) \qquad (1)$$

where

n = number of links in the network,
d_i = average delay on link i (vehicle-hours/hour),
C_i = average number of stops per second on link i, and
K = user-specified weighting factor (stop penalty).

The objective of the first study was to evaluate the traffic operation in an open network in which signal settings were determined by minimizing (a) total vehicle delay, (b) total passenger delay, (c) excess fuel consumption due to idling and speed-change cycles, and (d) total cost. The selected network, comprised of a six-lane arterial street intersected at five locations by two- and four-lane streets, was part of the Washington, D.C., network used for validating the UTCS/BPS computer program (8). The arterial had light traffic flows with an average of 300 vehicles per hour per lane. On a per-lane basis, the cross-street traffic volume was heavier than that of the arterial at three of the five intersections. Bus volumes over portions of the arterial reached 85 buses/h. Cross-street bus volumes ranged from 5 to 54 buses/h.

The PI in TRANSYT was modified to simulate the four optimization strategies mentioned earlier, and NETSIM was modified to generate vehicles based on a shifted negative exponential distribution. A range of cycle length of 40-90 s was adopted for the network. TRANSYT optimum cycle length and NETSIM optimum cycle length were then observed for each optimization strategy. It was concluded that

1. There is agreement between both programs on the optimum cycle length for minimizing the total vehicle delay and the total network cost.
2. There is a slight difference between the two programs on the optimum cycle length for minimizing the total passenger delay.
3. There is a large discrepancy between NETSIM and TRANSYT cycle lengths with regard to the fuel consumption logic.

A primary objective of the second study was to find the stop penalty (or a function describing it) that would provide the signal settings for minimizing fuel consumption in a network. Two networks were analyzed. One, a four-intersection open network in Blacksburg, Virginia, carried low-to-moderate traffic volumes. The second network, located in Arlington, Virginia, contained 24 intersections (20 of which were signalized) and carried high volumes of traffic. Since the TRANSYT-7 program version did not provide fuel consumption estimates, it was necessary to use NETSIM to obtain them. (It should be noted that more recent versions of TRANSYT not only include estimates of fuel consumption and emissions but also use a greatly expanded performance index function so that one can, if desired, perform optimizations based on fuel consumption alone.) For purposes of this study, NETSIM was modified to generate vehicles based on a shifted negative exponential distribution, as was done in UTCS-1. Results of the study showed strong relationships between fuel consumption and both average total delay per vehicle and average stopped time per vehicle. It was also shown that for these two networks the settings that produced minimum delay minimized fuel consumption. A TRANSYT stop penalty of zero should have produced this effect, but did not (based on NETSIM output). In fact, there appeared to be no consistent relationship between stop penalty and fuel consumption. These and other results of the study are contained in a thesis by Hill (9).

Sensitivity Study

The fuel consumption tables embedded in NETSIM are based on an analytical model developed by the Transportation Systems Center (10). It appears, however, that most researchers attempting to model fuel consumption requirements at intersections use Claffey's data (11). Claffey's data are the result of field testing of fuel consumption of highway vehicles under various operating conditions. However, the form in which Claffey's data are given is not compatible with that required by NETSIM, although NETSIM does have the flexibility of accepting alternative fuel consumption tables if the user wishes to provide them. Conversion of NETSIM's fuel consumption data to the form in which Claffey's data are presented revealed that, although the two data sets exhibited similar trendwise behavior, fuel consumption magnitudes were often quite different. A procedure was developed that converted Claffey's data to the NETSIM format and calibrated them for NETSIM's vehicle trajectory profile (12).

The primary purpose of the study by Hurley and others (12) was to ascertain whether or not significant differences existed in NETSIM output between the two fuel consumption models and also between the uniform distribution model used to generate vehicles and a shifted negative exponential distribution. Also studied was the sensitivity of fuel consumption and delay to saturation headway (or saturation flow rate). The effect of grade on fuel consumption and delay was investigated, although only in part because the NETSIM fuel consumption logic does not consider grade effects. That is, the effect of grade on saturation headway was considered, but the direct effect of grade on fuel consumption was not.

Most of the study conclusions were based on data generated for an isolated intersection under pretimed control, although comparisons were made for the same open network in Blacksburg referred to earlier. Conclusions reached from the study were

1. NETSIM's embedded fuel consumption data produced significantly lower consumption estimates than did the Claffey-based tables.
2. Significant differences were found in fuel consumption and delay output between the uniform and shifted negative exponential models for generating vehicles.
3. NETSIM fuel consumption and delay outputs are sensitive to saturation headways greater than 2.2 s.
4. Within the limits of the investigation, grade effects appear to significantly affect fuel consumption and delay only at high volumes.

RECOMMENDATIONS FOR IMPROVEMENTS

The NETSIM-related research described in the preceding section provides only a partial picture of our experience with the program. The following points out known and suspected problems in the program itself, some problems with and suggested improvements for the program documentation, and simple changes in program output that (from our viewpoint) would be helpful to the user.

Internal Logic

Cycle Failures

In the study of actuated controllers, it was observed that the program consistently contained zeros in the cycle failure column, regardless of input volume magnitude. This should be corrected.

Stops per Vehicle

Examination of NETSIM output for Blacksburg's open network showed that for one intersection the number of stops per vehicle was greater than 1. At the same time, there were only 5 cycle failures out of 48 cycles. We know of no logical explanation for this inconsistency, and it seems to us that the logic is incorrect for either stops per vehicle or for cycle failures (under pretimed control). We suspect that the stops-per-vehicle logic is at fault, since the signal timing was such that there should be few, if any, cycle failures for the approach volumes.

Dual-Ring Controllers

In a non-research application of NETSIM, operation of a four-intersection coordinated network in York County, Virginia, was to be evaluated. One of the controllers in the system was a dual-ring actuated controller. The average delay value for the intersection was estimated to be an obviously incorrect 372 s/vehicle by NETSIM. A similar estimate for the intersection assuming pretimed control was "only" 109 s/vehicle. The dual-ring logic is obviously faulty.

Grade Effects

Although the published results of our study addressed the effect of grade on fuel consumption related to passenger cars only, a cursory examination was made on the effect of grade when the traffic stream consisted of 15 percent trucks. No differences in either delay or fuel consumption were observed for grades between -5 and +5 percent that could not be attributed to randomness. If the differences are not due to randomness, then they are trendwise illogical. We suspect, then, that grade is not taken into account at all in the simulation, although grade is a program input item. This should be investigated and, if need be, corrected.

Headway Distribution

The findings of the sensitivity analysis show that delay and fuel consumption output is significantly different when the shifted negative exponential distribution is used to generate vehicles rather than the uniform distribution. It is not known for certain why the vehicle-generation logic was changed when UTCS-1 evolved into NETSIM, and no claim is made here that the shifted negative exponential distribution is the best one to use. However, in the interest of providing more valid output for small networks and isolated intersections under low-to-moderate volume conditions, the uniform headway distribution logic shouuld be replaced or made a user option.

Fuel Model

The sensitivity analysis showed a significant difference in fuel consumption output between the Claffey-based fuel model and that embedded in NETSIM. Again, no claim is made as to which is best. Both data sets are old and not representative of current vehicle population. Since it has been shown that these differences can be significant, we feel that a newer data base should be obtained and that such data should be based on field tests of fuel consumption. It is also recommended that the fuel model be expanded to consider the direct effects of grade on fuel consumption. This would not be a simple modification. Neither would it be an impossible one.

Program Output

The following are program output changes that we feel would be useful. Some would logically be program options.

1. Average queue per lane is a possible addition.
2. Intermediate network statistics as an option do not work as stated in the user's manual. When they do work, fuel consumption data are not included. One can, however, get cumulative intermediate results.
3. Average saturation percentage, information that is perhaps useful to some users, is improperly titled. To us, average saturation percentage is synonymous with degree of saturation; that is, demand flow rate divided by the product of saturation flow rate and the portion of the cycle that is effectively green. The average saturation percentage as output by NETSIM is the timewise average of link occupancy divided by total link storage capacity. It is felt that most users are familiar with the signal-related definition. In addition, output of degree of saturation (according to the signal-related definition) would be extremely valuable.
4. Fuel consumption output data in gallons per vehicle would be helpful because consumption expressed in total gallons can be misleading.
5. Lane occupancy output would be another very useful addition to program output.
6. Subinterval statistics as an option would include measures of deviation within each subinterval. Some possibilities are maximum delay, minimum delay, standard deviation of delay, ratio of standard deviation to the mean, and 85th percentile speed and 10-mph pace. It is not known if the program can provide the reliable data at this level of detail.

Program Documentation

The primary change that we feel should be made in the program documentation is in the form of an addition to the user's manual. The suggested addition would be a guide to the user that describes pitfalls commonly encountered by the new or occasional user and, most importantly, the limitations of the program concerning what it should or should not be used for. For example, we are not certain that the type of research described in this paper does not exceed the accuracy limitations of the NETSIM model. Certainly, one is on potentially shaky ground when he or she attempts to evaluate one simulation program on the basis of another's output, as was done with TRANSYT-7. If this is the case, it should be emphasized in the user's manual. Furthermore, if NETSIM as it now exists is not accurate enough to support research such as this, every effort should be made to make it so. The time and dollar costs required to collect and analyze field data for the research described in this paper would be prohibitive.

With regard to new user pitfalls, the suggested addition should contain guides about the number of runs or replications required to produce acceptable accuracy and warnings about the sensitivity of program output to random number seeds. For example, an analysis for an isolated intersection was made by using a total of nine replications. It was found that by increasing the number of replications from three to six, the ratio of standard deviation to the mean (for delay) increased. By using nine replications, the ratio decreased. A user could draw two possible conclusions from this: (a) three replications are sufficient or (b) more than nine replications are needed. Our studies also showed that there was more variation in data when vehicles were generated according to the shifted negative exponential distribution.

A final suggestion is that FHWA use some type of designation to distinguish different versions of NETSIM. Improvements are continually being made to the program, but it is difficult for the occasional user to know if the program version being used is the latest one. Perhaps numerical or alphabetical designations such as are used for other programs (e.g., TRANSYT-7, TRANSYT-6C, etc.) would be sufficient. Obviously, program documentation should be revised to reflect any program changes made. The existence of new modifications should be publicized to alert the user to them.

CONCLUSIONS

This paper has summarized the experiences, problems, and recommendations of researchers at one university relative to the use of the NETSIM program as a research tool. In our opinion, NETSIM is a useful and comprehensive program that could and should be made better. It is possible that the developers of the program never intended it to be used for the type of research illustrated here. Nevertheless, NETSIM's comprehensiveness and relatively low costs (when compared with the alternative of collecting and analyzing sufficient field data) will continue to make it attractive to researchers. It is felt, therefore, that efforts required to improve program accuracy would be highly beneficial to both researchers and practitioners.

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Simulation Developments in Progress

Guido Radelat

Traffic simulation is, at the present time, a very dynamic discipline. It is growing fast because it is still a young discipline where dogmas are few and new ideas are welcome. It is changing rapidly because it is closely linked with the rapid and continuous advances of the digital computer. Because it is almost impossible to follow all the developments that are taking place in traffic simulation, this discussion will be concerned only with the traffic simulation activities performed and sponsored by FHWA.

TYPES OF TRAFFIC SIMULATION ACTIVITIES

In the traffic simulation discipline there are two major skills involved: modeling and computer programming. These skills are so interrelated that sometimes it is difficult to distinguish one from the other; nonetheless, they are different.

Modeling is the representation of a real-life system by a more manageable system. Programming is the translation of modeling logic into a language that the electronic computer can understand. In general, modeling precedes programming, but the transition between these tasks is usually blurred. Very often there is considerable overlapping and the last details of a model are completed as a program is developed. This is one of the reasons why simulation models are frequently called simulation programs.

Six types of traffic simulation activities can be defined:

1. New model development,
2. Testing,
3. Implementation,
4. Enhancement,
5. Application, and
6. Maintenance and support.

The following paragraphs describe these activities.

New Model Development

Twenty years ago, when many doubts existed about the feasibility of simulating traffic on a computer, the development of a new model was considered the only worthwhile activity in this field. Now, model development is only a small portion of the efforts usually involved in traffic simulation. New model development consists of

1. Requirement analysis, which is the identification of the needs for the model and the functions it should perform;

2. Formulation of the conceptual framework or creation of the logic to represent a real-life system by a symbolic system;
3. Program design, where the structure and organization of the computer program are established; and
4. Program development, which consists of actual coding according to the established design.

Testing

There are so many things that can go wrong in a simulation model that testing has become an activity as important as development. And the most time-consuming task in testing is "debugging", or the detection and correction of errors in the computer program. Debugging starts when coding starts and never ends; experience has shown that large computer programs, including most of our simulation programs, are never completely debugged.

Testing also includes verification, or checking that the outputs of the model are reasonable. If they are not, there are either important bugs in the program or flaws in the conceptual framework that must be corrected. When the outputs are compared with equivalent values observed in the field or with outputs from a more reliable model, the task is called validation.

Once the model is verified and validated, its developer must demonstrate that it can perform satisfactorily the functions that are expected of it. This requires running the program in a range of scenarios that will cover most of the typical applications of the model. If the runs produce acceptable results, they constitute acceptance testing of the model. It is then assumed that the model has reached acceptable levels of validity and reliability.

The team that develops the model, because of its familiarity with the program and its conceptual framework, can perform very efficiently the changes required by the testing activities. For this reason, the testing tasks, except validation, should be performed by the model developer. Validation, on the other hand, should be conducted by a party not responsible for the development of the model to ensure objectivity.

Implementation

Implementation is an appraisal of the applicability of the model. Here, familiarity with the model is not an asset but rather a liability. A potential user of the model, not too familiar with it, should be selected, trained in the use of the model, and allowed to apply it to a practical problem under the guidance of the developer and sponsored by the agency that has developed the model.

The potential user will likely find deficiencies in the model and its documentation that are not easily perceived by those who developed them because they were too familiar with their products. The user can then recommend changes to enhance the efficiency and applicability of the model.

Application

Traffic simulation models have been used for evaluating new traffic control or traffic management strategies and observing the effect of various changes on traffic measures of effectiveness. They have also been used to analyze traffic flow interactions in a controlled experiment and to test specific traffic engineering techniques and variations in them.

Enhancement

Traffic simulation models need periodic enhancements. New model functions that were not foreseen during its development are requested by its users--for example, computation of fuel consumption. New advances in the state of the art of traffic control and traffic management also require changes in the model and in its program. Traffic signal control techniques, for example, change very rapidly. There are always new ideas of how to model particular traffic phenomena that suggest changes in the model conceptual framework. Finally, the rapid progress that the computer field is experiencing has an impact on simulation programs that can make them obsolete in a relatively short period of time.

Maintenance and Support

Maintenance is the group of tasks concerned with correcting, adapting, and improving existing programs after they have passed their acceptance test. Support is any action conducted to make possible or easier the successful use of a model. It includes providing the user with information about the model, distributing the program code and documentation, providing training, responding to questions, reviewing and correcting users' input, and keeping them informed about changes in the model.

Relationships Among Traffic Simulation Activities

Figure 1 shows the relationships among traffic simulation activities. New model development is always followed by testing. After testing, a model can be directly applied, but experience has shown that an implementation phase is very worthwhile. Implementation is a controlled application where the applicability of the model is carefully scrutinized and may indicate the need for enhancements and further testing prior to the release of the model for practical applications.

The application, maintenance, and support activities are closely related and interact with each other. Problems uncovered during model application that cannot be handled by regular maintenance operations may require new enhancement and testing.

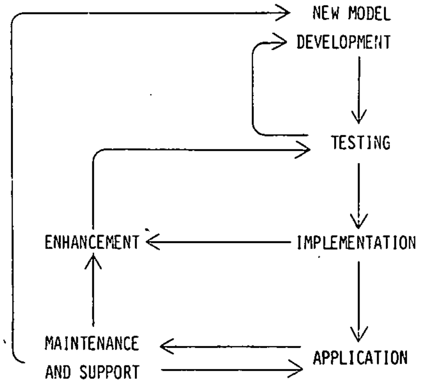
Very often, the implementation or the maintenance and support activities are omitted. This omission places an excessive burden on the application activities.

Finally, when models become obsolete or their programs are so inadequate or badly patched that their maintenance is excessive, it may be advisable to start all over again and develop a new program or even a new model.

PAST DEVELOPMENTS

With the main traffic simulation activities defined, we can now turn our attention to the role played by

Figure 1. Relationships among main traffic simulation activities.



these activities in the past [see Radelat (1)].

Evolution of Traffic Simulation Model

Traffic simulation was born in the mid-1950s right after the digital computer became available to traffic researchers. The simulation techniques, which combine analytical and empirical relationships with logical decisions, require an overwhelming amount of computations that only the electronic computer could handle.

The purpose of these models was to predict, in a quantitative fashion, the effect of traffic control techniques on real traffic. These models materialized as elaborate computer programs that represented traffic flow in single intersections, short sections of freeways, urban arterials, and even urban networks.

One of the approaches for portraying traffic was to represent each vehicle by a set of variables (such as vehicle type, position, speed, acceleration, etc.) and update this set of variables at fixed or variable time intervals. The models that followed this approach were called microscopic. Other models represented traffic in terms of overall parameters such as traffic volume, average speed, and density, or handled the vehicles in groups. These models were known as macroscopic.

Microscopic models are, in general, more accurate than their macroscopic counterparts because they make fewer assumptions, but their larger requirements for computer resources retarded their development in times when these resources were very limited. The advent of the third-generation computers in the mid-1960s made possible the development of microscopic models such as UTCS-1, which later became NETSIM.

Later on, when the application of traffic management strategies called for the analysis of traffic in large urban networks, macroscopic models were needed and the macroscopic TRAFLO was created. Now it is possible to simulate urban and freeway traffic at various levels of detail.

Lack of Reliability

The main problem with the early traffic simulation models was their lack of reliability. Models were not properly validated. Programs were not thoroughly debugged and demonstrated. The importance of testing was not yet evident. The result was a lack of credibility that resulted in the natural lack of use of traffic simulation in the traffic engineering community. This was not very encouraging for simulation model developers.

Nevertheless, as years of frustration went by, the need for proper model and program testing was becoming more definite. More rigorous validations were performed, program demonstrations became the rule rather than the exception, and model implementation efforts were initiated. At the same time potential users of the traffic simulation models were becoming more computer-oriented and found that, in many cases, field experimentation could not be more accurate than computer simulation. Also, it was realized that even a model that does not represent the absolute truth could be useful if it can give indications on the relative merits of traffic control alternatives. Then, traffic simulation began to have customers.

More Simulation Efficiency Needed

When traffic people overcame their reservations about simulation models and started to use them, they discovered that their programs were not very efficient. These programs called for computer resources that many of the users did not have or could not afford. Model developers made some efforts to improve the computational efficiency of programs in response to the demand of more efficient software. But at the same time they were getting requests for extensions in the capabilities of the models that would make their programs more complex and more demanding of computer resources.

Fortunately, advances in microelectronics had been producing dramatic reductions in computer hardware costs and increases in computational power. The cost of human time and thus the cost of producing and running software on newer and faster machines, on the other hand, had been steadily increasing. Recognition of these facts has led to a shift of emphasis in the traffic simulation field from machine computational efficiency to human efficiency as the prime consideration.

Considerable human time is spent in input preparation, output interpretation, and bug detection and correction when undetected errors in a program prevent model use. It was found that the human time involved in these tasks was substantially affected by the following factors:

1. Diversity in models and programs--Although diversity in the early stages of simulation resulted in desirable creativity, it later became a source of inefficiency and confusion;
2. Documentation--Most of the early simulation models were poorly documented because their developers were too busy trying to make the computer programs work and had little time for other things that were considered of secondary importance (later this situation improved);
3. Programming style--The program structure and coding style found in most of the early simulation programs and in others more recently developed left much to be desired and were characterized by inadequate design, large and complex subroutines that often performed several unrelated functions, and disorganized and poorly annotated code; and
4. Maintenance and support--Recognition of the importance of these activities has been very slow; therefore, most of the traffic simulation models have received inadequate maintenance and support--a deficiency that has resulted in sizeable wastes of user time in input preparation, output interpretation, and debugging.

CURRENT DEVELOPMENTS

TRAF System

To address the problem of improving human efficiency in connection with traffic simulation, the Office of Research of FHWA is developing a system of traffic simulation models named TRAF (2). This system is designed to represent traffic flow on any existing highway facility.

Since TRAF will be a single source of traffic simulation programs, the user need be concerned with only one set of documentation and one set of input and output format. This standardization will put an end to the confusion caused by the diversity of simulation approaches and format. It will also reduce considerably the overall learning effort in connection with the application of traffic simulation.

In the development of TRAF, special consideration is given to the task of producing the best possible program documentation. Instead of the detailed flow charts that were previously used to document many simulation models, TRAF uses a modified system of hierarchy plus input-process-output (HIPO) charts, which are more effective in depicting the logical structure of the programs. Numerous comments are included in the code and each variable of the program is defined in every subroutine where it appears.

The code itself is carefully planned for minimum branching, and it is completely modular (subroutines are short and perform only one function). A standard code format has been established that makes the programs easy to read and presents the logic as clearly as possible.

Also, an integrated traffic simulating system will facilitate the maintenance and support activities for two reasons: (a) With only one simulation system to maintain and support, these operations can be centralized; and (b) these activities can be automated to a large extent by using a specialized "operating system".

The creation of TRAF does not involve new model development, but the enhancement of what is regarded as the best traffic simulation logic available. This logic is in the form of modularized subroutines that are being stored in a master file. A program tailored to a particular application can be generated by an operating system that selects the needed subroutines, adjusts their dimensions, and integrates them. This flexibility will minimize the waste of computer resources because the programs contain only the user's selected features and dimensions required by the desired applications.

The models that are being integrated into TRAF are shown in Figure 2. The names of these component models consist of a prefix and a suffix. The prefixes NET, FRE, and ROAD indicate urban networks, freeways, and two-lane, two-way rural roads, respectively. The suffix SIM means microscopic and FLO macroscopic.

NETSIM, the microscopic model for urban networks was created 10 years ago and has been almost continuously enhanced since then (3). Recently it has been reprogrammed to conform to TRAF programming standards and further enhanced.

The macroscopic models for urban networks and freeways, NETFLO and FREFLO, form a subsystem called TRAFLO; that is, the macroscopic portion of TRAF. NETFLO was developed according to TRAF programming standards, and FREFLO is essentially the existing MACK freeway model, reprogrammed and adapted to the TRAF environment. NETFLO is beginning its implementation phase, while FREFLO is going through enhancement and testing.

FRESIM, the microscopic freeway model, will be primarily the freeway portion of INTRAS (4), a microscopic freeway corridor model that has been tested and implemented. FRESIM will be enhanced and reprogrammed before becoming part of TRAF.

Finally, ROADSIM, the microscopic two-lane, two-way rural road model is basically the TWOWAF model developed by the National Cooperative Highway Research Program (5). It is being reprogrammed and integrated into the TRAF system.

The TRAF operating system is shown in Figure 3. It is a computer program consisting of the following major components:

1. A master file where the modularized subroutines of the component models are stored;
2. A file maintenance program that automatically modifies the content of the master file;
3. A program generator that reads the features specified by the user, selects the subroutines that simulate these features, and forms an application program that satisfies user's specification; and
4. A report generator that produces various informative computer printouts.

Figure 2. Components of models that are being integrated into TRAF.

	Microscopic	Macroscopic
URBAN NETWORKS	NETSIM	NETFLO
FREEWAYS	FRESIM	FREFLO
TWO-LANE ROADS	ROADSIM	—

Development of Statistical Guidelines for Using Traffic Simulation

The traffic simulation models of the TRAF system are not deterministic but probabilistic. This means that their program outputs have random variations that reflect the randomness of the events simulated.

The variability of program outputs affects the practical applications of the models because it makes it difficult to characterize their statistical behavior. There are questions regarding the statistical aspects of traffic simulation that have never been properly answered, such as the following:

1. For how long should a simulation program be run to produce the desired results?
2. What is the level of precision of a simulation model? How valid is a validated model?
3. How can the outputs of the models be used to supplement field data?

At present, a study is being conducted by FHWA to address these and other statistical questions. The product of the study will be a set of statistical guidelines for model application, which, it is hoped, will make traffic simulation more effective.

Testing and Implementing TRAF System

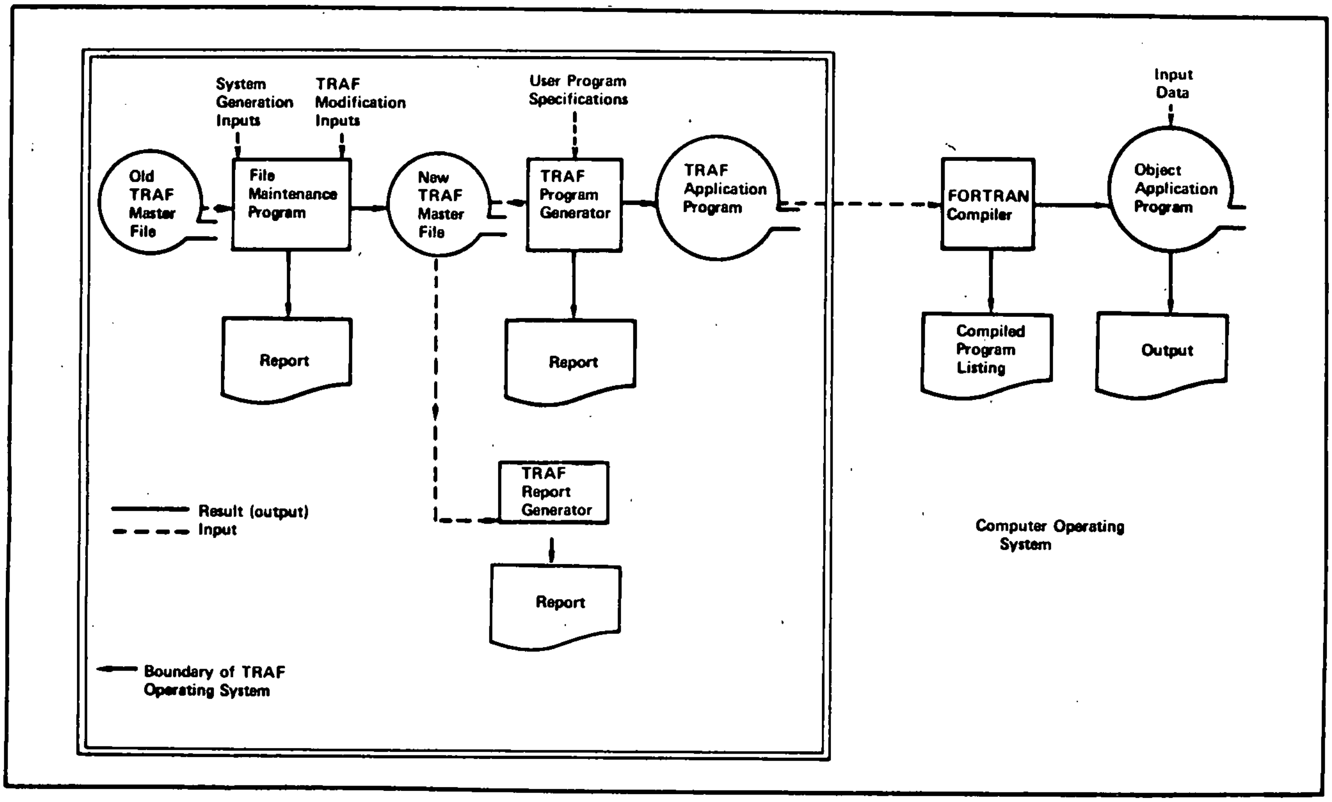
At present, there are no plans at FHWA for developing new traffic simulation models. A survey of the computer technology and prediction of computer developments in the near future is considered necessary before the needs for new models can be determined and plans for their development formulated.

Emphasis is now given to testing and implementing the models of the TRAF family; first as stand-alone programs and then as a system. The implementation of the TRAF system will be done gradually, starting with traffic simulation on urban networks and the macroscopic simulation of traffic on freeways. The next step will be implementing traffic simulation on the above facilities plus two-lane, two-way rural roads. Finally, the entire TRAF system will be implemented--including the macroscopic freeway simulation.

Model Enhancements

The integration of the various component models into the TRAF system is essentially an enhancement operation; no new model is being created. But in addition to the integration process, each of the component models is being reprogrammed, which is an enhancement, and its conceptual design is being improved. The NETSIM logic, for example, has not only been refined but it has also been substantially extended to simulate more complex traffic situations.

Figure 3. Elements of TRAF operating system.



Other traffic simulation model enhancements not included in the development of TRAF but performed, planned, or contemplated in the Office of Research are the following:

1. Calibration, validation, and refinement of the FREFLO macroscopic freeway model;
2. Improvement and updating of the traffic-actuated signal logic in the NETSIM microscopic urban network model; and
3. Incorporation of computer graphic capabilities to the models of the TRAF system (graphic displays have been provided for NETSIM in studies sponsored by the Office of University Research, U.S. Department of Transportation, and their results have been very encouraging).

Maintenance and Support

Up to now, very little has been done by FHWA to maintain and support its traffic simulation models. The need for these activities was not perceptible until traffic simulation began to be successful and the models used outside FHWA. The importance of these activities, however, is now being recognized, and we hope that much more emphasis will be placed on them in the future.

CONCLUSIONS

At the present time, a cycle of traffic simulation model development has been completed. Models able to handle virtually every traffic simulation need are now available. However, they have to be further tested, implemented, and enhanced so they can be more reliable, more efficient, and easier to use. They also have to be effectively maintained and supported so that the benefits of their applications can be maximized.

These existing models, with proper enhancements, will be probably useful until the end of this decade. Beyond this point there is reason to believe that the available computer hardware and software will be radically different from what existed when the models were developed and a new round of model development is likely to be needed.

ACKNOWLEDGMENT

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This paper reflects my views and does not necessarily present the official views or policies of FHWA.

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Possible Futures for Traffic Simulation

Paul Ross

This paper discusses the ultimate future of traffic simulation--that is, what features will traffic simulation programs have 20, 30, or even 50 years from now? The statements made here are necessarily hypothetical and subjective. No apology is made for that; there just does not seem to be any other way to cover the subject.

In this discussion of the future of traffic simulation, I will exclude ideas that are currently under development or planned. (See the paper by Radelat elsewhere in this proceedings.) This is not to say that no research is under way on these subjects. Indeed, I am aware of pilot studies or preliminary research on nearly all the features that will be described here. Nevertheless, it does not appear that many of these features will be incorporated into publicly released traffic simulation programs within the next five years at least.

TRENDS IN COMPUTER TECHNOLOGY

There are many things that will affect the future of traffic simulation. The most important of these will be the future of traffic itself. What kind of vehicular traffic will exist in the year 2000? smaller vehicles? larger vehicles? Will there even be individual vehicles? There certainly are conflicting trends in vehicular traffic at present, but it is far beyond the scope of this paper to sort them out. For the purposes of this paper, let us assume that traffic will not be radically different from a collection of individual vehicles as it is now. Let us further assume that no other changes--except perhaps in computers and computer technology--need to be predicted at this time. Such a restriction is necessary to limit the scope of the problem; otherwise, it would be necessary to deal with an impossibly broad topic.

What, then, are the likely changes in computers? And how will these changes affect traffic simulation? The following is envisaged.

Mainframe computers will get bigger, faster, and more expensive. This is a simple extrapolation of a well-known current trend. The price per calculation will continue to go down, although not as rapidly as it has in the recent past. Since manpower costs are essentially negligible in computer calculations, the cost of an individual calculation will remain insensitive to labor costs and will not rise in terms of real dollars. However, since the capital cost of individual mainframe computers will increase as their computing power increases, we will see fewer and fewer organizations able to afford the most powerful computers.

Small computers will become more powerful, and powerful computers will become smaller. We already have computers with full abilities that are small enough to carry in a briefcase (although they are hardly pocket-sized yet). The usual office will replace its typewriters with word processors that will be cheaper than typewriters--very much in the way that pocket calculators have driven the old mechanical desk calculators out of the market. These word processors will have computational capabilities fully able to run traffic simulation programs.

These devices might be better thought of as computers that also do word processing but they are more likely to be justified on the budgets as office equipment than as laboratory equipment. The more-deluxe versions of the word processors on the market now already have the ability to do mathematical calculations, and soon the cost of adding programmable scientific calculations will be just a few dollars--the cost of a silicon chip. Soon we will be able to run NETSIM on our office typewriters.

Public time-sharing services will excel at providing service to small or medium-sized organizations whose computing requirements fluctuate widely. One can easily visualize a small consulting company that needs negligible computing time except that once a week it runs a large simulation that requires an hour or two of CPU time and a few megawords of random-access storage. Clearly it will not be cost-effective for such an organization to purchase its own computer and it will have to turn to a public computer-sharing service. It will be in the interest of such a service to use the most powerful available computer in order to service as many customers as possible simultaneously. Extraordinary demands will probably be satisfied on a batch-mode basis.

Organizations with reasonably constant need for computing power will tend to buy their own in-house computer since they will be able to choose one to match almost exactly their individual requirements. These organizations will probably provide real-time operation on small computers or time sharing among several individuals on medium-sized computers simply because human time will be worth more than computer time. Batch-mode processing at night or on the weekend may be required for large jobs within such a setup.

Every computer powerful enough to run a traffic simulation program will have some form of graphic output. As a matter of fact, the graphical devices will be cheaper than hard-copy printers. Liquid-crystal matrix displays can be made without all the complicated moving parts that are inherent in hard-copy printers. When cathode-ray tube or liquid-crystal displays become common, there will be no reason to restrict the outputs to alphanumeric characters and most output displays will have full graphic capabilities. So, eventually, the office typewriter will not only be able to compute, it will also be able to produce pictures.

FUTURE DEVELOPMENTS

How will the above trends in computer usage affect traffic simulation? The following are speculations about future developments. They are arranged in order with the most certain and immediate prospects first and the most speculative and remote ideas last. Indeed, experimental versions of the first three ideas are already in use; it is just that no development or release of a traffic simulation program with these features is scheduled at the present time.

Graphic Displays

The surest thing is that simulation programs will make greater use of graphic displays. Since virtually all computer terminals will have a graphic device as its normal form of output, this development is inevitable. [The only thing that has held up the incorporation of graphics into NETSIM has been the fact that there is no common graphic language. The language used for computer graphics depends on the make of the terminal; it is not like FORTRAN, which can be executed on virtually any brand of computer.]

At first, NETSIM outputs will show such things as the queue lengths at all the intersections and various other forms of output information. Such displays will allow the user to grasp the overall operation of a network at a glance, which will be much quicker and more meaningful than wading through the reams of computer printout that are now presented.

Graphical output will be followed by graphical displays of the simulation program in operation. Pictures of little cars running around the network are generally thought to be a good public relations tool. That is, they are the kind of thing one likes to show when explaining one's results to a somewhat dubious committee of nonexperts. Animated operating displays are certainly useful for such explanations, but they are even more useful to the practitioners themselves. There is no more certain way to find mistakes in the input than to look at how the computer thinks the system is supposed to operate. Left turns coded as right turns or obvious mistakes in signal phasing stand out immediately. The technology to show full animation has been available for only a few years and is currently very expensive. However, it is certain to become cheaper and, over the time span we are considering, should become readily available.

Interactive Calculation

Traffic simulation programs will usually be interactive. That is, the operators will be able to interrupt the programs during execution and change various parameters. This interactive ability will be a natural outgrowth of the use of graphic terminals. Widespread use of graphics will, by itself, lead to more interactive programs. While it is possible to run a program in batch mode and then look at the outputs generated by the computer sometime later, this is not a convenient or natural way to use computer graphics. With graphic displays it is natural to have the computer instruct the display device to draw some complicated picture and then await confirmation that the picture was indeed drawn before proceeding with the next calculation. Consequently, it is a very small step to allow the operator to interrupt and change the program since the computer is waiting for a response from the terminal anyway.

With a time-sharing option, or dedicated operation on a small computer, at least some small amount of interactive computing seems inescapable. At a minimum, the program will analyze the input data and inform the operator of obvious errors before he or she leaves the terminal. A simple program could operate this way but we will soon see programs that ask the operator for input data in plain English and analyze it item-by-item for obvious errors and consistency with previous data. The operator will be informed of problems before his or her attention has moved on to the next data item.

Until graphic devices become common, this may be all the interactive capability that will be useful. But once the operator can see how the entire network is operating at a glance from some animated operating display, he or she will want to be able to control that operation. Adding interactive abilities during program execution will be natural.

On-Line Simulation

The interactive and graphic display features will lead to "on-line simulation" for traffic control systems. On-line simulation refers to a service provided to operators of computer traffic control systems. With this feature the operator, at the touch of a button, will start an interactive graphic simulation running. The program will start with initial conditions that are identical to those that are current in the real network at the time the button is pushed. If the program runs four or five times as fast as real time, the operator will be able to foresee events in his or her actual network and possibly test alternative strategies.

There are a myriad of cases where such ability would be useful. One example is a situation in which an accident completely closes a network link. Even if the control algorithm is able to provide an appropriate response to such a traffic situation, it will be useful to foresee how the traffic disturbances will propagate so that police can be dispatched appropriately and, perhaps, news media notified of impending congestion at critical locations.

The ultimate stage in on-line simulation will be a program that runs continuously and checks itself against the real traffic. In this way, the simulation program can adjust itself to changes in the vehicle mix and driver behavior without any human intervention.

Data Acquisition

As users of NETSIM and other microscopic simulation programs know, input preparation and data collection are inordinately tedious and expensive. There is a very real need for "automatic input" to such simulation programs. Automatic input here means providing accurate geometric data (such as link lengths, grades, and corner radii) and traffic data (volumes, turning movements, and traffic composition) with little or no human intervention.

For a start, it is suggested that aerial photographs projected onto a digitizing tablet would be quite useful. Link geometry could quite accurately be entered just by touching origin and destination nodes. Corner radii could be entered if needed. A single aerial photograph is not much use in estimating volumes, but the simulation programs could be easily written to use density (vehicle/mile) instead. Input that starts from cars at specific locations throughout the network would have the additional advantage that no initialization period would be needed before the simulation results are valid. A great majority of the input now required for the NETSIM program could be entered just by touching points on a digitizing tablet. While this would require substantially different forms of data input processing, the basic principles of NETSIM operation would not be affected. The technology to do all this is available now.

This procedure might correctly be termed semiautomatic input because a human operator must participate by pointing out the nodes, cars, trucks, corner radii, etc., to the computer. Is there a possibility of more-nearly-true automatic input? Yes, Sensor for Control of Arterials and Networks (SCAN) technology could be adapted to a completely automatic input system (1). SCAN is a television-based detector system in which the computer identifies the images of moving vehicles and tracks them over space and time. This technology could be adapted so that aerial motion pictures could be analyzed and virtually all the simulation input could be assimilated into the computer without human intervention. The SCAN detector could pick up the network geometry, volumes, and turning movements automatically. In effect, all we would have to do would be show the computer a movie of the network operation and the computer would be able to simulate it.

Integrated Simulation

Finally, all these features will be integrated to produce full, citywide simulations. Such programs will be fully microscopic (as NETSIM now is). We will show the computer an aerial motion picture and the computer will identify all the fixed and the moving objects. It will be able to classify the moving objects automatically as small, medium, or large automobiles; trucks; transit buses; school buses; fixed-rail transit; etc. It will even, if so ordered, identify all the pedestrians. After identifying these objects, it will deduce the origin-destination table for each class of moving object. The program will deduce the acceleration-deceleration curves for each class of object and the distribution of headways for "followers."

In short, the computer program will be able to assimilate all the information that it needs to run a complete simulation of everything that moves in a whole city--all the statistical distributions and all the adjustable parameters. It will measure these quantities and not merely assume characteristics measured in some other city.

The graphic output from this citywide simulation will be extraordinarily lifelike. Computer techniques already exist to identify and manipulate elements of pictures while maintaining photographic realism. The simulation program will identify the fixed-background photograph and maintain it continuously on the output display. The simulation program will also have identified which photo elements represent cars, buses, trucks, trains, pedestrians, dogs, cats, etc. The output will have these photo elements superimposed on the fixed-background picture and moving in lifelike ways. When the simulation program generates a new vehicle it will represent it in the output with a photo element chosen at random from those photo elements that were identified as being members of the same vehicle class.

CONCLUSION

None of this is particularly visionary. The techniques to accomplish all of these things already exist--although in cumbersome and expensive experimental forms at present. It is not a question of "Can these things happen?" They can. There is no doubt about that.

Will they happen? Yes, probably. As long as there are research programs.

Will any of these techniques become common? That is pure guesswork. It depends on so many things: government regulation, economic climate, public concern. We will not discuss how common these techniques will become; this paper has been speculative enough without going into those matters.

However, we can briefly speculate about items that will not become popular, although they are known to be feasible. For instance, a traffic simulation language will probably never become popular. General simulation languages such as SIMSCRIPT and Q-GERT serve a real need for persons who have to simulate unique operations, but there are not enough persons working in traffic analysis to support a comprehensive traffic simulation language. Moreover, traffic situations do not vary so much that they cannot be all encompassed in a single program. It is hard to define the dividing line between what is a "program" and what is a "language". A very general and flexible program could be regarded as a language by some persons. Certainly traffic simulations will become more general and flexible but the effort to keep them easy to use will maintain their identity as programs, not languages.

Finally, I believe that the best simulation programs will not incorporate optimization. Of course, the optimization programs that are already in use do incorporate some form of simulation or evaluation. However, they are not the most accurate forms of evaluation and there are reasons why they cannot be.

The most efficient forms of mathematical programming, such as linear programming, require that the system model have certain mathematical simplifications. (Linear programming, for example, requires that the model must be piecewise linear and the region of feasible solutions must be convex. Other techniques require other restrictions.) The optimization methods that use only the model output and make no assumptions about the form of the model (hill-climbing or other gradient methods) are inherently inefficient and cannot guarantee a global optimum. It is beyond the scope of this paper to argue why the best simulation models will always be microscopic in character, but it is obvious that a microscopic simulation program cannot be used with an efficient and accurate optimization technique. Therefore, accurate and efficient traffic system optimizations are inherently impossible and there is no point in even trying to use the best evaluation models. Equal accuracy can be achieved by using simple, but good, models and quick and accurate optimizations. On the other hand, it is likely that in the future all signal optimizations will be done on-line.

ACKNOWLEDGMENT

The ideas presented here are mine and do not represent the opinion of FHWA. In particular, the reader is cautioned not to draw any conclusions as to lines of research that FHWA will or will not undertake based on this discussion.

I am indebted to George Tiller, Guido Radelat, and many others whose ideas have been used without acknowledgment.

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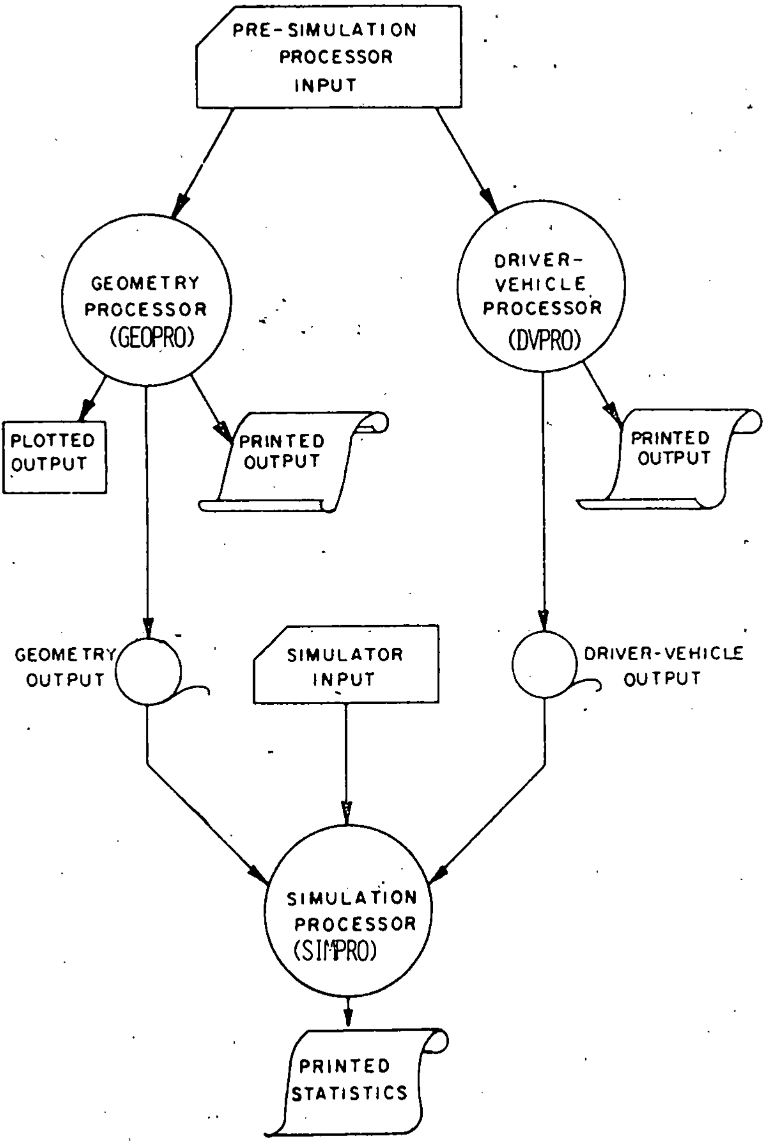
Part 4
Workshop Summaries



Workshop Sessions–I: Application of Simulation Models by Different User Groups

Workshop 1: Program Managers and Administrators

(Leader, Thomas Maleck; Recorder, Ryerson Case)

The purpose of this workshop was to discuss the use of simulation models, especially NETSIM, from the administrator's perspective. The participants were requested to share the results of their work experience in simulation modeling. Subsequent discussion centered on the use of TRANSYT and NETSIM. The participants felt strongly that the need for modeling transportation systems is here to stay and destined to grow rapidly. The results of several case studies were discussed, along with many of the advantages and disadvantages of modeling. The discussion was limited to (a) NETSIM is a good objective tool for evaluating competitive alternatives, equally supported by different disciplines or entities; and (b) NETSIM and TRANSYT are cost-effective means of assessing alternative signal timing strategies and for generating optimal timing plans in terms of the potential saving to the traveling public.

WHAT ARE USERS' IMPLEMENTATION AND SUPPORT NEEDS?

The principal concern of the participants was the resources required to implement a traffic simulation model. The burden consists of computer hardware, implementation of software, training of personnel, cost of data collection, and maintenance of software. The maintenance of a computer model and its numerous revised versions was debated extensively. It was concluded that maintenance of the model should be coordinated or done by a central agency, which could be government or a private contracting consultant.

Communication linkages among users are also highly desirable and require central support. Highly transportable computer languages are desirable. Although FORTRAN and COBOL are transportable, the feasibility of using higher-order languages, such as PASCAL or ALGOL, is questionable.

The time required to access new programs often takes one or two years after the model is accepted by the federal government. FHWA is concerned that the model be thoroughly tested before its release. It does not want the existence of the usual bugs to discredit the model, or result in the implementation of a less-than-desirable alternative. The users believed that there is a lack of appreciation of the ability of experienced users to recognize and correct deficiencies. They believed that the earliest possible access to improved models is desired. It was suggested that FHWA release early versions of new models to selected universities and experienced users for testing and implementation. A disclaimer would then be necessary. This procedure should not discredit the model, or lead to making it operational too soon.

Many models released by FHWA have been revised significantly by users and numerous versions are available. It was the consensus of the participants that users who revised the model must also bear the responsibility of supporting the revisions and providing adequate documentation.

WHAT NEGATIVE FEATURES RESTRICT USE OF MODELS?

Several of the participants were concerned that NETSIM is not "user friendly". It is too difficult and limited in the input and output facilities. The "forms display" procedure developed by the Michigan Department of Transportation was cited as a desirable means of inputting data. Graphic procedures were also suggested. A menu that allows the users to select the output MOEs to suit their needs should be provided.

The time required to access new versions was again discussed and deemed a negative aspect of simulation models. The users do not want the object version of new releases, as is the case with the urban transportation planning system (UTPS) package.

The need for simulation modeling is not appreciated by top management. There is concern that strong federal support is needed in this area and should not be diminished.

A negative feature discussed was the existence of numerous acronyms used in naming models. This is confusing. Only the latest versions of the model should be supported.

WHAT AREAS NEED IMPROVEMENT?

A simplified method of labeling the various models is needed and documentation should be limited to the latest version. Efforts should also be spent to help establish the credibility of computer modeling among program managers and administrators and to justify adequate budgeting of funds for further development and support. Many models are incompatible and effort should be made to provide a commonality of data input and output formats. There should also be a standardization of nomenclature.

Participants suggested that the Transportation Research Board express to FHWA its concerns for the current need of simulation models and their probable increased future demand.

Workshop 2: Developers, Researchers, and Teachers

(Leader, William R. McShane; Recorder, Carroll J. Messer)

The workshop for developers, researchers, and teachers examined four key areas related to the application of simulation models:

1. Education and training,
2. Assessment of NETSIM,

3. Key issues, and
4. Themes of special note.

It should be noted that of the 16 participants, 5 classified themselves as developers by virtue of extending or adapting NETSIM, 13 as researchers by virtue of their applications, and 13 as teachers. Twelve had used NETSIM; four had not.

EDUCATION AND TRAINING

Most faculty members present had exposed students to NETSIM, primarily in project work or thesis and dissertation applications. Several used it as a learning experience in which the student was expected to learn its use independently. This approach was generally thought to be good--in the context of these motivated students.

Actual classroom lecturing on NETSIM was generally limited, particularly at the graduate level. One or two hours of exposure of a survey nature was generally all that was devoted to NETSIM. The need for covering fundamentals and limited lecture time in a balanced program were cited as key factors in this emphasis. For practicing engineers, it was agreed that a hands-on, multiday workshop would be most appropriate.

The arrival of a new generation of engineers into the profession, a generation comfortable with computers and oriented to their use, was cited as a positive factor leading to greater use of such tools as NETSIM and other simulation models.

ASSESSMENT OF NETSIM

NETSIM is generally looked on as a powerful and valuable tool, one in which many of those present had faith. The success story reported by the Michigan Department of Transportation was well received and was found to be impressive. At the same time, it was noted that NETSIM has not "caught on" in a similar fashion in other states. It was noted that each state or region focused on an advocate of the model by working closely with local people (e.g., SOAP in Florida, PASSER in Texas, and FREQ in California). The exposition of working models to the profession, including the educational exposure cited above, was seen as a key contribution to the long-term growth in use and acceptance.

Specific experiences and concerns with NETSIM are addressed in the next section. More general themes are addressed following that.

KEY ISSUES

Five key issues were identified in the discussions: validation, credibility, technical problems, administrative problems, and degree of accuracy.

Validation

Much concern was expressed that the initial NETSIM (i.e., UTCS-1) validation was rather limited and is a poor foundation for the role now being played by the model. These fears were somewhat alleviated by the fact that several users present had actually validated NETSIM for some of their own applications. However, it was clear that the new user or potential user must be informed of the breadth of validation done. It should, therefore, be catalogued.

Credibility

The question of credibility is twofold: (a) Does the user believe and accept NETSIM as a valid and accurate tool? and (b) Does the client or higher-level administrator or public accept its use?

Regarding the first question, we must simply note that many of those present have used NETSIM. While they have discovered problems or limitations, they want to improve or adapt NETSIM, not abandon it. New users can be won with success stories, case studies, clear documentation, and a good model, with good support and evidence of its value.

Regarding the second question, it was noted that there is initial resistance, but that many will accept "computer results" with a strong credibility. This is sometimes a special asset, because, as one participant put it, "It is not just what good you do, but what good people think you do." Thus, such models can actually add to the credibility and objectivity of a project.

Technical Problems

Although detailed discussions about technical problems were generally left to another workshop, several items were noted. The dependence of NETSIM on a single random number string, rather than a distinct string for each major function (each with its own seed number) was identified as a substantial weakness. It was felt that it compromised the validity of pair-wise comparisons. The left-turn impact on through vehicles was noted as a special problem. This is directly traceable to an unrealistic rule for lane changing of through vehicles approaching in a lane blocked by a prior vehicle awaiting a turn opportunity. The existing NETSIM-actuated logic was thought to be too limited. At the same time, the need for good logic and good actuated modeling was found to be critical. An updated set of factors for both fuel consumption and emissions is needed.

These improvements were seen as adding to the value of an existing desirable and useful model. Their applications, such as modeling intersection noise via NETSIM (now being done), were also noted.

Administrative Problems

Two problems were of special concern. First, NETSIM, as currently modified, is what is released to users. In principle, it is possible that two users receiving tapes from FHWA a month apart will receive (slightly) different versions without knowing it. Some systematic, regular, update and prior-user notification would be appropriate. Second, the long lag for implementation of needed improvements was a matter of great concern. The cited 12- to 18-month lag before the "new NETSIM" of TRAF 1.5 is available to users was of concern. Furthermore, it is likely that this new NETSIM would still lack the critically needed actuated logic. An accelerated schedule and a systematic, regular updating are needed to meet user needs, gain model credibility and allow users to "sell" it with confidence to their management.

Degree of Accuracy

The issues of relative accuracy as needed in alternative comparison versus absolute accuracy as needed in validation were discussed. The question of significant differences versus percentage differences was noted. No resolution was reached in this workshop.

THEMES OF SPECIAL NOTE

Several important themes or judgments were identified and deserve special consideration.

1. The actuated logic is quite important to many users, especially in such states as California and Texas. It is questionable whether it makes sense to release TRAF 1.5 without such logic.
2. The selection of appropriate models is quite important. For many evaluations, TRANSYT may be quite sufficient and appropriate. It is faster and easier to use, but is of course a different tool. The promulgation of both TRANSYT and NETSIM by FHWA was noted.
3. The need to convince key administrators at the highest levels of state and local departments of transportation and traffic engineering operations departments of the value of simulation and computational models, properly applied, was identified as a key need. With a policy decision made, engineering staffs can be properly trained by standard short courses, etc. A plan for such key-management presentations is needed, perhaps including a short movie or primary visuals.

Workshop 3: Consultants

(Leader, Duncan Allen; Recorder, Ann Muzyka)

This workshop was intended to share information, experience, needs, and problems of consultants with respect to the use of NETSIM and other traffic simulation models. The workshop participants represented nine consulting firms in the traffic engineering-transportation planning field and included persons with varying levels of experience with NETSIM.

The initial discussion indicated that use of NETSIM by consultants was fairly limited (4 of 13 participants had made use of the program in consulting work). Subsequent discussion was directed toward determining some of the reasons for this limited use, and possible corrective actions.

MAJOR OBSTACLES TO INCREASED USE OF NETSIM

A number of possible reasons for limited consultant use were advanced, but the most frequently mentioned were high cost and limited applicability. A survey of the participants was conducted to estimate the relative importance of these factors. The results appear in the table below:

Reason	Most Important	Second in Importance	Third in Importance
Limited applicability	7	2	4
High start-up cost	6	2	5
High on-going costs	0	9	4

Consultants with NETSIM experience tended to consider limited applicability the major obstacle; typical of their remarks was, How often do I need a microscopic model? Consultants who had not used NETSIM had a stronger concern about the costs of acquiring working knowledge and, to a lesser extent, operating the program.

An effort was made to determine where in the consultant's decision-making processes these obstacles were encountered. In a competitive for-profit environment, this process is of necessity highly oriented toward providing cost-effective results. The selection of appropriate analytical tools is generally done for each individual solicitation or proposal, and proceeds as follows:

1. Identify the types of alternatives to be compared; most consultant work consists ultimately of recommendations for selecting among alternatives.
2. Identify whether candidate techniques offer MOEs appropriate for choosing a recommended alternative.
3. Identify whether candidate techniques can represent the differences between alternatives as variable input, or secondarily, as an easily modified embedded parameter or subroutine.
4. Verify, insofar as possible from model documentation or prior experience, that assumptions about the process being modeled are not at variance with current understanding or field data.
5. Estimate the cost of applying candidate techniques for the particular project.

NETSIM, or any other model, may be excluded from further consideration at several points in this process. The output available from NETSIM is not a problem, as many techniques and models produce the same MOEs. Some concern was expressed as to the accuracy of the fuel consumption model, but this was not used by all consultant users.

The input options and processing assumptions (points 3 and 4 above) are where the determination of NETSIM's applicability is made. Consultants are often asked to evaluate new types of transportation alternatives (e.g., pedestrian progression, TSM, information and signal control plans, enforcement strategies) for which appropriate models may not be available. Consultants understand that modifications to major software tools cannot be requested for every individual difficulty as it arises and, therefore, turn to independent program modifications, alternative models, or home-grown software. It is important to realize that the consultant user is often his or her own system analyst and programmer.

It was also felt that a lack of thorough knowledge of NETSIM's capabilities may also limit use and contribute to decreased use. This was felt to be attributable in part to documentation problems.

The second point where NETSIM is often abandoned is at cost analysis (number 5 above). Generally speaking, an alternative approach will be adopted if it is effective and offers significant start-up or ongoing cost savings, or even a predictable upper limit on total cost. Smaller consulting firms are particularly concerned with the cost of acquiring working knowledge for bidding purposes, estimated at upwards of $5000, when applications appear limited, and the expertise may atrophy with disuse or move elsewhere. There is also a general awareness that microscopic simulations are expensive to operate and often require outside computer resources. Comparisons are unavoidably made with macroscopic models and in-house mini or microcomputer-based approches. The net result is that NETSIM may not be used even when it is the only known model applicable (e.g., for uncoordinated signals or bus signal priority).

STEPS TO INCREASE USE

A number of specific developments relative to NETSIM that could improve perceived applicability and cost were identified. They include

1. Improved program documentation as follows: (a) an improved discussion of program logic, including an example, along the lines of Robertson's TRANSYT User's Guide; (b) an explicit table of embedded parameter values and the subroutines that employ them; and (c) additional material on a systems level (e.g., programmer's guide) and suggested configurations for RJE;

2. Dissemination of the costs of extensive benchmark applications of NETSIM versus other models;
3. Development of enhanced input preparation features; and
4. Improved program support, including a "hotline"; practicing consultants would not be in favor of contracting the support task to a potential competitor.

OTHER DEVELOPMENTS

A number of possible developments discussed at this conference were also addressed.

Graphics output was viewed with mixed feelings. Consultants are used to dealing with printouts and ultimately make recommendations based on quantities (MOEs), so that graphics output is not strictly necessary. A need was seen for directed research to produce displays that can effectively compare entire alternatives, rather than representations of simulated operations.

Linkage with traffic assignment was also discussed. There is a perceived continuing need for a microlevel assignment and evaluation capability, but doubts as to whether an interface between existing programs (e.g., UTPS/NETSIM) is a desirable approach. It was noted that due to their success with TRANSYT, some consultants are looking to the Transport and Road Research Laboratory and the United Kingdom for this type of capability (e.g., CONTRAM).

"New" NETSIM (TRAF) appears to incorporate many useful improvements. There was some concern expressed that TRAF perhaps might become as ungainly as UTPS and be difficult to modify independently when required.

CONCLUSION

The workshop concluded that the major obstacles to increased use of NETSIM by consultants were perceived limitations to applicability and high costs. These could be addressed by changes in documentation and support, as well as by program update. Careful research should go into the development and promotion of the TRAF package and graphics outputs.

Workshop 4: Traffic Engineers Involved in Operations and Geometrics

(Leader, Herman E. Haenel; Recorder, David B. Richardson)

Simulation models such as NETSIM, FREQ, and TEXAS have primary applications to traffic operations and geometric design. The models permit the traffic and design engineer the opportunity to model the traffic problem and analyze alternative possible improvements. The workshop group involved in operations and geometric design shared information on applications and needs for applying the NETSIM model and other simulation models. (Reports on the application of NETSIM and TEXAS for intersection-related traffic problems are also included among the contributed papers in this publication.)

APPLICATIONS

Several applications involving simulation models were discussed. These included the following:

1. A comparison of the TRANSYT and SIGOP models using NETSIM by the University of California at Berkeley and the Texas State Department of Highways and Public Transportation (both agenices reached the same conclusions independent of each other and decided to support the TRANSYT model);
2. A comparison by Texas of a fixed-time and traffic-responsive signal system using NETSIM, which resulted in a discussion to install the traffic-responsive model;
3. The utilization by Texas of the FREQ computer model to analyze future possible freeway developments (the results of the model were used as part of an analysis for determining which improvements were most cost effective); and
4. The utilization of the TEXAS and NETSIM models for analyzing several intersections; the TEXAS model was used by the city of Richardson, Texas, and NETSIM was applied in Fairfield, California (it was concluded that simulation models are tools that can be used to support and verify traffic engineering analyses and that their consistent success affirms their reliability in analysis of traffic-related problems).

There is a need to be judicious in the application of simulation models, however. As an example, the NETSIM model must be run several times in an analysis to obtain an average condition. The results of each run are a sample (or data point) of a distribution of results. This is due to the use of random sample numbers that cause traffic to respond differently on each run as is the situation in real life. Further, the smaller the study area (i.e., an intersection), the larger the number of runs required. Also, more runs are needed where the results of two or more possible solutions are close to each other.

COST-EFFECTIVENESS OF MODELS

Simulation models such as NETSIM become more cost effective as use for the study of a particular problem increases. For example, the analysis of many possible solutions at an intersection (i.e., pavement widening, channelization, and signal phasing) makes the study more economical than a manual study of the same variables.

Also, it is desirable to maintain a file of the problems studied. Toronto maintains an intersection data base file and other computer input for a simulation model for the area. As conditions change, a quick analysis can be made by using the original input with the new data base input (i.e., changes in turning movements and increased volumes) to determine if modifications are needed at an intersection or along a street.

UTILIZATION NEEDS

The following five basic needs were defined by the group.

1. There is a need for providing implementation support in placing simulation models in the various makes of computers. There are several makes of computers and each make has unique features in the application of FORTRAN. Many agencies do not have qualified personnel available to implement simulation models. It was also pointed out that larger cities find it desirable to implement computer models on their own computer.
2. There is a need to enable small cities to have an opportunity to use NETSIM and other simulation models. Texas provides access by cities to its computer for timing traffic signals that are primarily on the highway system. This is carried out through the use of computer terminals located at

each of 25 district offices. Improved traffic-signal timing is being obtained with this approach. Increased utilization of computer simulation models could be attained with an approach where cities could have access to a large, central computer through the use of computer terminals located within their offices. This possibility, as well as support by the states, needs to be studied.

3. An agency needs to assign one or more full-time persons to apply the simulation and optimization models. There is also a need to consider the use of NETSIM and other models in analyzing traffic-related problems and timing traffic signals. Persons using the computer models on a regular basis can do so quickly and accurately and can be knowledgeable as to which model to apply.

4. There are limitations to the size of the NETSIM model. Problems have arisen with the limited number (1600) of vehicles that can be processed by the computer model. There is also a need to increase the number of links that can be serviced. The NETSIM model has many uses and is of suitable size for the majority of applications, but there is a need from time to time to expand the size of the model. A modular approach may be best suited for expanding the model when necessary.

5. Consideration should be given to "humanizing" the computer and making it more friendly to the user such as through the use of English language entry and graphics. This approach makes the use of the computer more inviting to the engineer and planner. It can also make it easier for the user both in the input and output analysis stages of the model use.

CONCLUSION

The NETSIM model and other computer models are consistently providing good results for the engineer who uses them properly. The results (output) obtained from these models are being accepted by administrators and the public. The increased availability and ease of use will continue to expand the application and acceptance of these models. These two factors will benefit the user and, ultimately, the public through improved operations and cost-effective use of manpower and funds.

Workshop 5: Traffic Engineers Involved in Planning and Transit Operations

(Leader, David A. Berridge; Recorder, Dallas W. Hildebrand)

This workshop identified the needs and applicability of using traffic simulation models as part of the planning process and their possible uses in analysis of transit operations. The existing uses of NETSIM in these areas, the advantages and disadvantages of using microscopic network simulation, and the need for further support in implementing and utilizing traffic simulation as part of the planning process were also explored.

Participants felt that the existing planning models--for example, UTPS--were adequate models for traditional uses. These models are limited to macroscopic analysis and are becoming inadequate to address today's needs for detailed analysis. The emphasis in the planning process has expanded to include more than just the regional planning level. These needs include windowing critical sections of the region identified by the macroscopic analysis for more detailed evaluation. The process has expanded to include the interactive process of reevaluation of system impacts based on improvements in the overloaded areas of the network. Transportation planners are becoming increasingly involved in TSM at the corridor level, which requires better assessment of MOEs for evaluation purposes. Thus, microscopic analysis has become increasingly important in the planning process.

Two basic levels of analysis currently exist. A coarse-grain analysis at the macroscopic level, which is adequately handled by the use of planning packages similar to UTPS, and more detailed level of fine-grain analysis at the microscopic level are treated with simulation models similar to NETSIM and TRANSYT. There is a gap between the existing models and their level of detail, and this gap must be filled. Two possible models currently under development have the potential to fill this gap. They are the TRAFLO package and the UROAD-MICRO package. These models are being developed and are based on the identification by users at both ends of the spectrum for the need of some type of intermediate level of analysis.

Traffic simulation models, and NETSIM in particular, are currently being used for several different types of planning and transit analyses. They include

1. TSM at the corridor level;
2. Alternatives analysis including geometric design and signal upgrading;
3. Transit operations analysis including directional flow bus lanes, contraflow bus lanes, bus-preempt signal systems, and signal progression for buses; and
4. Evaluation of pedestrian midblock signals.

NETSIM offers many advantages over existing planning models. It provides a fine-grained microscopic level of analysis that the existing planning models do not. The program also provides standard MOEs that make alternatives analysis easier for the transportation planner.

NETSIM has the capability to simulate the operation of buses. The program also takes into consideration the interaction of buses with the traffic stream and the impacts of buses on the normal traffic stream. It requires an extensive amount of information about the operation of the buses. This bus information is easily entered into any existing network that has been previously coded for normal simulation. Bus routes are easily altered; therefore, it makes NETSIM an ideal tool for evaluation of bus route alternatives.

NETSIM also offers advantages over TRANSYT. These advantages include the ability to model the build-up and dissipation of queues in the traffic stream, the ability to model system degradation at or near capacity, and the ability to integrate buses with the normal traffic stream. These advantages are not without associated costs. These costs are far more extensive computer requirements. However, when one evaluates the costs of the computer time with the cost of implementing a proposal that is not an optimal solution, the benefits outweigh the costs.

When NETSIM is compared with existing planning models, there are several disadvantages that must be noted. NETSIM requires more extensive data than traditional planning models. This requires additional effort in data gathering at the planning level and also has the potential to make existing planning networks obsolete because there is no existing interface with the traditional planning models. Today's budget limitations make further data acquisition and network conversions difficult. The current output capabilities for NETSIM are limited. The ability to segment certain portions of the network for comparative analysis is impossible. In large networks this feature would be valuable to evaluate subsystem changes independent of the entire network.

There are several requirements to be met before a program such as NETSIM could be used on a regular basis. The major problem is the nontransferability of the model to many existing computer systems. Every program of this magnitude would require some minor modifications due to the differences in computer systems. However, because the program is currently written for one specific machine, the modification process is more extensive. Transferability becomes far more difficult with certain computer systems. Any time a program such as NETSIM is used, it requires extensive training. Some level of training should be provided at the national or local level to expose practitioners to the capabilities and applicability of the program.

A program such as this requires that the users have some method of communication. It is invaluable for users to trade information and analysis techniques. Some type of newsletter should be established for this purpose. Responsibility for coordinating such a newsletter should probably lie at the national level, either with FHWA or the Institute of Transportation Engineers. In addition to supporting a newsletter, someone must also be responsible for maintaining, updating, and debugging the program. This work could be done by FHWA.

If NETSIM is to be used in the planning process, some type of interface must be developed between the planning model at the regional level and the microscopic analysis performed by NETSIM. This would require the ability of NETSIM to be segmented for use with larger networks. The planners also require enhanced outputs for evaluation purposes. These enhancements include graphic output displays for use by the policymaker, for public presentation, and for the practitioner to better understand the network performance.

This workshop recommended increased support of NETSIM at the national level and formation of a users group to allow for exchange of ideas, problems, and solutions. FHWA is encouraged to complete and implement the TRAF package because this program has the capability to span the gap between microscopic analysis and macroscopic analysis. An interface should be developed between UTPS and the TRAF package to provide for sequential analysis. This would help minimize time and staff requirements needed to code separate networks for different levels of analysis.

Workshop Sessions—II: Technical Issues in Simulation Modeling and Application

Workshop 6: User Training

(Leader, Ann Muzyka; Recorder, David A. Berridge)

This workshop served as a forum for the design of a user training program in the application of traffic simulation models. These models were developed by FHWA for use by the community of transportation analysts. The objective of the meeting was to produce the best program for implementing this technology transfer. The participants included state and city transportation officials, university researchers, and consultants with extensive experience both in using and in training others to use the NETSIM model.

Many technology-transfer programs have been completed and have not achieved the results expected. Therefore, the workshop plan was to examine the nature of these training courses and to identify the elements responsible for their failure. It was agreed that the usual two- or three-day course of in-depth lectures that attempt to exhaust the subject merely exhaust the audience. The conclusion was that the requirements for a successful training program include active participation in a hands-on laboratory course, a strong local user network for mutual assistance and to combat any feeling of isolation, and sufficient time to assimilate the basic ideas and to apply them to meaningful local problems.

Concern was expressed about the cost of an extended training program. The budget for model implementation must be adequate to achieve reasonable goals and thus justify the cost of model development. A short course of comprehensive lectures in the use of so complex a model might discourage its use and adversely impact the credibility of the government. It was observed that the commitment of local management to provide the time and resources needed to make the model operational is of prime importance. For this reason, a brief training course for local decision makers is recommended. The model will be installed and used if managers are convinced that it will make their decision process easier.

USER TYPES AND SPECIAL NEEDS

The local decision makers are the ultimate users--the implementors of the model output. They include traffic commissioners, mayors, regional planners, state transportation heads, and transit officials. They need to know that the model can help them make decisions in choosing among transportation alternatives by using a rational, quantitative approach. They also need to know the level of effort required to make the model operational in-house and the time needed to produce valid results. This training must be brief, graphic, credible, and specific with respect to the strategies that can be evaluated.

The strategy developers are the actual users of the model for the analysis and evaluation. They include traffic engineers, transit operations managers, planners, and researchers. They need to know how to calibrate the model to their field sites, how to generate appropriate strategies, how to analyze results, and how to estimate simulation costs and identify resources required. In addition, if they are to be producers of the model output, they must have basic computer application skills. They will need to know computer requirements, model execution, and debugging procedures. This training must be comprehensive and practical.

TRAINING PRINCIPLES

The ordinary training course requires no preparation before attendance. It consists of many consecutive hours of in-depth lectures and many take-home documents. The audience is passive because there is no time to absorb the basic ideas and thus to formulate questions. The lecturers, usually highly qualified leaders in the field, are transmitting in high fidelity but the receivers are soon saturated and stunned. The result is that communication is never really established.

On returning home, the would-be user of this training is overwhelmed by the sheer volume of literature. Since no guidance is available for designing and implementing a plan to apply the technology to local problems, the natural reaction is to report to management that the course was interesting but not really very useful. In addition, there is often no commitment to use the technology on a local project and thus not much motivation to learn it.

In order to correct these deficiencies and provide a truly effective course, the following principles are offered.

Active Participation

Active participation is achieved by requiring prior preparation to a hands-on laboratory course. Brief lectures can be included to set up the experiments. Preparation for the laboratory sessions could consist of understanding the fundamental capability of the model and its field data requirements, identifying a set of appropriate local projects for model analysis, and receiving commitment from the local decision makers that the model will be used for alternatives evaluations. In the laboratory sessions, the users cooperate in teams while applying the model to specific problems.

User Network

An active local-user network is essential to the learning experience. A course given in a region to a set of users, who meet regularly to discuss technical issues, is an efficient and cost-effective combination of formal training and self-help. The interaction of peers accelerates the training process by providing support and a means of quickly solving the easier problems. The experts are also part of the network and address the difficult problems during site visits or by mail or telephone.

Structured Course

The course must have a well-defined structure. The set of laboratory projects must be graduated in difficulty. The initial projects should be simple enough to complete quickly in order to establish confidence and provide an overview. The final projects must exercise some of the model's more difficult features. Controls are needed to keep the learning process on course. The projects should have realistic schedules, milestones, and deliverables.

Meaningful Projects

A variety of standard test cases will be provided for the initial projects. After understanding the procedure, each user will design projects that are relevant to the local site and use actual field data. The course will emphasize the importance of maintaining contact with reality by constantly checking simulated traffic patterns against field observations.

Sufficient Duration

The user must have sufficient time to digest the training provided. A six-month period can be divided into three comprehensive preparation periods, separated by laboratory sessions and analysis tutorials, and culminating in a final presentation of project results.

The first preparation period of one month could consist of the study of a set of documents describing the range of application of the model, the design of networks, and the calibration of the model to a field site. The user performs this activity at home as preparation for the first laboratory session but has access to an expert by telephone. The first meeting of the group is a two-day laboratory session and takes place at a computer facility where prepared problems, i.e., exercises for the student, are solved. This session can also complete the course for those who do not need a thorough understanding of the model.

The next preparation period lasts three months, during which the users work on local site projects, collecting data and analyzing the results. At this time, they meet regularly with each other and also receive guidance from the experts through site visits and by telephone. This period is followed by another two-day laboratory session at a computer facility. The more difficult aspects of the model are studied then.

The last preparation period of two months is used to complete projects and prepare reports. The final meeting of one day is for the presentation of reports. At this meeting, local management is invited to see the wide range of local applications of the model and FHWA has the opportunity to learn of desired model extensions or revisions.

TRAINING MATERIALS

Training materials are different for each of the user types. They include films, slides, minitexts, and a detailed operator's manual. Films and slides are used to present a broad overview of the model's capability and cost to use. These are intended primarily for decision makers and should be brief and to the point. The documents consist of a set of minitexts and a comprehensive user's manual. The set of minitexts is provided for ease of use and to avoid intimidation at the outset. The first volume is an executive summary, which supplies the broad overview; it is all the decision maker will read but is also a good starting point for the strategy developer. Other volumes include model calibration, output analysis, case studies, bus priority analysis, traffic-actuated signals, energy, and pollution analysis. A comprehensive user's manual is needed that contains operating procedures, input preparation, flow charts, error messages, and test cases. This manual is to be used as a reference; it is not a learning tool anymore than is an unabridged dictionary, which it resembles in size and dryness. The use of a computer and a computer operator must be available at the site of the laboratory course.

LOCATION

Training takes place primarily in local areas but is coordinated from the central office in Washington, D.C. Laboratory sessions should be held in local areas to serve a set of users and to use the computer facility available there. This is done to encourage the formation of local-user networks for long-term cooperation and because these users often do not have out-of-state travel funds. In addition, the overview and final project presentations are made at local sites for the same reasons.

The central office in Washington, D.C., coordinates the training program and provides user technical support. A hotline is needed to solve problems that are beyond the capability of the local-user networks. The central office could maintain a national newsletter for users. This publication can contain corrections and extensions to the model, as well as descriptions of local projects. It is difficult to get users to submit articles but two incentives could be tried. A simple form could be supplied on which project information is written in short phrases. The cost of the annual subscription to the monthly newsletter could be one article.

COSTS AND BENEFITS

Although the training course extends over a six-month period, almost all of this time is spent in self-study by users at home. The costs to FHWA include preparation of the training materials, supervision of two laboratory sessions of two days' duration each and the final project presentation meeting, maintenance of a hotline, and travel to local sites by experts for project guidance. In addition, overview presentations of less than two hours' duration are needed for local decision makers. These should be charged to promotion. It was discussed in this workshop because of its overriding importance in obtaining the commitment needed to make the strategy developer's training viable.

The benefits to FHWA include the correct use of NETSIM by masters of the tool. The government is perceived as the developer and provider of a highly useful product. The community of users will disseminate new ways of using the model through their networks and serve as experts for the next generation of users. The cost of developing such a powerful model will be justified.

Workshop 7: Traffic Flow Theory and Modeling Considerations

(Leader, Carroll J. Messer; Recorder, William R. McShane)

The discussion of the workshop participants centered on a critique of the NETSIM traffic simulation model, considering its treatment of traffic flow phenomena and the resulting experimental design and evaluation requirements. A recommended set of NETSIM enhancements or user application needs was the desired output of this workshop. A total of 11 professionals actively participated in the discussion. The composition of the group included five consultants and six traffic simulation modelers with various areas of interest and experience. FHWA representatives with intimate knowledge of NETSIM were active members of the workshop.

The group concluded that NETSIM offered the user many positive features. Those positive aspects included a detailed traffic model evaluation, a bus route operational evaluation, a wide range of problem applications, extensive MOEs, the capability to evaluate unequal cycle times, and simulation of traffic-actuated signals.

THEORETICAL CONSIDERATIONS

Perhaps due to the composition of the group, theoretical considerations of traffic flow modeling tended to focus on calibration information for several of the basic traffic flow variables. The simulated behavior of queue formation and discharge at traffic signals was reviewed. Values for queue discharge lost times were questioned as to their validity. Concern was similarly expressed regarding the acceleration-versus-speed relationships included in the "new" NETSIM model to be used in FHWA's TRAF 1.5. The appropriate shape of the acceleration-speed curve at low initial speeds was discussed with reference to work being done at the Midwest Research Institute. The important linkage of queue discharge modeling with vehicle acceleration from the intersection's stop line was noted. It is critical that the lead vehicle should reach its desired link speed at the desired elapsed time since start of green and at the desired travel distance.

Considering experimental design, topical questions were those of determining the number of runs needed for statistical accuracy, how long should each run be, and what variables significantly impact computer run time. It was noted that the variance of most traffic-related variables significantly increases as the volume-to-capacity ratio approaches 1.0. This characteristic tends to make the identification of lack of fit between field data and simulation model results more difficult to detect at high volume levels.

In the same vein, the question arose as to whether a simulation model should attempt to replicate the variability observed in the real world or whether one should attempt to develop and implement techniques for reducing the variability of the process so that the output results would more likely estimate the mean value of the process. Clearly, the direction is now to replicate the real world, gaining realism and credibility by the latter avenue rather than the former.

It was noted that FHWA has a research contract planned in the near term to identify the statistical nature of NETSIM's outputs as related to a taxonomy of network and traffic characteristics. User guidelines for developing cost-effective experimental designs are envisioned, including sample size requirements and run time estimates. For the present, run times were noted to be more strongly related to the total number of vehicles being simulated for a given computer system than to any other traffic or network topology feature. As a rule of thumb, a network containing 600 vehicles would take approximately 1 s of CPU on an IBM 360 to simulate 1 s of real time, 1200 vehicles would take 2 s of CPU, etc. Realistic checks on other machines also exist. The figures cited are based on experience at the FHWA facility.

PERCEIVED USER NEEDS

The following is a summary of the recommendations developed by the workshop participants regarding their perception of desirable NETSIM enhancements or design features.

1. Modeling of a more sophisticated traffic-actuated control should be given the highest priority. An FHWA-sponsored project to provide this desired capability is under way.
2. Fuel consumption and emission rates for new cars under actual traffic conditions should be developed. FHWA is understood to be supporting an effort to conduct the necessary testing at the Oak Ridge National Laboratory in Tennessee.
3. Program logic and traffic modeling are not well documented and are outdated. Resources should be provided to support a new documentation effort to existing standards, and a commitment to annually update the documentation should be made as long as FHWA supports the NETSIM model.
4. An experimental design guide should be prepared to assist the user in establishing the scale of the appropriate evaluation plan.
5. FHWA should consider the option of creating, from the basic recommended NETSIM model, a model designed specifically for the evaluation of urban arterial streets with fixed-time or actuated control.
6. The inclusion of a traffic assignment model in NETSIM, particularly with operator bypass, is not recommended at this time.

Workshop 8: Data Collection and Preparation

(Leader, David B. Richardson; Recorder, Les Kelman)

The essential purpose of this workshop was to identify the major requirements and scope of effort required to collect and assemble data for input to NETSIM and other simulation or optimization models. Although there are several areas of possible discussion associated with these tasks, the workshop itself focused on three specific topics for detailed examination and comment: (a) identification of data requirements, (b) the data-collection process, and (c) program coding and validation.

It is a well-known fact that the results obtained from any model are only as good as the data provided for program execution. The "garbage-in-garbage-out" adage holds true for NETSIM, as well as any other comparable model. The emphasis in this workshop, however, was to determine the level of data accuracy necessary for successful program execution, recognizing the staff and budget constraints under which most jurisdictions must operate. If this underlying theme could be adequately addressed, programs such as NETSIM could be placed within reach of the practical user. As stated in the user guide, "the effective use of NETSIM is totally dependent on the quality of input data". A clarification of this statement in quantitative terms would be beneficial to both the current and potential user community.

IDENTIFICATION OF DATA REQUIREMENTS

The data requirements for NETSIM are greater than those for the more frequently used optimization models such as TRANSYT or SIGOP. The payoff, however, is that the output is more representative of real conditions. Unfortunately, the extensive data requirements tend to reduce the attractiveness of NETSIM to potential users. The workshop participants identified certain areas in which clarifications and/or modifications would result in NETSIM's perception as a practical tool for traffic engineers and not just as a model that is used for research purposes.

1. Do all data parameters have equal importance? An appreciation of the relative importance of the input parameters would ensure that the appropriate level of effort was expended in the different areas of data collection. For example, are accurate traffic volumes of greater, equal, or lesser importance than target speeds? A ranking of data inputs would assist NETSIM users in minimizing the data-collection effort with only a marginal reduction in the accuracy of the results.
2. How sensitive is the model to the absolute accuracy of the data on which it is based? It would be useful to know, for example, if the model is sensitive to a 5, 10, or 15 percent change in bus dwell times. An appreciation of the sensitivity of the model to the various input parameters would be beneficial in establishing the sample size, confidence limits, and general statistical significance of the data to be collected.
3. Is it necessary to collect all the data? It was recommended that a range of parameters be provided in the user's manual for different types of locations, traffic flows, operating characteristics, etc., that could reduce the data requirements for any agency wishing to use a short-cut method. The question could be asked, of course, Would use of a short-cut NETSIM model produce a more representative simulation than use of the evaluation routine in the TRANSYT model?

DATA-COLLECTION PROCESS

The process of data collection requires a full appreciation of the actual data requirements to establish a cost-effective collection program. The three major subareas that are identified here are planning, equipment, and manpower.

Comprehensive planning is the key to successful data collection. The user must know his or her needs, recognize what the data are to be used for, and how they are to be coded into the model. Of considerable importance is the bias associated with the collection activity. For example, the daily, weekly, and seasonal variations in traffic volumes can have a significant impact when comparisons are drawn between expected and actual results.

There are three sources of data available for the program user: (a) internal--that which are already on file with the agency; (b) external--that which are available from other sources such as data from a transit authority; and (c) data that must be collected for the specific purpose of running the model. A complete review should be carried out to establish all data available from sources (a) and (b) prior to designing the new data-collection program.

The use of automated techniques in the data-collection process has not, in fact, reached the same level of sophistication as the models themselves. This area is probably the weak link in the chain and possesses much potential for achieving a reduction in the overall data-collection effort. There is also an additional bonus with respect to the reliability of the data collected. The following techniques were proposed as candidates for consideration:

1. Volume counts from detectors;
2. Photologging for both operational characteristics of the traffic and the physical characteristics of the network;
3. Aerial photography for a multiplicity of data;
4. Street-level photography for parking characteristics and network data;
5. Microcomputers, such as that proposed by Glazer and Courington for performing "floating-car" or "speed and delay" traffic flow studies;
6. The Traffic Engineering Logger, as developed by the South African National Institute for Transport and Road Research, to establish traffic-stream characteristics; and
7. A portable event recorder, as developed by the University of Strathclyde, Scotland, for gathering information about vehicle speeds, journey times, and fuel consumed.

It was postulated that experience with these techniques and/or equipment is available within the traffic engineering community, but tends to remain undocumented. Information exchange on automated data-collection methods could encourage the increased use of these techniques and result in improved methods being developed.

The availability of manpower (or lack of it) is often a key factor in an agency's decision to use NETSIM. The use of permanent staff as opposed to the use of temporary staff raised the issues of cost, reliability, practicality, and the level of supervision required. Concurrent-versus-staged data collection was also noted. Concurrent collection may require a "cast of thousands", depending on the network size, whereas staged collection requires validation and manipulation to transform all elements to a common base. The cost-effectiveness of using automated techniques as opposed to labor-intensive techniques must also be considered, along with simplifying the field work (and thereby enabling most, if not all, of the data reduction to be carried out in an office environment) and the use of the available software packages to reduce, analyze, and validate the collected data.

PROGRAM CODING AND VALIDATION

In models, such as NETSIM, the coding procedure is laborious and yet requires accurate work together with a certain degree of interpretive skill to reduce traffic and network characteristics to finite numbers. Accurate, representative coding requires good engineering judgment. To reduce staff costs and to effectively use available staff, however, there is a strong tendency to automate the coding by reducing it to a series of simple steps. In assigning the coding task, consideration must be given to achieving a balance between quality and cost.

The inclusion of the diagnostic checking routines was viewed as an extremely positive feature as was the development of the preprocessor module that may be used to diagnose errors in the input stream and may be run as a separate program. Expansion of the preprocessor module to check for reasonable parameter boundary levels could reduce the amount of manual checking during the coding procedure. For example, the program could flag any saturation flow value less than 1200 or greater than 1800 vehicles per hour-green. In addition, it was suggested that the preprocessor module be adapted for running a coding check on smaller, more readily available computers, thus making it more accessible to the smaller jurisdictions. This stand-alone preprocessor module would not only facilitate the coding and validation procedures, but also could be used as a learning tool to familiarize new users with coding intricacies.

Incorporation of the results of the previously mentioned sensitivity analyses into the user's manual would also provide much-appreciated assistance in the coding procedure. A what-if guide for the different parameters would give a useful indication to a coder of the implications of a coding decision. A user information exchange would result in expanded guidelines and reduce the quantity of original work required by new users to become adequately familiar with the program.

CONCLUSIONS

The workshop participants concluded that

1. There is a need for the NETSIM User's Guide to include guidance with respect to the relative importance of the different input parameters, the sensitivity of the model to the absolute accuracy of the various input parameters, and a range of global parameters.
2. Comprehensive planning is the key to reliable and accurate data collection.
3. The use of automated techniques could reduce the overall effort required for data collection.
4. The availability of manpower (or lack of it) is often a key factor in an agency's decision to use NETSIM.
5. A stand-alone preprocessor module that could be run on smaller computers would have many benefits.
6. The preprocessor module should be expanded to check for reasonable parameter boundary levels.
7. There is no substitute for engineering judgment in the coding procedure.
8. There is an important role for FHWA to play in the dissemination of user experience with NETSIM, particularly in the areas of data-collection techniques, global data inputs, sensitivity analyses, and improved coding procedures.

Workshop 9: Computer Resources, Maintenance, and Support

(Leader, George Tiller; Recorder, Alexander Ugge)

The following consensus on critical issues related to computer resources, maintenance, and support was reached.

COMPUTER RESOURCES

Needed computer resources are generally available, but sometimes expensive. The cost factor becomes important as use of computer programs increases. Computer resources should be distributed rather than centralized. The idea of having all models reside on a federal computer, accessed by users through terminals, was not supported. Citations were made of bad experiences with centralized computer services. Models should reside on many systems under local control. The possibility of a combination approach exists, i.e., a facility available to those who do not want to go into models but just want answers in the easiest possible way.

The ideal situation viewed was based on a terminal/microprocessor connected to a larger system in a state, etc., and possibly networked with other similar systems. Also, large central mainframes to provide the best combination of responsiveness, local control, number-crunching power, and communication are possibilities.

The federal government, it was felt, should not reserve the right to modify the source code of programs. There is unhappiness with the UTPS approach of distributing only machine language so no changes can be made. More trust in the end user having some sense and knowing what to do was urged. Users should also be viewed as a resource, able to provide assistance in many cases to help get the job done and provide support for various aspects of the research and development program. Recognize, however, that the federal government cannot be asked to provide support for user-modified code.

MAINTENANCE AND SUPPORT

The following conclusions were reached:

1. Primary role of the federal government is the collection and distribution of information about simulation models--i.e., a "clearinghouse" function to serve states and others.
2. There should be less decision-making authority resting in federal government; correspondingly, there should be less responsibility for the quality and the reliability of computer programs.
3. With controlling decisions made by states and other users in concert, the federal government should (a) maintain up-to-date computer codes, data, and documentation for all models and distribute these on request, subject to criteria of a controlling body; (b) provide notices to users of bugs discovered, fixes installed, enhancements, new generations, etc., through a newsletter or other means; (c) provide hotline-type assistance to users with problems (there is a need to keep all models operational on the federal system and have expert personnel available); (d) provide training as requested by the controlling body; and (e) provide management and coordination of maintenance and support activities, whether provided by the federal government, a federal contractor, states, universities, or other users.

Suppose, for example, that a new version of a popular program needs thorough testing (as agreed to by states and other users), but FHWA upper management decides not to budget money for this effort, causing a delay in the useful implementation of the model. The responsible manager uses his or her automated distribution system (part of the clearinghouse service) to send letters to 50 state departments of transportation informing them of this decision and inviting responses. Many states and others with strong feelings on needs for the model write to FHWA. The manager now has powerful support for the position to spend money on testing.

ANCILLARY ISSUES

Other concerns expressed by the participants in this workshop focused on the following ancillary issues:

1. Naming of programs should be improved.
2. Text or handbook (tutorial) on general principles of simulation and optimization is needed.
3. Selective output should be provided on all models.
4. Some standardization is needed--a minimum set of common parameters (using common terminology) that every simulation or optimization program provides. Standards should include file structure, formats, etc., so that a graphics program, for instance, could be applied to these parameters to generate a broadly understood visual representation of model performance.
5. Carrying this standardization concept a step

further, a generalized simulation and optimization data base structure to support the interaction of independent models should be developed.

Workshop 10: Promotion and Implementation

(Leader, Ryerson Case; Recorder, N. Barr)

The subject of this workshop was the promotion and implementation of traffic simulation models for application by the traffic engineering community. The purpose of the workshop was to determine why such models are not used more extensively by traffic engineers at the working level and to propose actions that would improve the promotional and implementation processes. There were seven participants, representing federal, state (provincial), and city governments. The consultant community was not represented.

Discussion focused initially on the present promotion and implementation process as it exists in the United States and Canada. This is essentially a top-down process in which the central agency is the developer and distributor of simulation programs, and lower levels of government and the consulting community are the users. In contrast to the United States, where the central agency is the federal government, Canadian provinces receive no federal support in this area and are each responsible for their own promotion and implementation, a situation that tends to lead to wide disparities in their quality of traffic engineering at the local level in some provinces. In Ontario, the research and development branch of the transportation agency disseminates programs virtually on a person-to-person basis, which is a time-consuming, though effective, process.

At one time, FHWA also carried out implementation on a personal basis by research staff, but this proved impractical and implementation was often given a low priority. With the creation of FHWA's Implementation Division, research results are now systematically translated into practical implementation packages. They are routinely distributed to the regions, divisions, and the states with extra distribution to other agencies and organizations. FHWA tries to work through a lead agency (usually a state) for distribution to users at lower levels of government. A wide array of material is available, including a brochure announcing the availability of documents (manuals, specifications, etc.) as well as program tapes. Pilot-city (minimum of three) evaluations are carried out before release of the programs.

WHY SIMULATION PROGRAMS ARE NOT BEING USED

Although there have been some examples of local agencies taking excellent advantage of the FHWA-sponsored programs, there is evidence that the implementation packages are generally not getting down to the local level. In identifying the reasons for this, we divided the problems into those that are primarily at the federal level and those that are primarily at the local level.

Federal Level

1. Inadequate internal promotion--This is evidenced by weakening support for some programs, due in part to the fact that staff is mainly technically, rather than public-relations, oriented.
2. Credibility problems--Lack of resources for software and other support adversely affects confidence of users in simulation programs and simulation in general.
3. Poor support at field level--Field staff is construction oriented and is not knowledgeable in the simulation area.
4. Difficulty in establishing lead agencies--Rural orientation of most state departments of transportation creates a communication problem resulting generally in poor support at the state level. FHWA packages are not getting down to the local level. The Urban Mass Transportation Administration, which works directly with the cities, is more effective in this respect.
5. Lack of user feedback--One of the main federal concerns is in the area of user feedback, which is essential to make the agencies more responsive to local needs.

State and Local Level

1. Lack of state support--Only a few state departments of transportation are willing to undertake a lead-agency role in their state. Small cities, which need strong local encouragement and support, suffer.
2. Lack of resources--Many states, counties, and cities lack the qualified staff and fiscal resources to effectively use simulation programs. They also lack executive-level promotional material necessary to sell their management on supporting simulation as a valuable traffic engineering tool.
3. Lack of understanding--There is a general lack of understanding of the role and benefits of simulation in traffic engineering practice at all levels. They are not getting the message. The rural orientation of most state departments of transportation contributes to the problem as well as the lack of traffic engineering representation in the metropolitan planning organizations.
4. Ignorance of FHWA resources--Despite the many publications widely distributed by FHWA, many local agencies and potential users are uncertain as to what support is available and whom to contact.
5. Poor communications between local user groups--Effectiveness could be significantly enhanced by interaction between various local user groups.

RECOMMENDATIONS

Federal Level

1. Improved promotional material is required at two levels to give a better understanding of the role of simulation in traffic engineering: (a) executive level--a simply written brochure outlining the benefits and costs (staff, computer, etc.) of simulation could be very useful in gaining support from management (this has been successfully done in other areas, such as the NCHRP-sponsored brochure on Freeway Corridor Traffic Management); and (b) technical level--more material is required to convince potential users of the benefits of simulation (these could include additional information on simulation and its role in traffic engineering; user experiences, case studies, etc.; types and availability of simulation programs; and availability of support; the upcoming traffic simulation handbook will be very useful provided it is sufficiently comprehensive);
2. Increased commitment to program maintenance and support--an essential service to encourage use of simulation programs;

3. Internal promotion--emphasis on improving internal promotion of FHWA programs;
4. FHWA organization information--additional effort should be made to disseminate FHWA organization charts and the names and phone numbers of individuals who should be contacted for information or for obtaining implementation packages; routine distribution at all technical meetings, seminars, etc., of such information would be very useful;
5. Increased emphasis on establishing lead agencies--may be state, county, city, or even university; encourage locals to be more involved in the testing and validation of programs; and
6. Encourage formation of user groups--particularly under the auspices of professional organizations.

State and Local Level

1. Lead agency role--states should undertake lead agency role and give strong support to the federal program; they should devote the necessary resources to promote and distribute simulation programs locally;
2. Improved user feedback--local needs and problems are essential feedback to guide the federal program and, indeed, to support it;
3. Increased participation in program evaluations--FHWA would like more locals to be involved in testing and validation of program and to hold training courses, etc.; FHWA needs "friendly locals" to show user interest that helps in justifying program development; and
4. Formation of user groups--lead agency should strongly encourage formation of statewide user groups.

Workshop 11: User Interface

(Leader, Amir Eiger; Recorder, Duncan Allen)

The purpose of this workshop was to define and conceptualize various capabilities that would ease user interface with traffic simulation programs. The focus of the discussion was on those additional capabilities that would facilitate the implementation of various models by (a) reducing the costs associated with input coding and (b) providing comprehensive, yet easily interpretable, outputs.

The discussion addressed topics in the following three areas: front-end software, data management, and output processing. There was unanimous agreement that the existing input data preparation, coding, and debugging processes in traffic simulation programs are some of the major stumbling blocks for implementation. Two alternatives were discussed--the development of front-end software to permit input stream specification via a remote terminal (as in Michigan) and input specifications by using interactive computer graphics. It was felt that in the short term the Michigan system would be easier to implement, although some questions were raised as to its portability given the computer system for which it was developed. With respect to the development of front-end graphic preprocessors, the importance of maintaining stability of input formatting requirements as programs are updated was stressed. This is in view of the fact that input format changes can force changes in the graphic software. Discussion then ensued about the need for data management to facilitate input data changes and output processing and in that light all three items are related.

Graphic output processing can facilitate the interpretation of the outputs of the simulation. Various output display options were discussed:

1. Graphics for alternatives analysis;
2. Two-dimensional network drawing with link MOE displays (if we have color) or three-dimensional displays, which would function as screening models to identify critical links or sections;
3. Animated displays for analysis of problem locations, e.g., inefficient signal timing, turn pockets, and channelization; and
4. Time-space diagrams to evaluate progressions.

The basic notion of output processing is to provide the user with more information than is made available through the present outputs.

In addition to software enhancements on both front and back ends of the simulation programs, some discussion was conducted on potential systems. The suggestion was made that the pre- and post-processors on microcomputers can be locally operated with the simulators running in the mainframes. Some reservations were expressed about the portability of the software developed in such an environment.

There is an urgent need for software development to facilitate input and output processing. To facilitate implementation, the input side should be attacked first. To increase the usefulness of the simulation model as an analysis tool, the output end should be enhanced. In either case, there should be a movement away from the model definitions of links.

Workshop 12: Optimization Versus Simulation

(Leader, Nathan H. Gartner; Recorder, Sam Yagar)

The main objectives of this workshop on optimization versus simulation were (a) to identify the complementary roles of simulation and optimization models within the context of traffic systems analysis, (b) to discuss issues emanating from a broad range of practical applications of the models, and (c) to provide recommendations concerning their use and future development.

FRAMEWORK FOR ANALYSIS

The objective of analysis is to provide optimal (or at least improved) solutions to problems arising in real life. Optimal decision making in, and modeling of, traffic systems follows the same basic steps used by operations analysts in a variety of engineering and management areas:

1. Structuring of the real-life situation into a mathematical (or computer) model, abstracting the essential elements so that a solution relevant to the decision maker's objective can be sought;
2. Exploring the structure of such solutions through manipulation of the model and developing systematic procedures for obtaining them;
3. Developing a solution that yields an optimal value of the system MOE or possibly comparing alternative courses of action by evaluating their MOEs.

This basic analysis and design process is illustrated in Figure 1; although the figure depicts these steps in a sequential manner, there may be considerable repetitive cycling within the process; this occurs when (a) more detailed analysis leads to

Figure 1. Basic analysis and decision process.

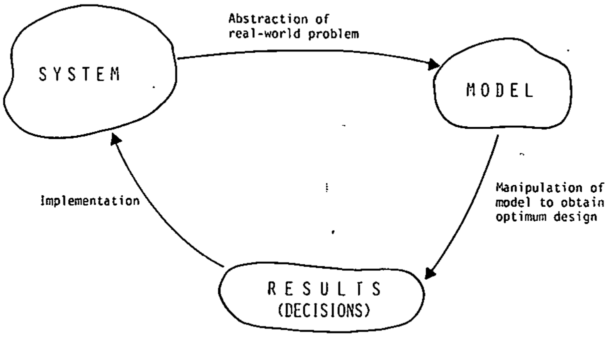
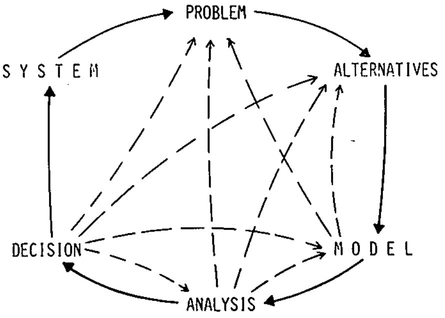


Figure 2. Iterative nature of analysis and decision process.



new insights that require a redefinition of the problem, (b) limitations on knowledge and analytical capabilities do not permit the simultaneous consideration of all aspects and implications at any one stage, or (c) newly discovered constraints (which may be technical, financial, or political) impeded the implementation of proposed solutions; thus, an interative process becomes necessary such as is shown in Figure 2.

MODEL CLASSIFICATION

Since the objective of analysis is to lead to optimal solutions, we would like, ideally, to have computer models that provide such solutions with minimum user interaction. (The notion of model is used here in its broader sense, i.e., as representing the entire analysis process and not only the abstraction of the physical system.) However, the current state of the art supplies such models only for certain limited applications. These are generally known as optimization models. In other applications, where the "best" solution is obtained through extensive user interaction with computer evaluation, the model is called a simulation model. In all cases, the basic framework shown in Figure 1 is pertinent. Given below is a very broad classification of models, listed in order of degree of computational complexity. The first three are considered optimization models; the fourth is a simulation model.

1. FORMULA. The model constructed is simple enough so that calculus can be used to derive the optimal solution. The result is a formula that directly calculates optimal values for the design variables, given the input data (example: Webster's formulas for optimal cycle time and splits.)
2. MATHEMATICAL PROGRAM. The model is complex, involving a large number of variables and constraints, yet is amenable to systematic optimization by an iterative computerized procedure without user intervention. A global optimum for the design variables is obtained (example: The MAXBAND program that provides the values of offsets, cycle time, phase sequences, and progression speeds on all links that will maximize arterial bandwidths; optimization is based on mixed-integer linear programming).
3. SEARCH PROCEDURES. Because of the increased complexity of the model, usually involving networks, a standard mathematical programming method is not applicable. Heuristic procedures are used that search for the best possible solution but cannot guarantee optimality (examples: TRANSYT, SIGOP).
4. SIMULATION. In all those cases where the analytical formulation is difficult or where too many simplifying assumptions are required to build a model that is amenable to optimization, simulation is the best and, in many cases, the only quantitative tool available. Simulation can be used to estimate values of parameters of the system with great precision (e.g., MOEs such as delays, stops, fuels consumption, etc.) and to explore transitional processes (i.e., to obtain a picture of the system moving through time). Design of an improved system is obtained by evaluating distinct alternatives specified by the user, i.e., by performing trial-and-error experiments on the model (example: NETSIM).

In general, the use of simulation is not advocated for situations where a suitable optimization model is available and can be solved without great effort. The reason is that the optimization models usually provide optimal or close-to-optimal solutions, whereas the simulated model, which is descriptive in nature rather than normative, only compares the effectiveness of various alternatives prespecified by the user.

The discussion in this workshop focused on the relative merits of using various models as experienced by the participants.

Two participants addressed the question of degree of detail of models. Lieberman classified models as atomic (e.g., TRANSYT), molecular (e.g., FREQ), compound (e.g., UTPS), and, further, large-scale models used for urban structure and land-use analysis. He felt that in many cases the analysis should be supported by a detailed simulation (e.g., NETSIM) for accurate evaluation. Yagar, on the other hand, mentioned results from a comparative study conducted on Bloor Street in Toronto. In this study there was no significant difference between the predictive capability of NETSIM (UTCS-1) and TRANSYT when compared with results of field travel-time measurements, although there is a substantial difference in the detail offered by the two models. Furthermore, a much simplified UTCS-1 network model of the arterial (containing about one half the total nodes) gave similar results (i.e., travel times) to those obtained with a full network model. Thus, microprecision is not always necessary and sometimes simulation detail can be saved in order to gain optimization capability. With a simpler model it should be possible to screen more alternatives, yet invest the same computational effort.

May discussed the philosophy and historical evolution of the FREQ model family. Originally started as a freeway operations evaluation tool, decision capabilities were later added at the request of state officials. It now comprises an integrated sequence of simulation (evaluation) and optimization models. This sequence can comprehensively evaluate (predict) and optimize operations in freeway corridors, including ramp metering, traffic signals, spatial shifts, and modal shifts.

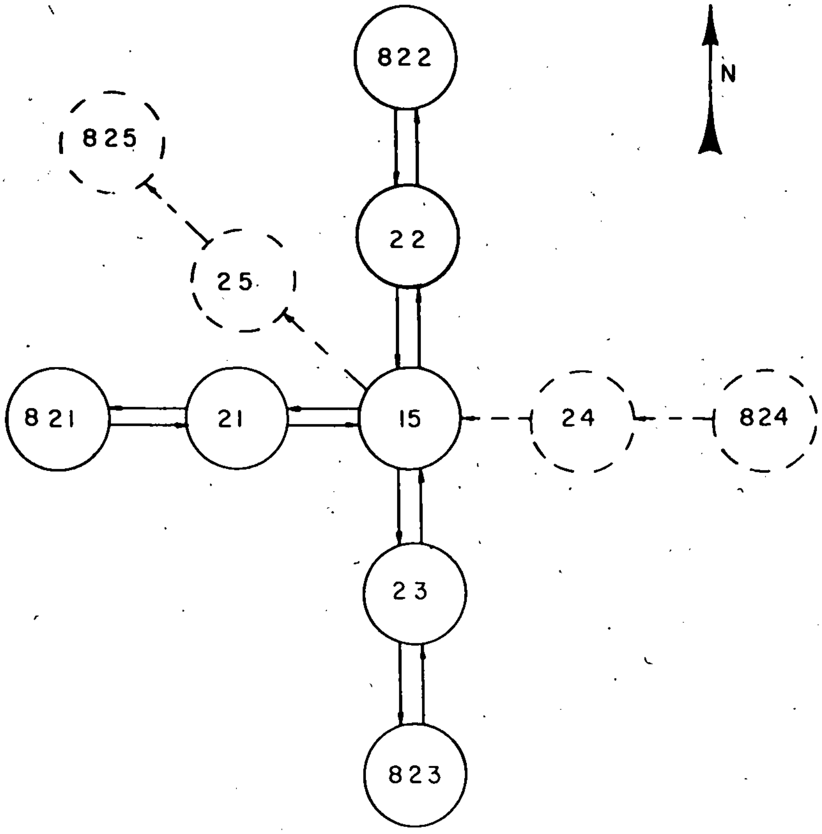
Courage addressed a number of issues relating to the proper use of models: careful selection of criteria for optimization (e.g., bandwidth versus forward-link opportunities), total accounting (volumes on all approaches to an intersection), and counterintuitive results stemming from improper use (e.g., adding a lane at an intersection may increase delay).

CONCLUSIONS

The main conclusions reached in the workshop follow:

1. Analysis models (tools) are not ideal and need to be modified in the field.
2. It is clear that models cannot be used without judgment (i.e., as a black box). Therefore, an attempt to provide a different model for each application is rather futile. There is always need for user ingenuity in the application process because the analyst becomes an essential component of the optimization-decision loop.
3. The accuracy required is related to the specific problem addressed and may vary widely from problem to problem. It is a critical aspect of the modeling stage.
4. The objective of design decisions may vary with the interest of party (e.g., developer versus city), and this may also have legal implications. All aspects need to be properly considered.
5. Traffic simulation has progressed from developmental stages to maturity to dissemination. More effort should now be spent in improving the decision (optimization) capabilities of analytical models, aided by simulation.

Part 5
Contributed Papers



Signal Timing Optimization and Evaluation: Route M-53 (Van Dyke), Macomb County

R.E. Maki and D.R. Branch

In August 1980, FHWA solicited a proposal for an advanced project entitled "Local Agencies Signal Optimization Project". This is a summary of the final project report.

The major objectives of the program were to evaluate the effectiveness of optimizing timing plans, to train local agencies in the use of TRANSYT, and to evaluate the level of effort required for, and payoff of, signal timing optimization. We subsequently entered into a contract with FHWA to optimize a 10-mile, 26-signal network on highway M-53 (Van Dyke). Revised timing was implemented through the cooperation of the Macomb County Road Commission.

The contract called for an evaluation of the cost and effectiveness of new timing plans with documentation in an evaluation report. More specifically, the Michigan Department of Transportation staff was to collect traffic and street network data, code the data and run the TRANSYT program, retime the signals in the field, fine tune the system, obtain "after" evaluation data, and prepare an evaluation report for FHWA.

The short-term goal was to optimize splits and offsets for the 80-s a.m. and p.m. dials (two offsets) and the normal 60-s dial. Flasher schedules were also adjusted. Also, the lengths of vehicular and pedestrian clearance intervals were also checked. The study section is a 10-mile length of state trunkline M-53, a major north-south arterial with average daily traffic of more than 60 000 vehicles. Peak-hour flows are directional in some areas but not consistent throughout the section, reflecting origins and destinations other than home-central business district (Detroit). There are several major factories as well as commercial establishments bordering the M-53 right-of-way affecting traffic patterns. Several major east-west county roads and I-696 further influence traffic in the Van Dyke corridor.

M-53 retains a constant seven-lane cross section (two-way left-turn lane) from Eight Mile to Fifteen Mile Road with right-turn lanes at some intersections. Further north, the through approach laneage varies from two to three lanes. The side street approaches vary widely from one lane in some areas to as many as four in others. Speed limits increase from 35 mph in the southern end to 45 mph in the north.

While the basic trunkline cross section is fairly constant, many special geometric features have been implemented to facilitate turning traffic. These include "New Jersey left-turn lanes", directional crossovers, at-grade loops, and free flow ramps. Since most of these movements have little effect on the signalized portion of the intersection, we have not tried to simulate them but have eliminated them from the study, adjusting volumes accordingly. The network simulated is simpler than that in the field, but we feel that little reliability is lost.

Though we were treating M-53 as an arterial, it is, in fact, a segment of a larger network of county roads and city streets. We were constrained by the existing cycle lengths, the time of day, and we were also concerned about significant offset changes. System hardware limitations precluded an addition of a third dial unit as part of this study.

DATA COLLECTION

In order to conduct this study and provide input to the TRANSYT 6C, 7, and NETSIM models, it was necessary to collect a large amount of data on current traffic volumes and turning movements. Manual turning movement counts and pedestrian counts were conducted at all signalized intersections on Van Dyke within the study limits during the peak eight hours.

The existing signal system is limited to two dials, including a 60-s normal dial, operating at times other than the morning and afternoon peaks, when an 80-s dial is used. Though different offsets can be used between morning and afternoon, the splits are the same. The telephone interconnect is unreliable in wet weather. Generally the controllers are in good condition. Several intersections revert to flashing mode during very-low-volume hours. Travel time data were obtained before and after the timing changes by using a "floating car" equipped with the Greenshield's Traffic Analyzer. In addition, data relating to lineage, intesection spacing, special geometrics, and signal plans were gathered. No parking is permitted within the Van Dyke right-of-way.

Three runs were made in each direction during each of three periods studied. In summary, the average travel time decreased 2 percent while stop time decreased by an average of 50 percent. The number of stops decreased 13 percent on the average. Results are given in Table 1.

SIMULATION RESULTS

The system was optimized by using TRANSYT 7 as requested in the contract. TRANSYT 6C was used to obtain fuel consumption data. We also ran the NETSIM model to evaluate the splits and offsets and to compare results. The turning movements and flow data are summarized on the link-node diagram, a portion of which is shown in Figure 1.

A caveat is in order before evaluation of output data. The network simulated was the mainline only without adjacent nontrunkline signals. In TRANSYT, side street data were measured. Fuel consumption on the side street approaches due to idling only is included in the TRANSYT data. No fuel consumption data or delay information were gathered on the side street with NETSIM. Intersections with one-sided signals were not simulated so the number of nodes was 22 rather than 26.

TRANSYT RESULTS

By using volume data for the appropriate hour, signals were optimized and evaluated for three periods: a.m. peak, p.m. peak, and off peak. Results are shown in Table 2. The data indicate savings of more than 140 000 gal of fuel per year. This is the difference between the fuel consumption with the existing signal settings and those implemented, multiplied by the hours of operation of that dial, and adjusted for traffic volumes.

The implemented settings differ from the optimized only in splits. This is because some of the splits were readjusted after manual calculations of capacity were performed by using the critical lane volume method. Compromise splits were used in some cases since the existing equipment restricts us to one split on the 80-s dial for both a.m. and p.m. periods.

Some of the results in Table 2 appear difficult to explain. Looking closely at only the a.m. peak, the delay more than doubles between optimized settings and implemented settings though the only difference is a small percentage split at a few intersections. Speed is also reduced greatly. Review of the link-by-link output not included in this report showed that almost all of the increased delay could be attributed to four side street links that were oversaturated. Yet the splits were set by critical-lane capacity analysis. This points to the importance of inputting proper saturation flow values to TRANSYT.

Table 1. Travel time and delay studies.

	P.M. Peak		A.M. Peak		Off Peak	
Item	SB	NB	SB	NB	SB	NB
Before						
Avg travel time (s)	1209.0	1371.0	1096.4	1135.6	1025.1	1133.8
Avg stop time (s)	230.9	299.4	151.4	174.5	93.4	119.3
Distance (0.01 mile)	945	977	945	977	945	977
Avg running speed[a] (mph)	34.8	32.8	36.0	36.6	36.5	34.7
Avg travel speed[b] (mph)	28.1	25.7	31.0	31.0	33.2	31.0
Avg stops/run	10.3	12.0	9.3	9.0	7.3	9.7
Avg time/stop (s)	22.42	24.95	16.28	19.39	12.79	12.30
After						
Avg travel time (s)	1167.6	1315.3	1103.9	1120.2	1025.0	1105.9
Avg stop time (s)	69.7	181.5	103.4	81.3	41.3	58.3
Distance (0.01 mile)	945	977	945	977	945	977
Avg running speed[a] (mph)	31.0	31.0	34.0	33.9	34.6	33.6
Avg travel speed[b] (mph)	29.1	26.7	30.8	31.4	33.2	31.8
Avg stops/run	8.7	11.3	5.7	7.7	6.7	7.0
Avg time/stop (s)	8.01	16.06	18.14	10.56	6.16	8.33
Change Before to After (%)						
Avg travel time	-3.42	-4.06	+0.68	-1.36	-0.01	-2.46
Avg stop time	-69.81	-39.38	-31.70	-53.41	-55.78	-51.13
Distance	0.00	0.00	0.00	0.00	0.00	0.00
Avg running speed[a]	-10.92	-5.49	-5.56	-7.38	-5.21	-3.17
Avg travel speed[b]	+3.56	+3.89	-0.65	+1.29	0.00	+2.58
Avg stops/run	-15.53	-5.83	-38.71	-14.44	-8.22	-27.84
Avg time/stop	-64.27	-35.63	+11.43	-45.54	-51.84	-32.28

Note: NB = northbound, SB = southbound.

[a] Running speed = distance x 3600/travel time - stop time.

[b] Travel speed = distance x 3600/travel time.

Figure 1. Link-node diagram of turning movements and flow data.

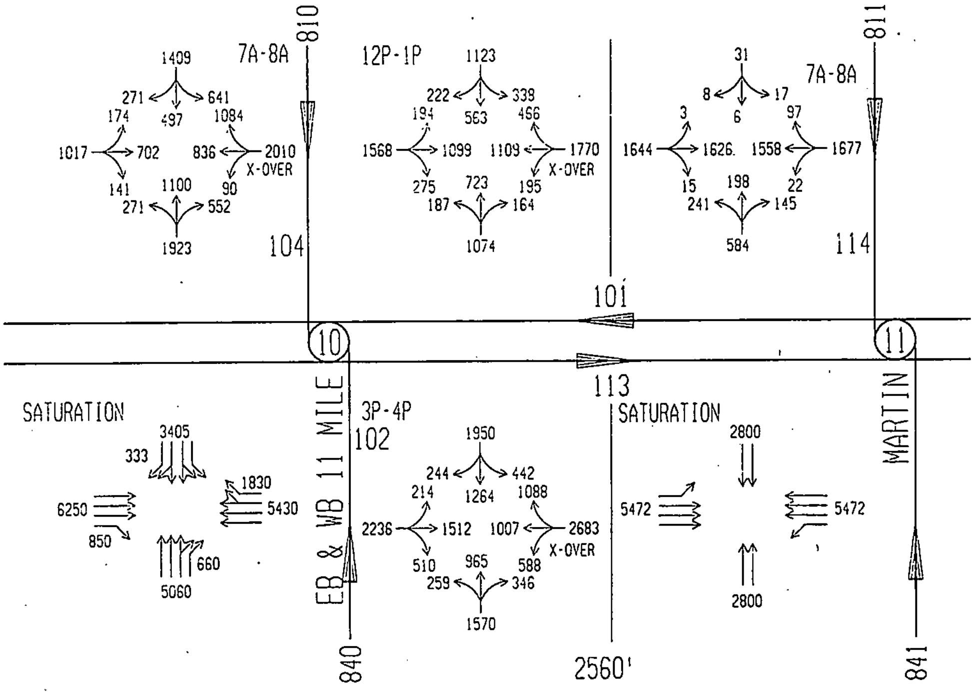


Table 2. TRANSYT optimization output.

Period	Delay (vehicle-h/h)	Gasoline (gal/h)	Hydro/carbon (kg/h)	Carbon Monoxide (kg/h)	Nitrous Oxides (kg/h)	Performance Index	Speed (mph)	Time (vehicle-h/h)
A.M. Peak								
Existing settings	627	1813	153	1647	108	627	22.1	1346
Optimized settings	320	1776	125	1319	106	320	28.6	1039
Implemented settings	717	1775	161	1728	109	717	20.7	1436
P.M. Peak								
Existing settings	906	2405	207	2227	140	906	20.9	1857
Optimized settings	578	2342	177	1887	138	578	25.4	1529
Implemented settings	892	2338	206	2207	140	892	21.1	1843
Off Peak								
Existing settings	201	1669	112	1182	98.9	201	31.5	893
Optimized settings	178	1651	110	1154	98.2	178	32.3	870
Implemented settings	181	1650	110	1160	98.5	181	32.2	873

Table 3. NETSIM simulation output.

Period	Delay (vehicle-h/h)	Gasoline (gal/h)	Hydrocarbon (g/mile)	Carbon Monoxide (g/mile)	Nitrous Oxides (g/mile)	Speed (mph)	Time (vehicle-h/h)
A.M. Peak							
Existing settings	627	2668	2.53	37.55	5.07	23.5	1495
Implemented settings	490	2562	2.36	33.97	5.04	26.0	1370
P.M. Peak							
Existing settings	607	2796	2.49	36.21	5.10	24.1	1549
Implemented settings	509	2741	2.37	33.75	5.06	26.0	1463
Off Peak							
Existing settings	268	1988	2.20	30.68	5.01	28.9	995
Implemented settings	278	1993	2.20	30.74	4.99	28.6	1005

At volumes near or exceeding saturation flows, the increases in calculated delay are large with just minor changes in split due to the nature of the delay model used. Since the side street delay is included in the network speed calculation, this value is also affected.

NETSIM RESULTS

The NETSIM evaluations (Table 3) were run to see how closely they correlated with the TRANSYT output. Traffic volumes, turning movements, splits, and offsets were the same for both.

It is interesting and perhaps coincidental that the existing delay in the a.m. peak was the same in both simulations, 627 vehicle/h. This is remarkable since NETSIM does not include side street delay. The remaining values on the chart follow the same relative changes as the TRANSYT output with a few exceptions. The off-peak implemented settings gave slightly poorer values for the measures of effectiveness than existing settings. Total fuel savings based on the NETSIM output was 93 000 gal/year. Though this value was not corrected for current vehicle fleet, the saving of 4200 gal/intersection is a close value to that used for estimating fuel savings for the 11 demonstration cities selected in the FHWA study.

COMMENTS ON TRANSYT

Detailed comments regarding the use of TRANSYT 6C and 7 will not be discussed. Version 7F, now being implemented, promises to alleviate many of the problems we have encountered in using the previous two models. Generally, we have found that the offsets given by the models appear good when shown graphically on time-space diagrams. For arterials, offsets may be obtained by simpler models or by manual computation that may be just as accurate. We chose this simple system to better understand how TRANSYT works.

The TRANSYT model is not too complex and with some training the coding is readily mastered. However, there is a need for guidelines on the effect of the various weighting factors. We ran 45 optimizations by using different weighting factors and saturation flows. TRANSYT 7F documentation should provide the necessary guidance.

Further system optimizations should require considerably less personnel and computer time. TRANSYT 7F is a much faster model and is easier to code and interpret.

RECOMMENDATIONS FOR M-53 (VAN DYKE)

In addition to optimization of splits and offsets, several other aspects of the signal system were reviewed as part of this study. These include condition of control equipment and reliability of telephone interconnect. Length of vehicular and pedestrian intervals, and flasher schedules, signal head visibility, need for pedestrian indications, and need for geometric revision were also evaluated. All of these cannot be discussed here. But some comments are appropriate concerning implemented or planned changes that will further increase capacity and safety while reducing delay, fuel consumption, and emissions.

Lack of telephone interconnect reliability has consistently been a major problem in our system's optimization reviews. We plan to replace the Van Dyke interconnect with time-base coordinators that will ensure proper offset and also allow more flexibility in timing plans. Flasher schedules at some intersections were lengthened. Yellow intervals were lengthened at several intersections. We are pursuing extended flasher operation or possible removal of two poorly spaced signals on the south end of the section.

It is safe to conclude that motorists will save at least 100 000 gal of fuel yearly on Van Dyke and more if the plans are implemented. Considering only fuel savings, the cost of this project, completed in February 1981, was returned to the taxpayers by the end of April in the same year.

System Timing Optimization and Evaluation of US-12, Detroit

R.E. Maki and J.J. Saller

This report is a summary of the analysis that led to the recent publication of the final report entitled "Michigan Avenue Traffic Flow Study" by Ross Roy, Inc., and the Traffic Safety Association of Detroit. One of the original purposes of this study was to evaluate improvements to a traffic signal system that would save fuel and travel time and reduce accidents. The study was modified to identify other energy-saving improvements. The results could be used for project selection and improvement.

The corridor selected for review consists of a 4.8-mile section of Michigan Avenue (US-12) within the city of Detroit. This portion of Michigan Avenue extends from the fringe of the central business district (CBD) at 6th Street to the city limits at Wyoming Avenue. It is a principal link in the street network and serves as an alternate route to Interstate 94. The adjacent land use is commercial-industrial.

Michigan Avenue average daily traffic (ADT) varies from approximately 20 000 vehicles near the CBD to 33 000 vehicles near Wyoming Avenue. Typical directional peak-hour volumes are about 1500 vehicles/h. See Figures 1 and 2 for directional flow by hour. The existing laneage on Michigan Avenue can adequately serve this volume. In the section from 6th Street to Livernois, seven lanes are provided including a center lane for left turns. From Livernois to Wyoming the cross section is five lanes. In addition, parking is provided on both sides with a peak-hour prohibition that theoretically should provide another travel lane for each direction. There are 64 intersections in this section of Michigan Avenue of which 25 are signalized. The posted speed limit is 35 mph.

DATA COLLECTION

In order to conduct this study and provide input to the NETSIM model, it was necessary to collect a vast amount of data relevant to current traffic on Michigan Avenue. The following briefly describes the data collection, sources, and reliability.

Traffic volumes in the form of 8-h manual turning movement counts were obtained at 16 signalized intersections. Pedestrian counts were conducted at the major intersections. Traffic estimates were prepared for those intersections where manual counts could not be taken due to staff limitations.

The existing signal system on Michigan Avenue throughout the study area is a two-dial hardwire interconnected system. The average life of the 25 intersectional controllers is 24 years, with the operating time ranging from 6 to 31. At the present time these controllers receive little or no preventive maintenance.

In addition to the equipment data, it was necessary to obtain a physical description of Michigan Avenue. These data included the distances between intersections, laneage, existing traffic signal timing plans, and parking control. The average peak-hour speeds on Michigan Avenue are 20-23 mph, and stops averaged 1.2/mile.

The speeds obtained from the NETSIM runs are weighted average speeds (bidirectional) for the entire system and are figured by total distance of travel (all vehicles) divided by total travel time. These speeds would not agree with the speeds obtained from test vehicles in the field.

NETSIM BACKGROUND

The practicing traffic engineer has long needed a problem-solving aid to evaluate the cost and benefits of alternative methods of traffic control. Simulation modeling has evolved as a tool with the advent of the high-speed computer. By approximating real-world conditions, modeling gives the engineer the ability to inexpensively choose the best alternatives before actually committing financial resources.

NETSIM is one such tool developed by FHWA for traffic engineers. The NETSIM model has been formally validated against field data. The model has been used successfully by the Michigan Department of Transportation and throughout the country for the last few years.

The first step taken in the use of the model is construction of a link-node diagram that represents the actual street network. Links are stretches of roadway-connecting nodes. They are directional and may be either entry or exit type or internal to the system under study. Nodes are points at which vehicles enter, exit, or are controlled, such as signalized intersections.

The next step is to gather the input data. These include entering counts, turning movements, road and intersection geometrics, channelization, types of control, operational signal timing desired, and detector placement if used. The network is then coded onto a 80-column FORTRAN card and the network is ready for simulation.

The NETSIM output shows the following:

1. Listing of input card deck,
2. Link and network statistics,
3. Number of stops per vehicle,
4. Stopped delay,

5. Total delay,
6. Travel time and speed,
7. Signalized cycle failure,
8. Fuel consumptions in gallons,
9. Mileage, and
10. Emissions generated (hydrocarbons, carbon monoxide, and nitrous oxide) in grams.

By controlling the variables, such as signal split, offset, laneage, etc., the effects of any change to a system are simulated and benefits are derived by comparing alternatives.

NETSIM RUNS

As with any simulation program, it is necessary to make some realistic assumptions to correspond with the specific conditions in the field. The assumptions used and the bases for those assumptions are as follows:

Figure 1. Directional flow by hour: 6th Street and Michigan Avenue.

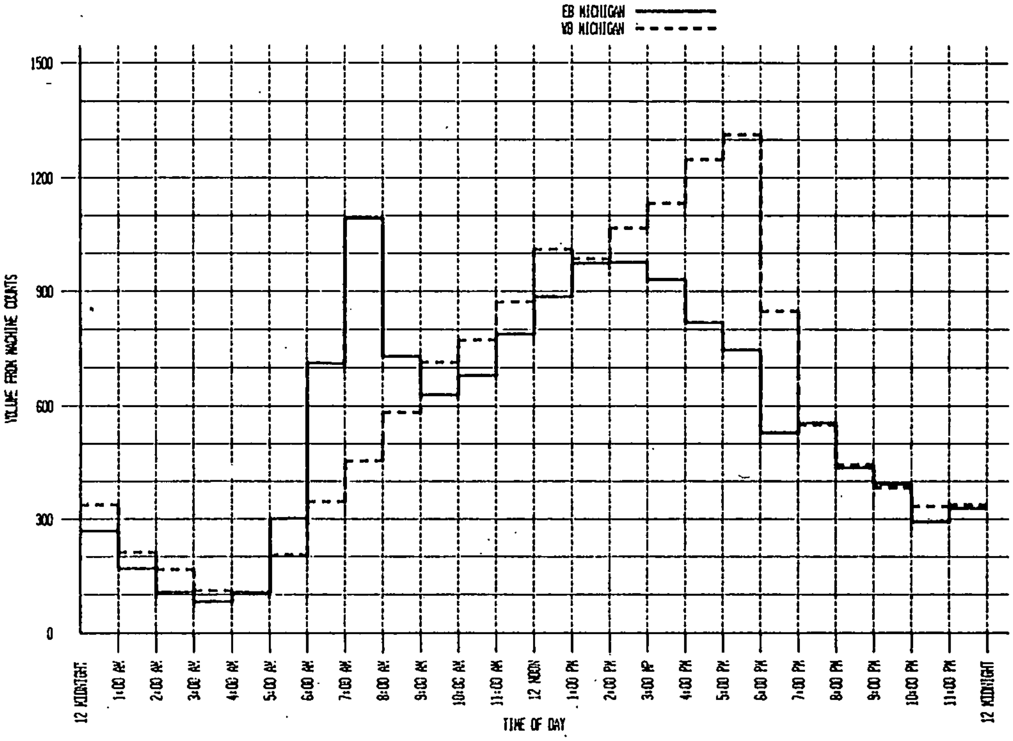
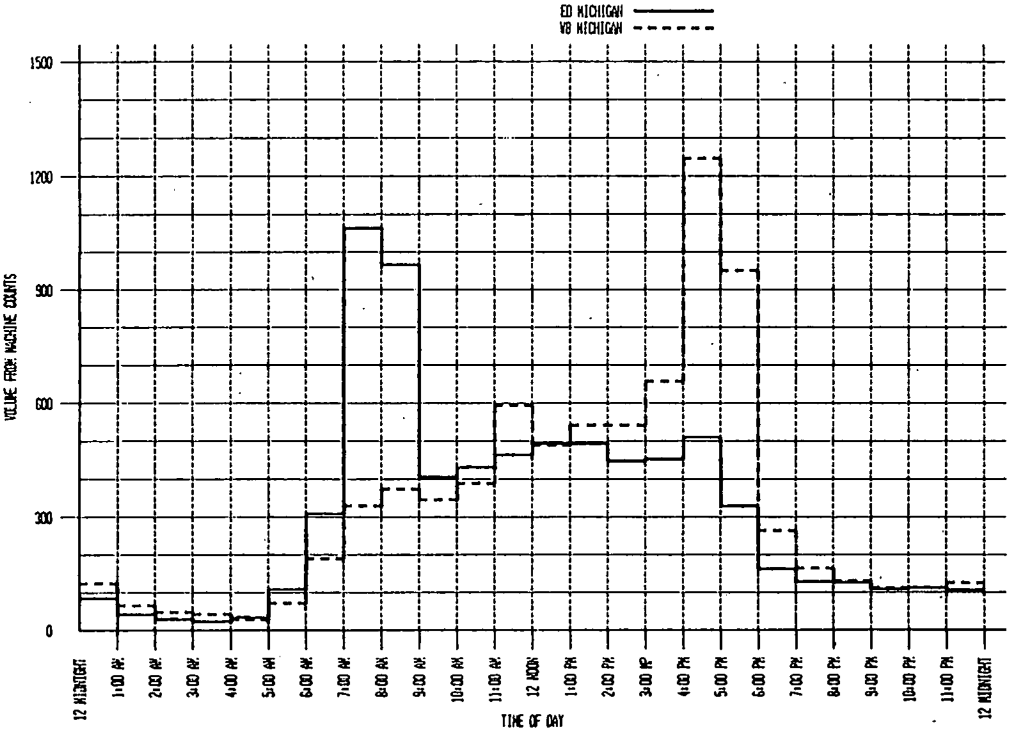


Figure 2. Directional flow by hour: Wyoming and Michigan Avenue.



1. The evening peak hour is from 4:30 to 5:30 p.m., obtained from manual and machine counts taken during February and March 1980. The peak period ranges from 3:45 to 6:00 p.m.
2. Only signalized intersections were used in the simulation due to the maximum number of nodes allowed in the program.
3. A 3.0-s starting delay and 1.9-s headway were used. These figures are based on previous studies.
4. The speed used was 35 mph, which corresponds to the posted speed limit.
5. Some intersections did not have machine or manual counts, so it was assumed that 100 vehicles/h enter the system at these points. This was approximated from field observation and comparisons with adjacent intersections for which counts were available.
6. It was observed that parking violations were substantial enough during the evening peak that no use was made of the extra lane provided during the outbound peak.

It is our belief that the above assumptions are reasonable, based on observations of the study area. Any other assumptions made are so noted.

There were nine alternative, plus the existing (as installed), timing plans tested. The alternatives tested were in-field timing (assumes failed interconnect), existing with no-parking areas properly enforced, using timing permit offsets, timing permit with no parking enforced, timing for bidirectional flow, timing for directional flow (no parking enforced), timing for 100 percent outbound (westbound), timing for 100 percent outbound no parking enforced, timing for bidirectional flow eight-signals removed, and timing for 100 percent outbound flow eight-signals removed. The results of the NETSIM runs are shown in Table 1.

CONCLUSIONS AND RECOMMENDATIONS

It is obvious that at least portions of the interconnect system have failed due to the age of the equipment. Most of these controllers are about 24 years old. The greatest benefits can be achieved by reinstalling a good interconnected system.

Benefits can be derived by not operating, by relocating, or by removing the existing signals on Michigan Avenue at Trenton, Cecil, 35th-Greusel, 31st-Lockwood, 23rd, 16th, 6th, and Cochrane. All of these signal locations have very minor cross-street volumes and are poorly spaced for efficient progressive movements on Michigan Avenue. The successful resolution of any or all of these signal locations will produce substantial energy, pollution, and time benefits.

In order to do a cost/benefit estimate, gasoline was assumed to be $1.25/gal and dollar value of delay to motorists was set at $3 per person/h. Peak-hour fuel consumption and delay were multiplied by 10 to give the daily value and by 300 to give a yearly value. A summary of user savings is given in Table 2.

A cost estimate of $40 000/intersection was used for complete modernization including controller replacement and new interconnect. A 20-year life is assumed with zero salvage value. For simplicity, maintenance costs are assumed to remain unchanged. An interest rate of zero was used due to uncertainties of inflation and fuel prices.

Upgrading the existing system of signals would produce a yearly fuel savings of 130 000 gal and savings of about 170 000 h of delay. The dollar value is $620 000 with a cost/benefit ratio of 12.5. Upgrading would also reduce hydrocarbon emissions by 10 percent, carbon monoxide by 10 percent, and nitrous oxides by 5 percent.

Table 1. Results of NETSIM runs.

Alternates	Vehicle Trips	Stops per Vehicle	Avg Speed (mph)	Avg Delay per Vehicle (s)	Total Delay (min)	Fuel Used (gal)	Vehicle Emissions (g/mile)		
							HC	CO	NOX
In-field timing (existing)	9760	3.08	18.44	93.73	15 247.5	1076.86	3.05	48.16	4.82
Existing no parking enforced	9776	2.88	19.15	84.01	13 688.7	1051.62	2.92	45.71	4.70
City's timing from permits	9767	2.47	19.72	76.03	12 375.8	1033.32	2.89	44.86	4.75
City's timing, no parking enforced	9780	2.22	20.45	67.61	11 020.9	1002.09	2.75	42.45	4.58
Offsets for bidirectional flow	9781	2.73	19.45	79.54	12 966.2	1043.33	2.91	45.29	4.74
Offsets for bidirectional flow, no parking enforced	9802	2.44	20.32	69.32	11 325.0	1014.99	2.78	42.90	4.63
Offsets for 100 percent outbound flow	9787	2.50	19.79	75.11	12 252.4	1032.16	2.88	44.55	4.74
Offsets for 100 percent outbound flow (no parking)	9803	2.23	20.62	66.32	10 834.8	1005.30	2.75	42.37	4.63
Offset for bidirectional flow, eight signals removed	9781	2.32	20.11	71.26	11 617.0	1009.71	2.78	42.93	4.57
Offset for 100 percent outbound flow, eight signals removed	9768	2.15	20.58	65.91	10 730.1	995.09	2.75	42.91	4.60

Table 2. Savings per year compared with existing in-field timings.

Alternates	Fuel Gallons (000s)	Fuel Cost ($000s)	Delay in Person-Hours (000s)	Cost of Delay ($000s)	Total Savings Cost of Delay and Fuel ($000s)	Benefit/Cost Ratio
In-field timing, existing						
Existing no parking enforced	76	95	78	230	330	Unknown
City's timing from permits	130	160	140	430	600	11.7
City's timing, no parking enforced	220	280	210	630	910	Unknown
Offsets for 100 percent outbound flow	130	170	150	450	620	12.5
Offsets for 100 percent outbound flow, no parking	200	270	220	660	930	Unknown
Offset for 100 percent outbound flow, eight signals removed	250	310	230	680	990	20

The greatest benefit can be derived by signal system upgrading with signal removal or relocation as previously stated. Nearly $1 million in benefits can be returned each year to the public from an initial investment of $1 million. Therefore the cost/benefit ratio is about 20.

Signal System Modernization and Timing Optimization Study: Ludington Street, Escanaba

Kenneth L. Slee

The major function of the Community Assistance subunit is to provide traffic engineering assistance to local governments for improving safety at problem locations. By request from the city of Escanaba, Michigan, a complete engineering study was performed with recommendations for improving traffic flow and reducing accidents.

The city's entire signal system was studied focusing on Ludington Street, which is the major arterial street through the central business district. Existing Ludington Street is a narrow four-lane, two-way facility with angle parking on both sides of the street and functions basically as a two-lane, two-way roadway due to restrictions and narrow laneage. The network studied is a 30-block area with the major portion of the traffic in the seven-block central business district.

DATA COLLECTION

The existing signal system in Escanaba included 10 outdated, one-headed signals centered on the main streets, all working independently. The six signals along Ludington Street operate on a two-dial system.

Traffic volume data include 24-h machine counts as well as 8-h turning movement counts at the 10 signalized locations. The Ludington Street corridor averaged 15 000 vehicles/24-h period. The speed limit is posted at 25 mph.

Ludington Street is 64 ft wide from face-of-curb to face-of-curb. The cross streets are 54 ft wide with 12-ft radii in all quadrants of each location.

Accident patterns for the three-year study period included head-on, left-turn, and rear-end accidents. The major accident pattern involved angle-parked cars.

NETSIM ANALYSIS

The network simulation model was used to provide measures of effectiveness for existing traffic flow statistics. The proposed alternative included signal modernization, interconnection, removal of unwanted signals, parallel parking, and a five-lane facility with a center lane for left turns. The "existing" and "proposed" NETSIM analyses were compared for improvements in the traffic flow. The major statistics compared were average speed ("proposed" indicated a +72 percent), average delay per vehicle ("proposed" indicated a -72 percent), total delay ("proposed" indicated a -72 percent), and stops per vehicle ("proposed" indicated a -25 percent). These statistics appear along with the remainder of the measures of effectiveness in Table 1.

Table 1. NETSIM analysis: Escabana.

Measure of Effectiveness	Existing	Proposed	Change (%)
Stops per vehicle	2.37	1.77	-25
Avg speed (mph)	11.07	19.06	+72
Avg delay per vehicle (s)	133.5	37.03	-72
Total delay (min)	10 379.9	2953.6	-72
Hydrocarbon (g/mile)	4.23	2.78	-34
Carbon monoxide (g/mile)	74.63	42.69	-43
Nitrous oxide (g/mile)	4.52	4.24	-6
Fuel consumption (gal)	399.77	282.39	-29

CONCLUSIONS AND RECOMMENDATIONS

Cost/benefit analyses were computed by using projected accident reductions. Project costs were estimated at $120 000 with a 0.66 year time-of-return based on accident reduction.

Benefits were estimated by using a cost of $1.25/gal and $3 per person/h of delay. A factor of 3000 (a factor of 10 for daily x a factor of 300 for yearly) was multiplied by the hourly fuel and delay consumption to estimate a yearly value. The yearly benefits are $440 000 in fuel consumption and $1 336 000 in delay reduction. This reflects a 352 140-gal reduction in fuel consumption and 445 312 h of delay reduction.

NETSIM provides a more real-world view of existing and proposed traffic characteristics than other methods available. It makes available other measures of effectiveness that were not previously considered. NETSIM helps sell many safety projects to the use of the general public because the model outputs statistics into common terminology.

Comparison of Alternative Traffic Control Strategies at a T-Intersection

Bruce F. Schafer

Among the various parameters that may be evaluated for each roadway by NETSIM are average vehicle occupancy of roadway segment, stops per vehicle, average operating speed, and delay time per vehicle. The major features of the NETSIM model are listed below.

1. Microscopic, stochastic simulation of individual vehicle movements;
2. Simulation of full range of control features, including "Stop and "Yield" signs, turn controls, parking controls, fixed-time signals, vehicle-actuated signals, and real-time traffic control and surveillance systems;
3. Modular structure incorporating detailed treatment of car-following behavior, network geometry, grades, bus traffic, queue formation, intersection discharge, intralink friction and midblock blockages, and pedestrian-vehicular conflicts; and
4. Provision for flexible mix of standard output measures.

Other parameters that may be evaluated are bus system operational analysis, fuel consumption, and vehicle emissions for each individual vehicle grouping by type, automobile, truck, and bus. Major user options for the model include the following:

1. Simulation of traffic-actuated signal control;
2. Simulation of a surveillance system comprising various types of detectors;
3. Simulation of bus traffic;
4. Simulation of transient blockages within the traffic stream, such as parking violators, construction activity, and "incidents" such as stalled cars and accidents;
5. A variety of standard output options, including tabulation of origin-destination volumes; and
6. Statistical analysis of model outputs.

NETSIM MODEL USE

The NETSIM model is user-oriented. Noted here are model inputs and summary of input conditions, respectively. The inputs are readily available to the traffic engineer from office files or may be obtained from field data. The location-specific inputs are intralink target speeds, intersection discharge rates, input flow rates, frequency of rare events, intersection turning movements, bus system data, traffic composition, pedestrian flows and delays, amber phase behavior, network geometry and special channelization, signal timing, and detector location and type. The networkwide inputs include vehicle-generating distributions, gap acceptance distributions, parameters in car-following routines, parameters in lane-switching routine, and parameters in intersection movement routines.

INPUT CONDITIONS

The basis of all input data into the model for simulation is the link-node diagram. The link-node diagram converts the road system into a computer format for data translation. It is imperative that the link-node diagram for the system accurately represent that roadway, central business district, or intersection being modeled.

On completion of an accurate link-node diagram, the input data are then coded on preprint, 80-column, data-coding forms. On completion of computer simulation runs to debug data errors, the actual simulations are made, with changes in various control strategies, geometrics, etc., made for each run. Following completion of various simulations, comparison is then made of change effects on the system operation being modeled.

The model has been used for evaluation of various control strategies on arterial roadways and individual intersections. As with any form of analytical tool, the model has its limitations. In particular, its effective use is totally dependent on the quality of data inputs.

This is particularly true in the case of network coding and the treatment of unusual or non-standard traffic conditions. Considerable reliance must be placed in this case on the ingenuity of the analyst to abstract the essential operating characteristics of the network that he or she wishes to simulate and to transform these into an appropriate set of quantified, coded inputs.

The model includes a large number of discrete input parameters describing various aspects of traffic performance. These may be estimated either as a set of standard "default" values embedded in the program or as input to a given model run. The capacity to override the standard set of default parameters provides the user with an important degree of flexibility, particularly with respect to the treatment of non-standard geometry or operating characteristics that are unique to that area. It also imposes an additional requirement on the analyst, however, to evaluate very carefully those input characteristics whose accurate estimation appears critical to the particular study or intended analysis.

A wide range of potential user options and output formats is provided. Again, this is done deliberately to provide the maximum possible degree of analytical flexibility. However, this still imposes a requirement on the analyst to carefully structure the problem at the outset and identify clearly the options to be invoked and outputs to be generated before making a simulation run. It is particularly important in this context that a carefully structured program be developed for the analysis and evaluation of model outputs.

INTERSECTION STUDIED FOR SIMULATION

Figure 1 illustrates the intersection on East Travis Boulevard and Dover Avenue in Fairfield, California, as it appeared in 1977. The intersection had experienced a rear-end accident problem from vehicles waiting to turn north on to Dover from eastbound East Travis due to the lack of a left-turn pocket. The intersection met volume warrants from signalization, but funding was limited.

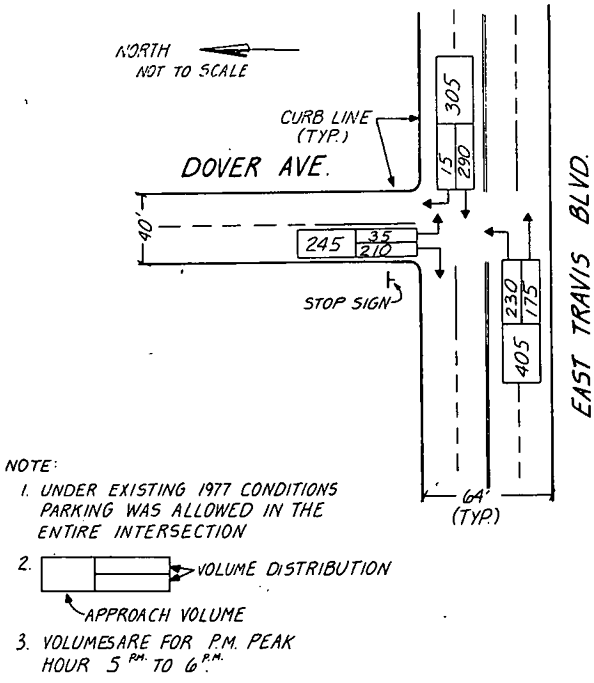
A number of alternatives with various laning and traffic signal control strategies were evaluated in order to maximize benefit for dollars invested.

ALTERNATIVE INTERSECTION CONFIGURATIONS ANALYZED

The various alternatives analyzed are listed below:

Alternative	Alternative Description
Existing	Existing stop sign traffic control and laning (Figure 1)
1	Existing stop sign traffic control, left turn lane for west approach of East Travis with no parking on East Travis, left and right turn lanes on Dover, with no parking on Dover
2	Two-phase traffic signal (Figure 2) for traffic control with existing travel lanes
3	Two-phase traffic signal (Figure 2) for traffic control, with traffic lane configuration of alternative 1
4	Three-phase traffic signal (Figure 2) for traffic control with traffic lane configuration of alternative 1

Figure 1. East Travis Boulevard and Dover Avenue: existing condition, 1977.



All alternatives were compared with the existing intersection operation.

The link-node diagram for the intersection is shown in Figure 3. The model runs were made on the California Department of Transportation headquarters computer facilities.

COMPARISON OF SIMULATION RESULTS

Table 1 lists certain specific results for each of the alternatives modeled. By inspection, the existing traffic control without turn pockets appears to operate most efficiently. However, a very minor decrease in overall efficiency would occur with the installation of turn lanes on Dover and East Travis. Through elimination of on-street parking it would be possible to install the turn lanes, thereby creating a refuge for turning vehicles. This would end vehicles turning from the through lane on East Travis and keep right-turning vehicles on Dover from being held up by the low volume of vehicles turning left from Dover.

Figure 2. Two-phase and three-phase proposed traffic signalization.

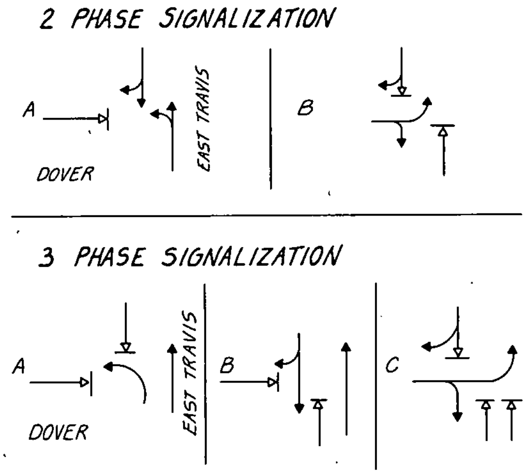


Figure 3. Link-node diagram: East Travis Boulevard and Dover Avenue.

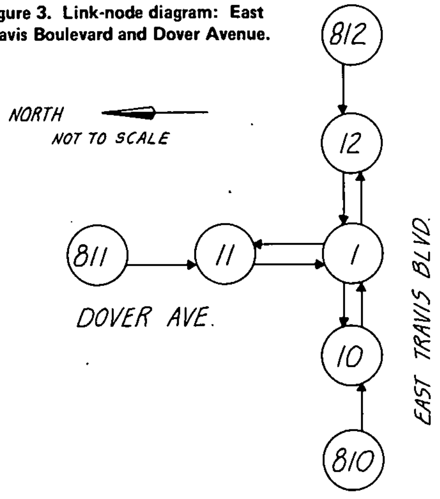


Table 1. System values for alternatives studied.

	Fuel				Vehicle Emissions (g/mile)		
Alternative[a]	Avg Speed (mph)	Stops per Vehicle	Total Delay (min)	Consumption (miles/gal)	Hydrocarbons	Carbon Monoxide	Nitric Oxide
Existing	20.34	0.30	31.2	9.69	3.67	59.58	7.84
1	20.25	0.31	31.5	9.67	3.68	59.98	7.84
2	18.03	0.51	44.5	8.77	4.31	70.91	8.84
3	19.78	0.37	33.4	9.50	3.80	61.98	8.00
4	19.24	0.40	36.1	9.36	3.93	63.90	8.18

Note: System values are model outputs for each of the alternatives for the entire system shown in Figure 3 during the peak hour from 5:00 to 6:00 p.m.

[a] Traffic input volumes and turning movements were the same for all alternatives.

The fuel use and air quality consequences of each alternative are also listed in Table 1. Increased emphasis on air quality impact of transportation alternatives can be evaluated via an optional subprogram resident in the NETSIM model.

RECOMMENDED PROJECT

Based on analysis of parking use, traffic engineering analysis of field data, NETSIM simulation data analysis, and professional judgment, it was recommended that the turn pockets on Dover Avenue and turn pocket on East Travis Boulevard eastbound movement with stop sign control on Dover Avenue be implemented.

CONCLUSION

In my opinion, the NETSIM computer simulation model further expands the traffic engineer's ability to analyze and evaluate alternatives in a cost-effective manner.

Typical Application of the TEXAS Model

Glenn E. Grayson

This paper describes a simple application of the TEXAS computer model by a traffic engineer in a small city. (TEXAS is a microscopic model for simulation of traffic at a single intersection. It is currently available from the Texas State Department of Highways and Public Transportation.) TEXAS allows traffic engineers to evaluate changes in intersection parameters (traffic flow, intersection geometry, and intersection control) and to see what effect those changes have on the vehicles' and intersection's performance. TEXAS is comprised of three separate computer programs: GEOPRO, DVPRO, and SIMPRO (see Figure 1).

GEOPRO takes geometric information about the intersection system (approach lengths, number of lanes per approach, lane geometry and type, and location of any sight distance restrictions) in a cartesian coordinate manner; it produces a list of possible paths down which vehicles will travel. This path information is used as input to SIMPRO. DVPRO also produces input for SIMPRO. This driver-vehicle processor takes volume and headway distribution information and creates a time-ordered list of vehicles. Three types of drivers and 16 classes of vehicles are used. SIMPRO takes these two inputs and a third, which contains the description of intersection control (from unsigned to signed to signalized) and the duration of simulation. Vehicles are "stepped through" the system, and speed and delay statistics are gathered for each time increment for each vehicle.

At the end of the simulation run, the statistics are summarized for the total intersection, for each approach, and for each turn movement in each approach. During a typical time increment, each car examines the vehicle in front, the adjacent lane(s), and the traffic control at the intersection. Then it makes a deterministic decision whether to speed up, slow down, start, stop, or change lanes. Because of the deterministic nature of the model, the traffic engineer is able to ascertain the effects of a change in one of the three parameters (traffic flow, intersection geometry, and intersection control) with only two runs: "before" and "after". The following is a description of how I used the model in just this way and was able to make comparisons between two runs.

Richardson is a Dallas suburb with a population of 80 000. Its 53 traffic signals are located at arterial intersections on a suburban grid and are, for the most part, noninterconnected and fully actuated. When these signals were installed, multiphase, fully actuated operation was the state of the practice. At many of the locations left-turn phasing was provided, even though during the peak period only three to five vehicles made the left turns each cycle. It had been observed that those three left-turning vehicles were causing unnecessary delays to the opposing through movement. With the increased emphasis today on reducing overall delay and fuel consumption, about 10 locations were targeted for protected left-turn removal in one or both directions. On January 10, 1981, left-turn green arrows

Figure 1. TEXAS model: flow process.

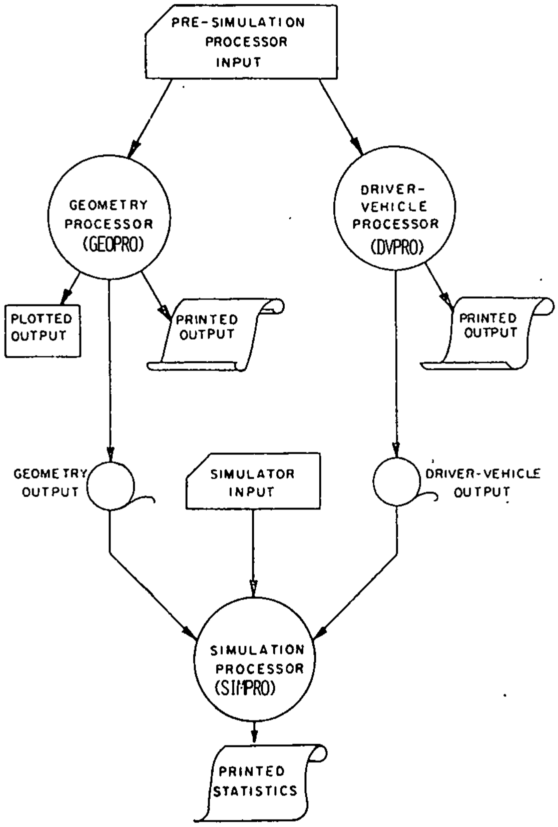


Figure 2. Sketch of Arapaho-West Shore model location.

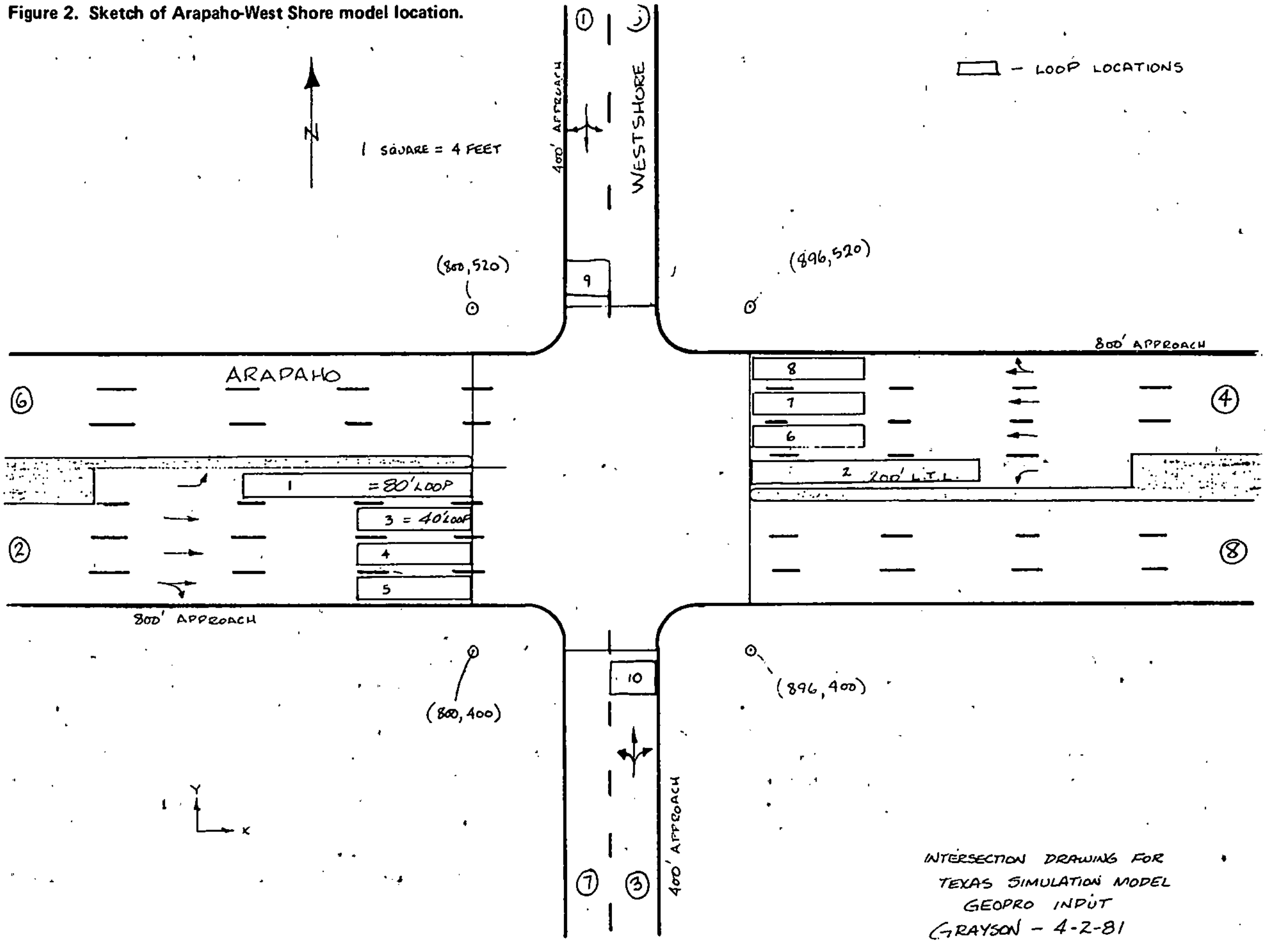
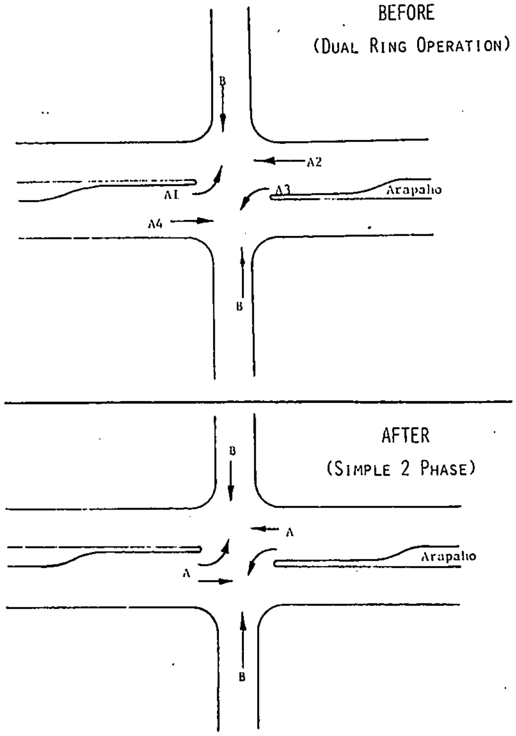


Figure 3. Before and after signalization phasing.



were bagged at three intersections for a three-month test. Citizen complaints begin to come in to the traffic engineering office and to the city manager's office. At this point, it was decided that it would be worthwhile to get some quantitative data to corroborate the engineering judgment used. The computer simulation approach was chosen for analysis, and the necessary input data were gathered to run the TEXAS model. (The Texas State Department of Highways and Public Transportation provides computer time to localities for these types of model runs.)

The location chosen to be modeled (Arapaho with West Shore) was similar to the other two. Arapaho is a six-lane divided major arterial and West Shore is a 36-ft undivided collector street. Figure 2 shows a simplified sketch of the intersection from which all necessary geometry information was taken. Volume counts were taken in the left-turn lanes and the through lanes on Arapaho, and for each approach on West Shore. Five-phase signalization (existing prior to January 10, 1981) was simulated for the first SIMPRO run. Two phase signalization (after January 10) was simulated for the second SIMPRO run. Figure 3 shows the before and after signalization phasing.

Reported statistics from each run include total delay, stopped time delay, queue delay, travel time, average speed, queue lengths by lane, and traffic signal performance. These are reported for the intersection as a whole, for each approach, and for each turning movement on each approach.

By analyzing these statistics from the before and 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.

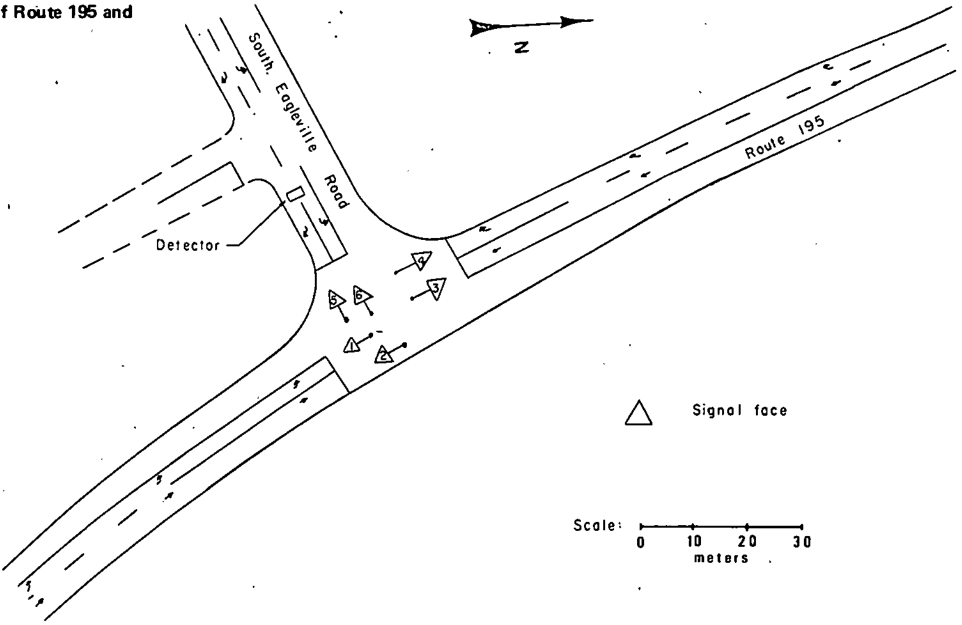
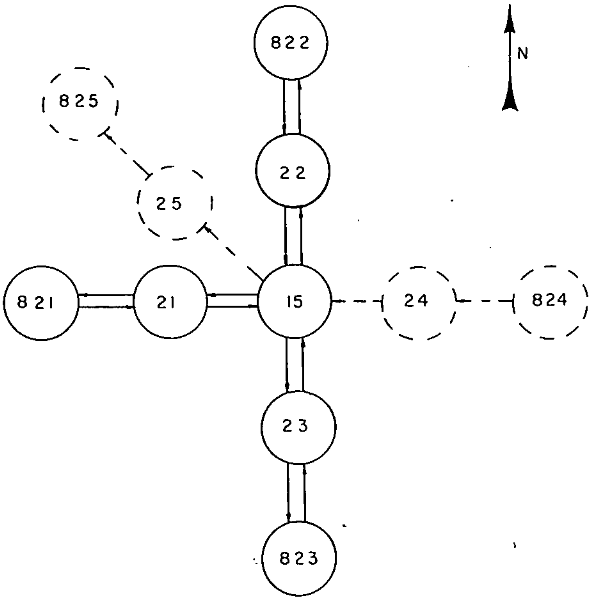


Table 1. Timing chart for semi-actuated signal at Route 195 and South Eagleville Road.

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.

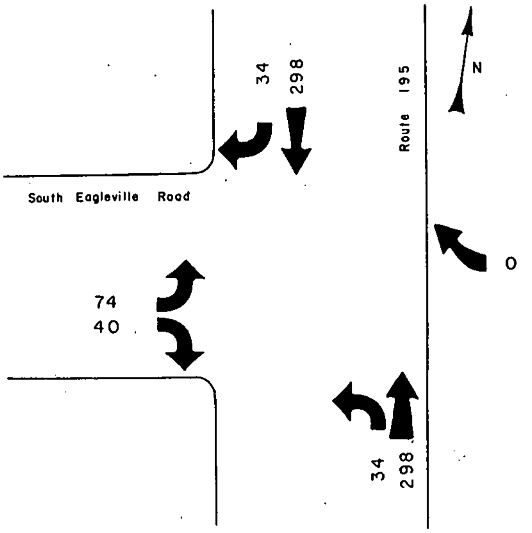
Link operation cards were completed by assuming no right-turn-on-red, one moving lane per link, de-

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.

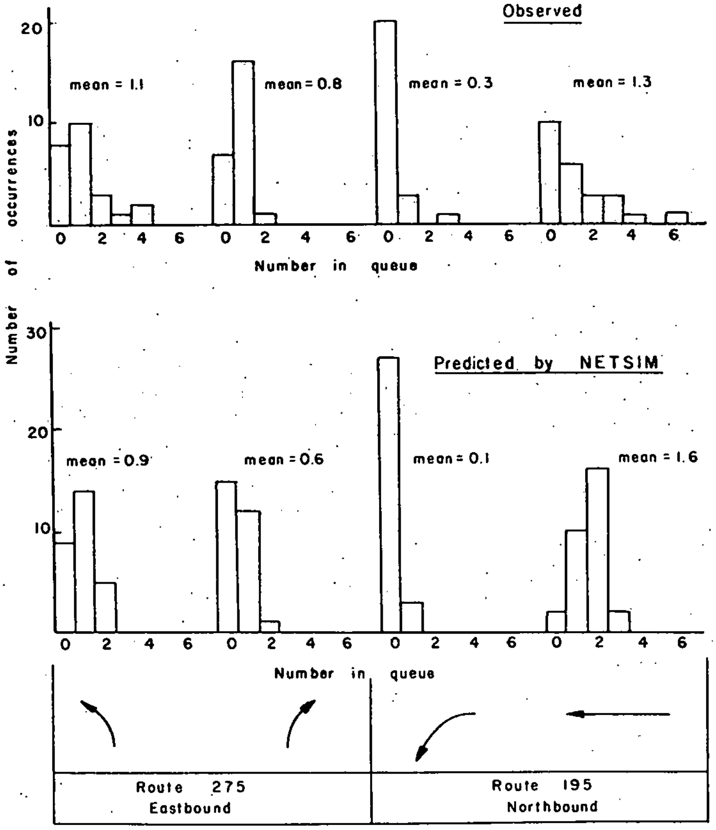


Figure 5. NETSIM-Webster comparison with 3-s lost-time and equal-approach volumes.

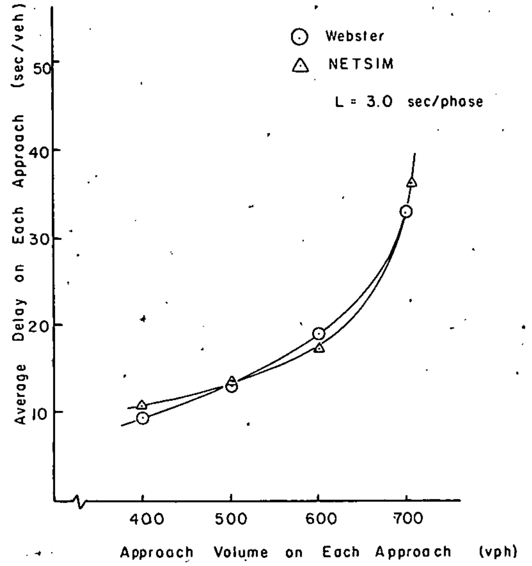
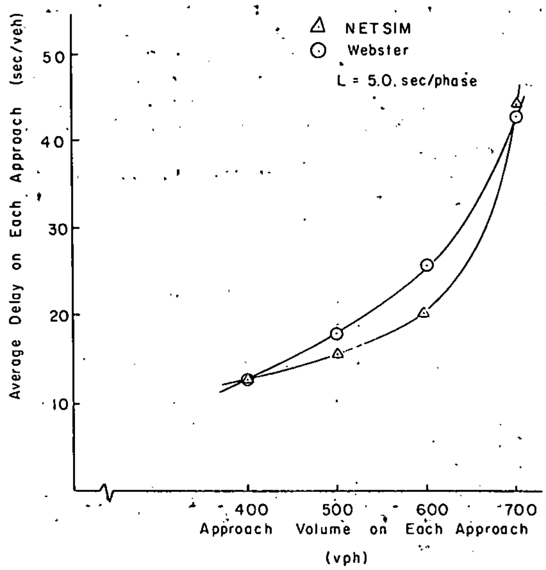


Figure 6. NETSIM-Webster comparison with 5-s lost-time and equal-approach volumes.

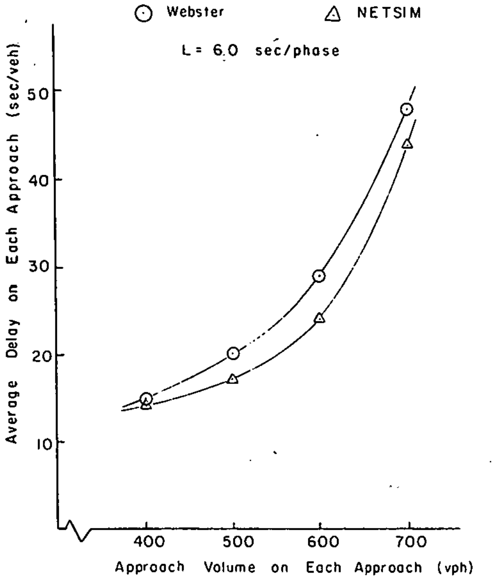


prepare the data card for this phase. The length of the amber (flashing "don't walk") interval is 13 s, but the program allows for a maximum amber duration of only 9 s. Therefore, the four extra seconds were added onto the green (walk) interval.

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 requirements. 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.

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

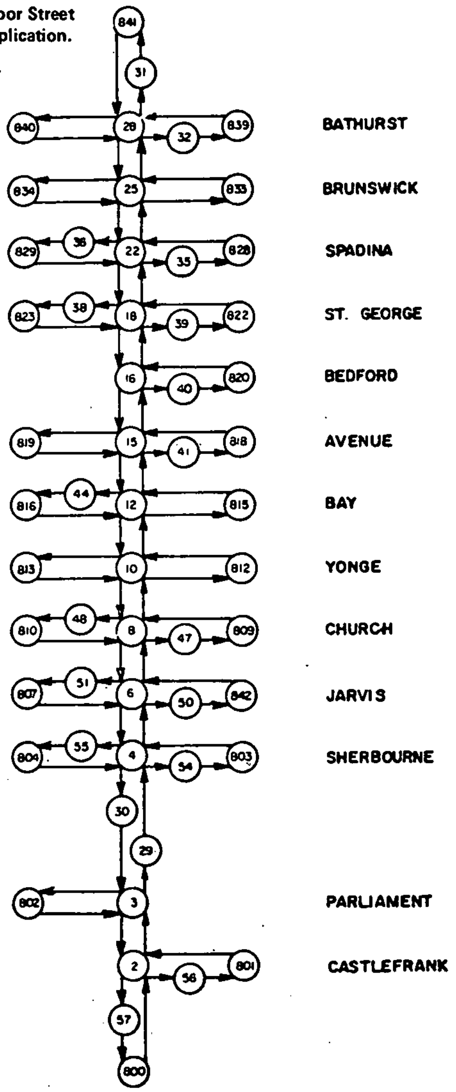


Table 1. Floating-vehicle data for Bloor Street network.

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.

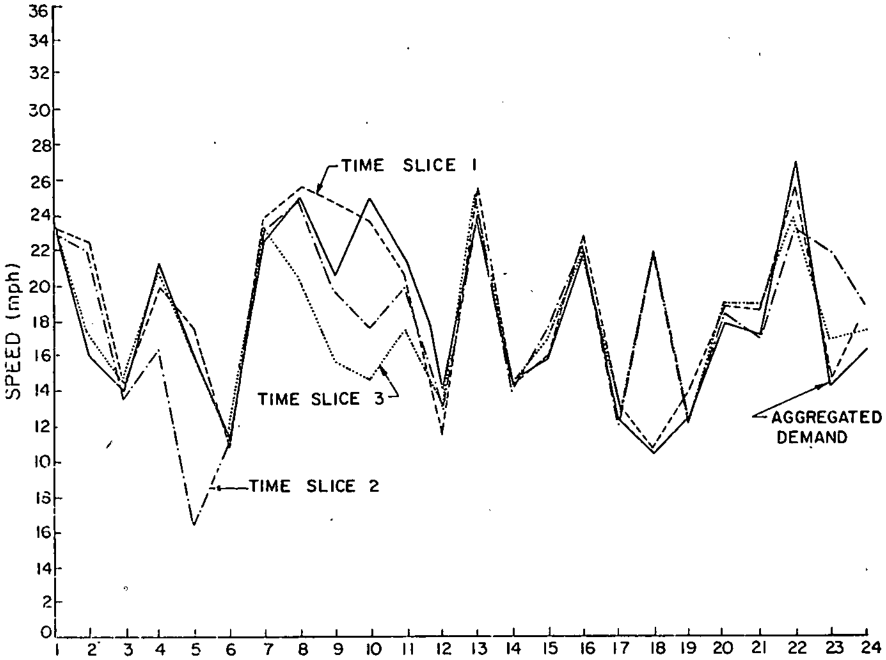
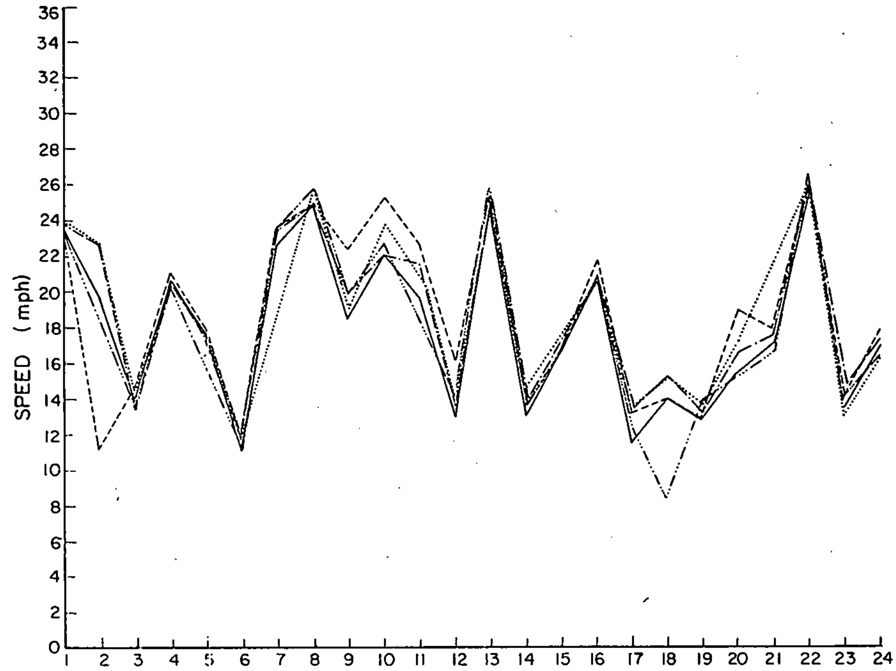


Figure 3. Section speeds predicted by UTCS-1's use of simplified network and five different random number seeds.



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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Using TRANSYT for Evaluation

Sam Yagar and E.R. Case

A companion paper in this report summarizes the operational aspects of the UTCS-1/NETSIM models in terms of user-interface and evaluative characteristics (see preceding paper in this section). In the same study in which UTCS-1 was evaluated (1) the TRANSYT model by Robertson (2,3) was considered as an alternative evaluation model to UTCS-1.

Since TRANSYT was developed as an optimization procedure, it has to be able to evaluate various schemes in order to find an optimal one. This paper looks at the evaluative capability of TRANSYT and the effects of varying certain parameters when applying TRANSYT. While comparing the evaluative capabilities of TRANSYT and UTCS-1/NETSIM, this paper does not advocate TRANSYT as a replacement for NETSIM. It is noted that TRANSYT can only be considered as an alternative to NETSIM for certain types of applications. For example, TRANSYT cannot treat networks with more than one cycle length in a simple application. This is discussed in this paper along with other TRANSYT shortcomings and potential pitfalls that the TRANSYT user should avoid. Also discussed is the question of TRANSYT's sensitivity to time-aggregation of flow volumes and to the user's preestimate of link speeds (an input data requirement of TRANSYT).

DESCRIPTION OF TRANSYT FLOW MODEL

Unlike UTCS-1, which attempts to simulate the details of individual vehicle dynamics, TRANSYT is based on platoon dispersion. It considers the distribution of traffic over time at each single location of interest in the TRANSYT network. Examples of time-distributions of traffic are illustrated in Figure 1a. Figure 1 represents a typical cycle of the distribution of traffic over time just downstream of a traffic signal. In general, the peak level at the beginning represents queue service at the saturation flow rate, the second distinct level represents arrivals during the green phase after the queue has been served, and the lowest level represents turning movements onto the street during the red phase. TRANSYT applies a platoon-dispersion algorithm to the distribution in Figure 1a in estimating the behavior of these vehicles farther downstream. The effect is that the distinct pattern is lost and a dispersed distribution such as that illustrated in Figure 1b is obtained. To obtain the distribution of traffic entering an intersection, TRANSYT basically superimposes the distributions from any upstream locations whose dispersed platoons converge at that intersection. This combination procedure preserves the relative offsets of the platoons being superimposed. When the combined dispersed distribution is filtered through another traffic signal, it again attains a structure such as that in Figure 1a.

The above procedure represents an abstract type of simulation model, one that attempts to emulate rather than to simulate the traffic flows in a network. TRANSYT is easier to work with than NETSIM, as it requires less-detailed data and employs a simpler form of data input. Its performance evaluation procedure also requires much less computer time than NETSIM's. TRANSYT needs a quick evaluative procedure because it employs an iterative "optimization" model that has to perform many evaluations in optimizing the aggregated operation of the traffic signals in a network. Therefore, it has to be selective in choosing the aspects of a traffic network that it will model. The level of its success in this regard can be seen in the studies reported in Yagar (1,4).

COMPARISON OF TRANSYT AND UTCS-1 PREDICTIONS

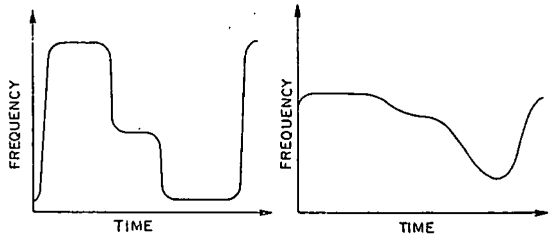
In a study conducted on Bloor Street in Toronto, speeds were predicted by the TRANSYT model as well as the UTCS-1 model. The simulation results were than compared with speeds obtained by floating-vehicle studies. The experimental results are illustrated in Figure 2. There is no discernible difference in quality of prediction relative to the standard of comparison, which was based on 10 floating-vehicle runs. Since it was not practically feasible to conduct the number of floating-vehicle runs required to ultimately find the better model, there was no discernible difference between the models. In fact, the models predicted an average performance, based on average data, while the floating-vehicle results were based on a number of realizations that reflect the varied measures of performance various users will encounter. In view of the results in Figure 2, the question is raised whether a practically sized sample of traffic data has a sufficiently small statistical variance to provide a better test of traffic control strategies than a carefully derived model and, in fact, whether the test of a model based on manually obtained data is even appropriate.

SENSITIVITY OF TRANSYT TO TIME-AGGREGATION OF FLOW VOLUMES

The effort required to simulate a sequence of short individual time slices is considerably greater than that required to simulate one longer period with aggregated demands from the viewpoints of data collection, data reduction, and computer processing (1). A study was therefore conducted on Toronto's Bloor Street network to determine TRANSYT's sensitivity to the time variation in the input flow demands as simulated by the use of short time slices. This was done by comparing the individual TRANSYT speed predictions for each of three sequential 20-min time slices to the speeds that would be predicted if these sequential flow levels were aggregated into a longer period.

The speeds predicted for the links of the Bloor Street network by using the aggregated peak-hour volumes are plotted in Figure 3. For comparative purposes the speeds predicted for the individual

Figure 1. Typical time distributions of traffic at specified locations.



(a) Just Downstream of a Traffic Signal
(b) Some Distance Downstream of a Traffic Signal

Figure 2. Comparison of UTCS-1 and TRANSYT with floating-vehicle confidence intervals (shaded background).

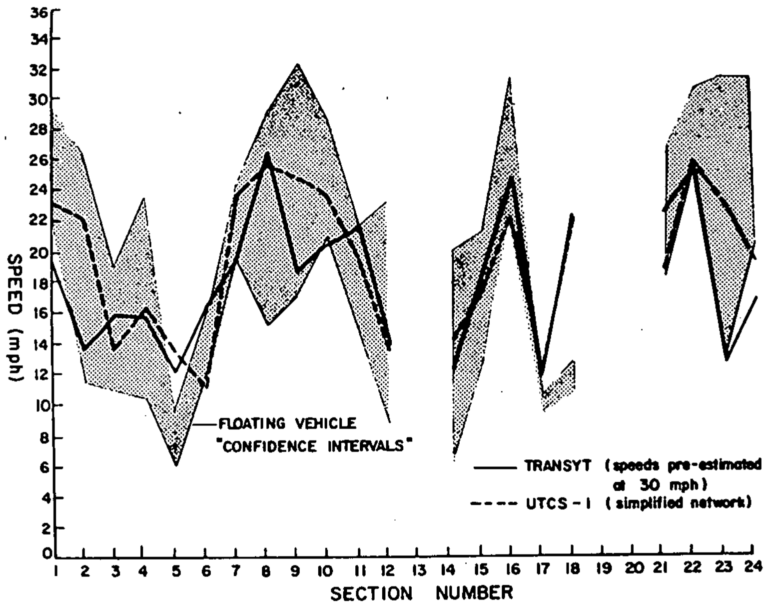
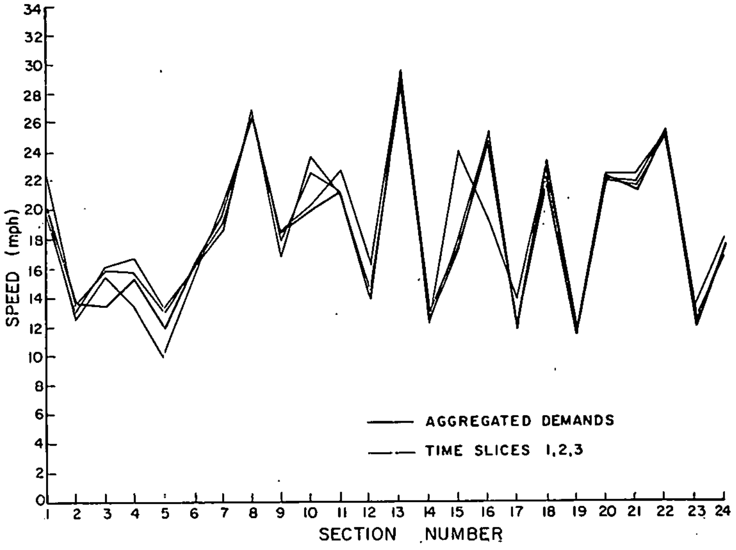


Figure 3. Comparison of TRANSYT results for individual time slices and aggregated demands.



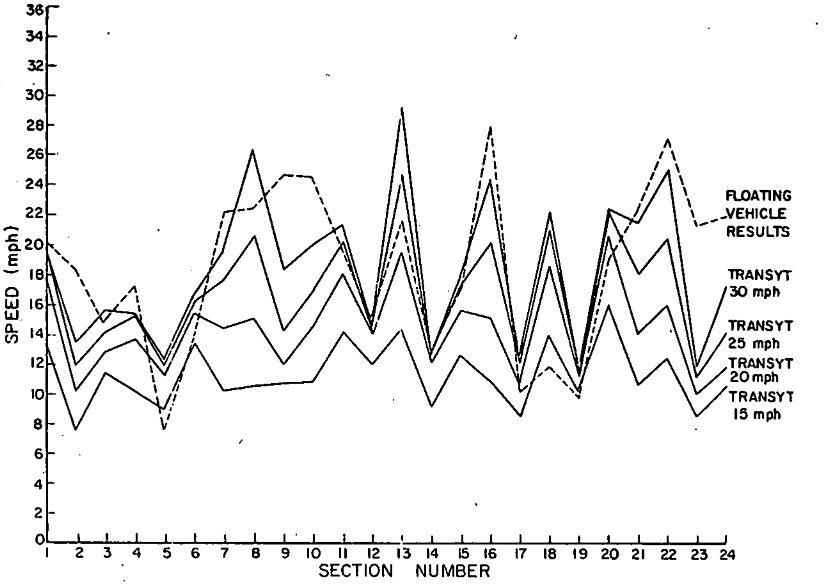
time slices are shown in the background. As with the UTCS-1 simulation (1), there are some inconsistencies where the results from using the aggregated demands are extreme, notably for links 3, 10, 21, and 23. However, these inconsistencies are less pronounced than with the UTCS-1 experience described in our other paper in this report. Also, it is conceivable that some travel time has been transferred to or from adjacent links in that case. It appears that TRANSYT, like UTCS-1, is not very sensitive to a reasonable level of time aggregation of flow volumes. This result is supported by more recent results obtained by using TRANSYT 7 in a network in Waterloo (5). It would therefore seem reasonable to use peak-hour volumes rather than shorter time slices in applying TRANSYT.

SENSITIVITY OF TRANSYT TO PREESTIMATION OF LINK SPEED

The definition of the term average link speed in the documentations (2,3) of the TRANSYT model is rather unclear. Rather than attempting to arbitrarily interpret this definition, a study was performed on the sensitivity of TRANSYT results to various interpretations of this term. This was done by assuming that the average link speeds on all links were the same unknown value and treating this value as a parameter. The intention of the substudy in this section was to observe the sensitivity of the results to the variation in this parameter and to calibrate the parameter for the Bloor Street network. This calibrated value could then also serve as a rule-of-thumb estimate of average link speed for other similar networks.

The operation of the Bloor Street network was simulated by using a common value of average link speed for all links in the network. Simulations were performed by using values of 15, 20, 25, and 30 mph for this parameter. The section speeds predicted by TRANSYT are plotted in Figure 4 for each of the values assumed for the average link speed parameter. The average floating-vehicle value is also plotted for each section. It is seen that TRANSYT is very sensitive to the estimated speed values. Therefore, the user should be quite careful in estimating them. Since the TRANSYT documentation

Figure 4. Calibration of average link speed parameter for TRANSYT with respect to floating-vehicle studies.



(2,3) does not seem to be specific enough for this purpose, we have adopted that value for average link speed (30 mph) that gives the best results relative to the floating-vehicle speeds. This is, in a sense, a calibration of our Bloor Street TRANSYT model to floating-vehicle results.

It is noted that only the evaluative capabilities of TRANSYT were considered in this study. Before using TRANSYT as a signal optimization tool, one should ensure that the preestimated speeds (or travel times) correspond to the values that the model requires, as TRANSYT's evaluations have been found to be sensitive to these preestimates. Its optimizations rely on its evaluations and would, therefore, be at least as sensitive. Since the optimization procedure determines optimal offsets, it would find them for the link speeds (or travel times) that it perceived. Incorrect preestimates would cause the TRANSYT optimization procedure to suggest incorrect offsets and therefore non-optimal solutions.

SOME POTENTIAL PITFALLS FOR TRANSYT USERS

Some minor problems were encountered in using TRANSYT 5. These potential pitfalls are described for the benefit of prospective TRANSYT users. [Some of these problems have been alleviated in more recent versions of TRANSYT.]

1. The program did not accept any negative offsets or any offsets greater than half the cycle length when specified on the type 88 cards. These were therefore specified on the type 12 cards along with the red-green splits.
2. Volumes entering a link from given upstream links as specified in columns 30, 45, 60, and 75 of the type 32 cards must be ≥10. This is stated in the manual, but no reason is given for it.
3. For both evaluative and optimization purposes, TRANSYT requires that a common cycle length be specified for all of the traffic signals. This can be overcome partially by partitioning the network so that all of the traffic signals of each subnetwork have a common cycle length. Problems of boundary interface between subnetworks still remain, however.
4. In treating closed loops, TRANSYT must have a sequence in which it is to treat the links in the loop. It must know the flow on a link before it can treat that link. However, the flow on each link in the loop will depend on the flow on another link in the same loop. In order to have a starting point, a dummy link must be defined, parallel to one of the links in the loop and with a link number that is the negative of its parallel link. [In TRANSYT 7, loops are generated internally--the user no longer inputs a link list.]
5. TRANSYT requires an estimate of average journey time or speed for each link (specified on card type 32, columns 31-35). There is difficulty in interpreting the definition of this link speed. This paper has attempted to provide some guidance in this regard.

CONCLUSIONS AND RECOMMENDATIONS

Although TRANSYT has been developed as an optimization model, its evaluative capabilities were found to be commensurate with those of UTCS-1, at least relative to the floating-vehicle standards to which they were compared. Since TRANSYT's data and computer requirements are less than those of UTCS-1, it is recommended that TRANSYT be seriously considered for any evaluative purposes to which it is applicable.

It would be desirable to have a TRANSYT type of model developed that could simulate the effects of queuing delays and spillbacks that occur due to limited queue storage capacities of the links. This would increase the scope for TRANSYT's applications.

TRANSYT's estimates of link speeds were found to be quite insensitive to aggregation of time slices, but very sensitive to the preestimation of link speed that the user must specify in the data input. For the Bloor Street network, a preestimate of 25 to 30 mph was required.

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Interactive Computer-Graphics User Interface for Traffic Simulation Models

Shih-Miao Chin

The sustained dependence on automobiles and decreasing availability of urban land has intensified the urban traffic problem. The practicing traffic engineer has long needed a problem-solving aid to deal with the increasingly sophisticated and complex urban traffic flow problem. In order to understand the behavior of an urban street system and to evaluate various corrective strategies implemented on such a system, one has to construct a model that best represents the internal relationship among components and accurately predicts the system performances. Due to the size of the urban street network and the random nature among vehicles and drivers, it is impossible to use an analytical approach to model such a system. On the other hand, a simulation model becomes appealing in modeling the large urban network. Furthermore, with the aid of modern digital computer technology, it is economical and practical to apply digital computer simulation modeling in solving vehicular movement problems on a large urban street network. Subsequently, many computer traffic simulation models have been developed in order to help the traffic engineer to deal with complex urban traffic flow problems. Among these, NETSIM, TRAFLO, INTRANS, and FREQ6PE are the most widely known.

ISSUES WITHIN TRAFFIC SIMULATION MODEL

Although computer traffic simulation models are useful in predicting the performance of urban networks, certain deficiencies quickly become apparent. A simulation model is only a simplification of an actual system. The results obtained from such a model are only as good as its capacity to reflect, in this case, a real-world urban street network. The vehicular flow within an urban network is a very complex phenomenon. In order to fully describe and/or accurately predict such a system, the traffic simulation model must be relatively complex. Consequently, computer traffic simulations require extensive input data bases.

One study (1) shows that 85 percent of the total cost of an initial NETSIM model run consists of information coding costs. For succeeding runs, approximately 65 percent of the total cost is in input data modifications. There are several probable reasons for such high input data preparation costs. Conceptually, most traffic simulations are modeled on a simplified link-node network. A node represents the intersection, and a link represents the street segment between intersections. Some microscopic models even require more detailed representation of traffic lane configuration within the link. Unfortunately, the digital computer cannot process such a link-node network. Every necessary piece of information must be digitized. A clerical service is required to "translate" the link-node network into rows and columns of machine-acceptable digital data. The intuitive physical meaning of the geometry and signal information is oftentimes lost during the translation process. The coder is consequently faced with the problem of constantly referring to the network diagram and user's manual. This is time-consuming and confusing. In addition, much of the required input data does not always follow a logical order. As a result, some input information is duplicated. This interrelated information requires the coder to recall prior input data, a situation which in many cases leads to inconsistencies. Finally, options have to be provided within the input field in order to accommodate a variety of situations. Such option spaces are often scattered throughout the input data field and may not follow any apparent pattern from the user's point of view. Consequently, many errors may result in the input data file. The traffic simulation model has the capability of detecting errors and prints out error messages. However, the error message is often in numerical format and does not clearly indicate the mistake made by the coder. More decoding and encoding clerical work is required between the network diagram and the alphanumerical input data listing.

On the other hand, the traffic simulation model also requires many different and sometimes conflicting measures of effectiveness (MOEs) to describe the overall performance of the network. The number of MOEs is frequently further complicated by the size of the network. As a result, voluminous outputs are generated by the computer. Although they are presented in an appealing format, they are sometimes difficult to interpret. While the outputs are useful in defining the existence of potential problems, it may be difficult for the user to understand how such problems have evolved during the simulation. It is difficult for such a large amount of information to be conveyed to and assimilated by the user within a short period of time.

INTERACTIVE COMPUTER-GRAPHICS USER INTERFACE

With regard to the problems associated with the use of computer traffic simulation models, interactive computer-graphics user interface, in conjunction with existing simulation packages, can aid in reducing or even eliminating many of the deficiencies. Since pictures convey more information than do tables and in a more easily assimilated manner,

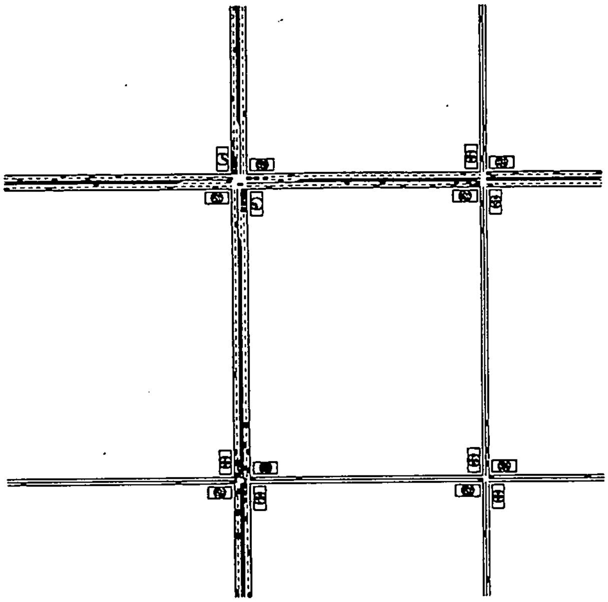


Figure 1. Display of one time frame for a four-intersection network generated by GRANT.

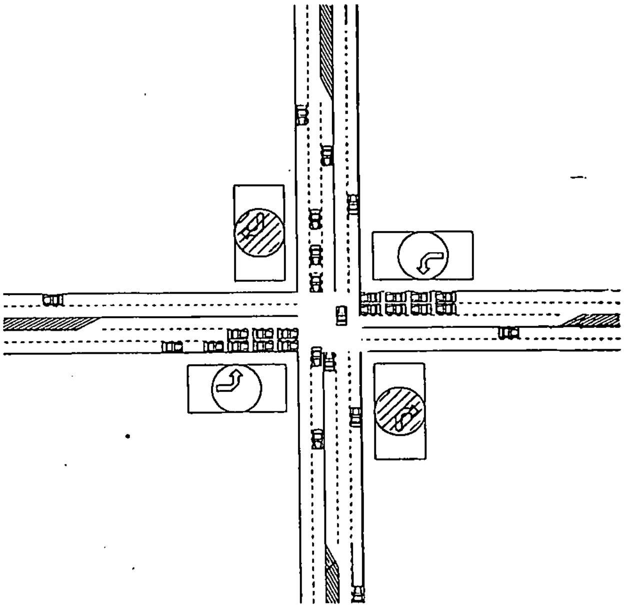


Figure 2. Display of enlarged intersection generated by GRANT.

computer graphics aid immensely in demonstrating the operation of the traffic simulation models. Therefore, such user interface is an invaluable aid to the understanding of the traffic simulation models, preparing input data, detecting errors, and interpreting their results.

RECENT DEVELOPMENTS

The use of interactive computer-graphics user interface alone or combined with existing packages is relatively recent. Generally these developments can be categorized into three major groups according to their utilities, namely, generation of animated traffic flow, graphics display of generated MOEs, and computer-graphics-aided data preparation and debugging.

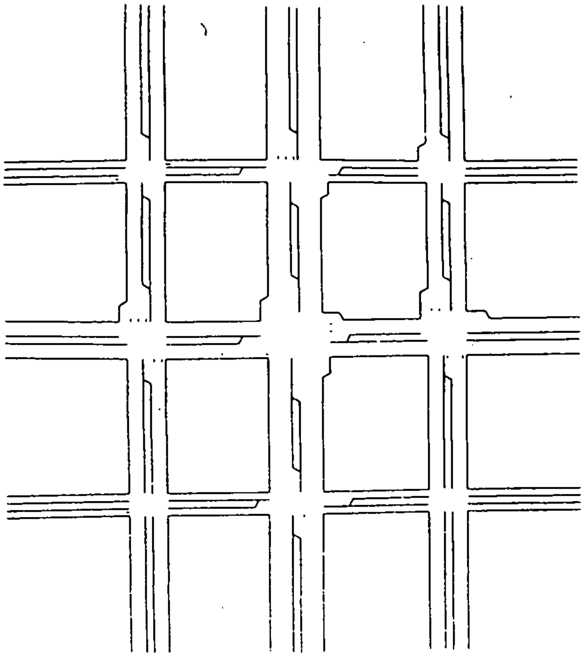


Figure 3. Queue length display generated by NETSIM/ICG.

Animated Traffic Flow

The STARK/NBS (2) model is a fairly detailed simulation model that uses deterministic traffic behavior rules including such factors as lane-changing logic, gap acceptance, right-of-way, and car following. However, the model is not flexible in admitting input data. The model has the capability of producing a CRT-based movie of the simulation. This gives the model the appearance of realism. The Aerospace Corporation Model VPT (Vehicle Performance in Traffic) (2) is an exceptionally detailed, totally microscopic network model. The user may choose desired output from a wide variety of traffic-related MOEs including movie representation of the network flow. NETSIM (3) is an extension of the UTCS-1/SCOT model. The model is a microscopic simulation, dealing with the movement of individual vehicles in an urban street network, according to car-following, queue discharge, and lane-changing theories. Joline (4) of Aviation Simulation International developed a movie presentation of the UTCS-1 model that displays the movement of individual vehicles within an urban network. This film has been useful in demonstrating the relationship among traffic flow patterns and signalization timing and illustrating the model's functions to potential users. This work also has helped to identify errors in the model that have led to various modifications.

The movie representation of the animated traffic flow is expensive and its applications are limited. Despite the movie representation, Eiger, Chin, and Woodin (5) have developed a program, GRANT, that generated NETSIM-based passive displays of animated network vehicle flows on a CRT (Figures 1 and 2). Modifications of the network geometry or related parameters can be easily accommodated. Such animated displays can be used in searching for high-performance traffic management strategies. Subsequently, a revised program NETSIM/ICG (6) has been developed that can provide both real-time and passive animation of traffic flow. Furthermore, the animated queue length display is also provided by NETSIM/ICG (Figure 3). With this capability, the

Figure 4. Four network MOE graphs generated by NETGRAF.

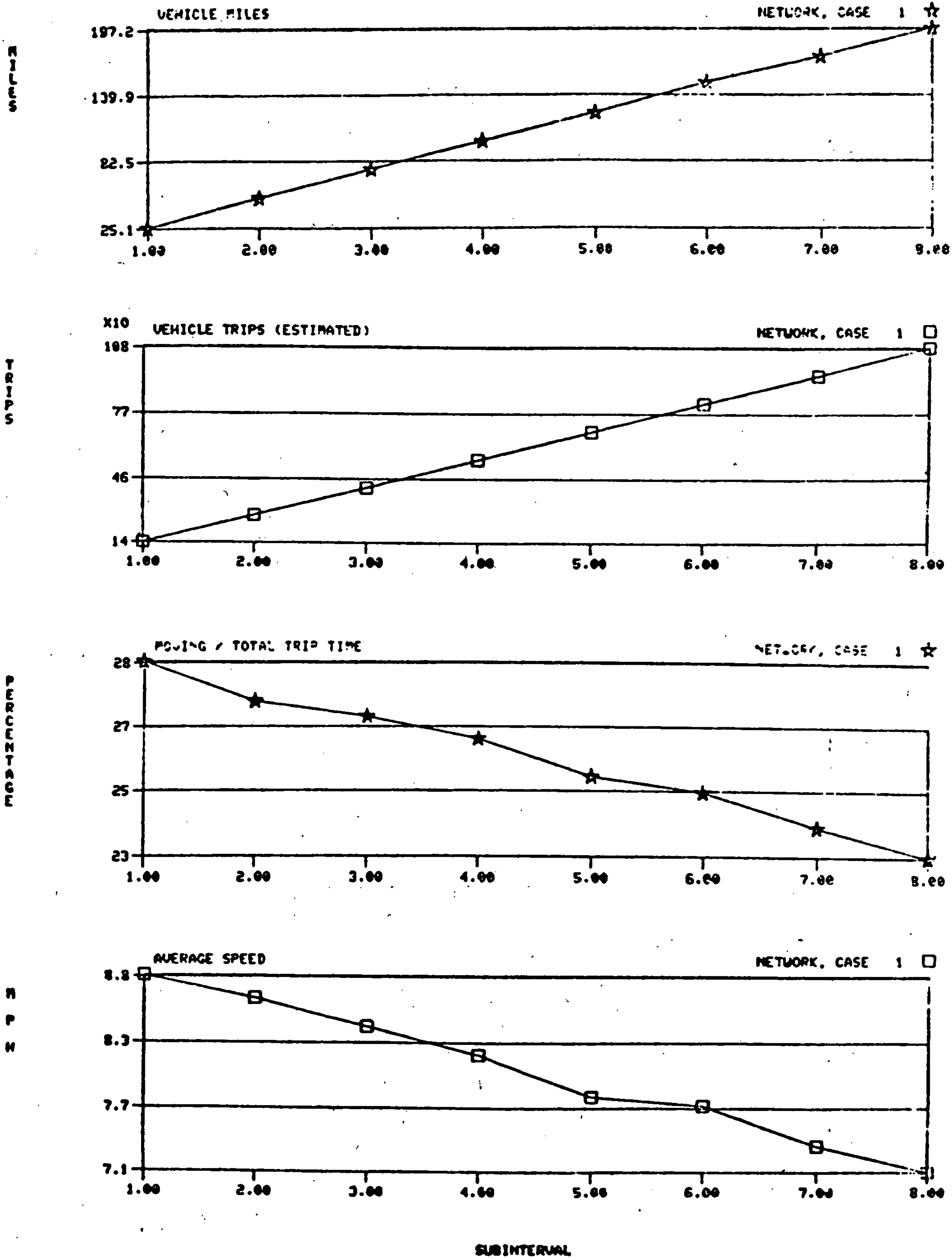
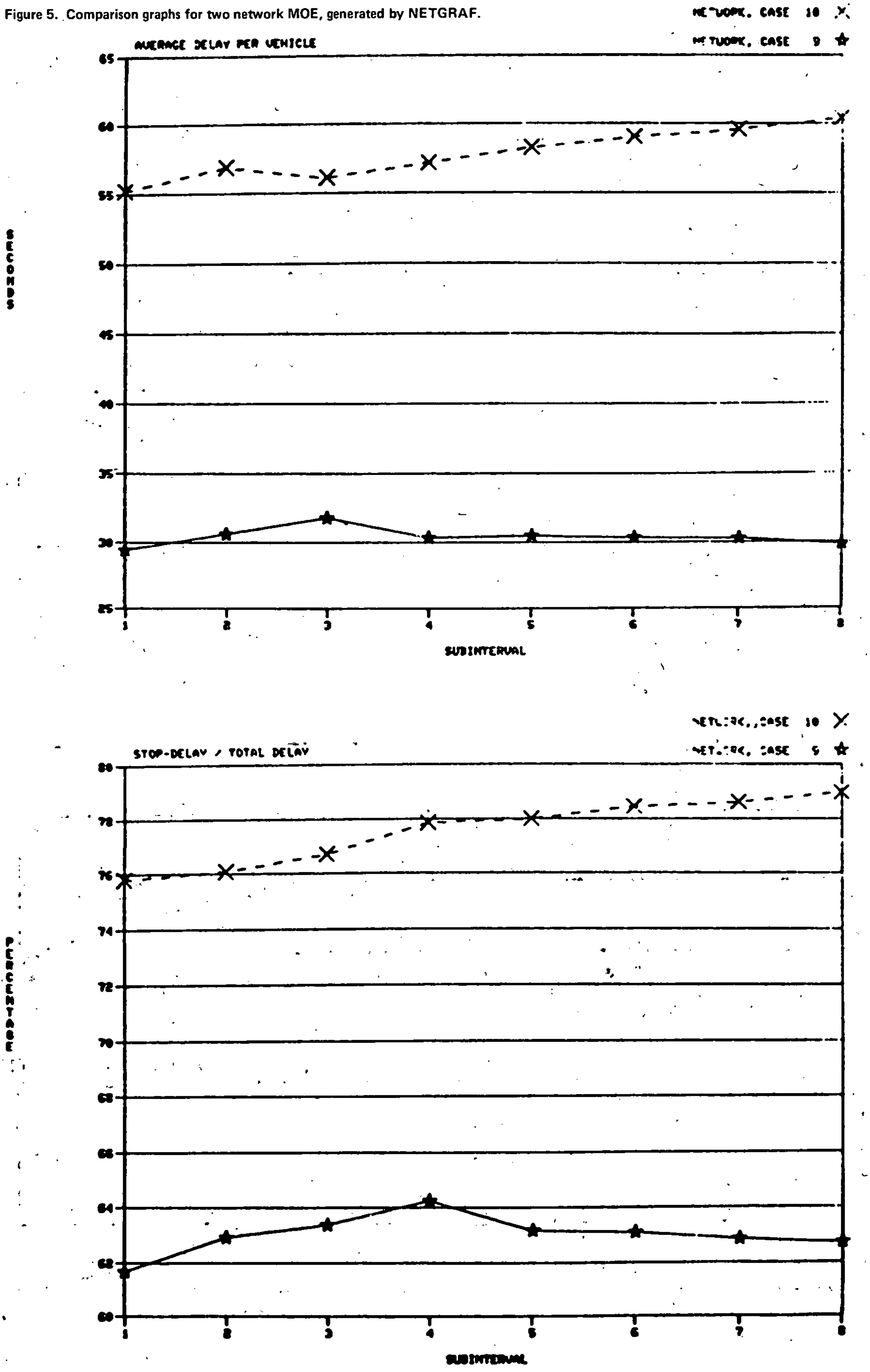


Figure 5. Comparison graphs for two network MOE, generated by NETGRAF.



traffic engineer can obtain similar information as animated traffic flow but with less computation and display.

MOEs Display

Parakh (7) proposed to improve the analysis of a large-scale flow problem by visually displaying the output of a computer simulation. His proposed Graphical Interactive Traffic Simulation (GRITS), a deterministic platoon-level model, can produce local-global displays of simulated network conditions. More specifically, the program has the capacity to display, at each intersection, the three-dimensional plots of MOEs as a function of signal split and cycle time.

Schneider and others (8-10) have developed the NETGRAF system, which is a graphics system designed to aid the use and interpretation of NETSIM results. The MOE data can be displayed for one NETSIM model run (Figure 4) or comparisons between different simulation runs (Figure 5). These graphs can be used by the traffic engineer to aid in the development of new strategies designed to achieve higher performance levels. NETGRAF is easy to operate and inexpensive. A novice user can learn to operate it with only a few hours of training and, with less than a week's experience, can easily generate 40 graphs/h. Limited experience with a small test network has shown that the computer time cost of producing the graphics is less than fifty cents each.

Along the same line, Schneider and others (11,12) also developed the FREGRAF system, which is a computer graphics program to aid the use and interpretation of a macroscopic freeway simulation model FREQ6PE. This simulation model was designed to assist the formulation and evaluation of entry control plans for freeway ramps. The user first defines the problem, develops an appropriate data base, and then uses FREQ6PE to simulate the existing condition. After studying the output and graphs (Figures 6 and 7) generated by FREGRAF, an objective function would be selected and an optimization process is performed to find the optimal ramp control plan. FREQ6PE would then be used again to simulate the problem area under the optimal control plan. New output and graphs would then be generated, with which the user would try to modify the control plan to eliminate or reduce some MOEs to an acceptable level. With limited testing, the objective of finding a control plan by using a graphic aid, FREGRAF, that can outperform the strategy generated by the optimization program in FREQ6PE is not entirely achieved. However, it is believed that further tests with an experienced traffic engineer would obtain more desirable results. Like NETGRAF, FREGRAF is also inexpensive to operate as a limited-experience user can easily produce 40 graphs/h at a computing cost of less than fifty cents each.

NETSIM/ICG developed by Chin and Eiger provides

Figure 6. Existing queue length, speed, and on-ramp spillback relationship generated by FREGRAF.

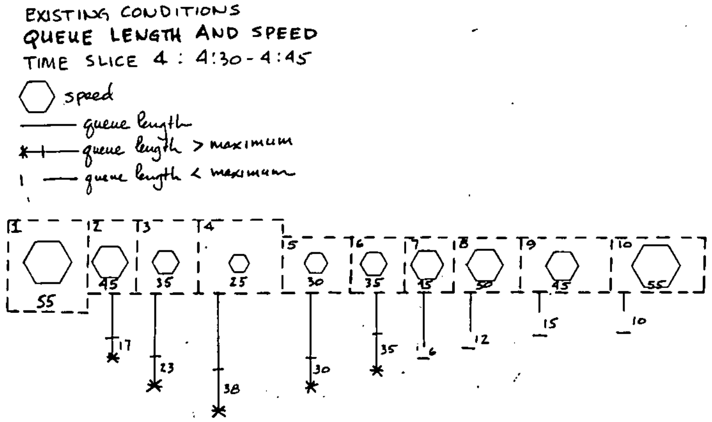


Figure 7. Speeds on all freeway segments over all time slices generated by FREGRAF.

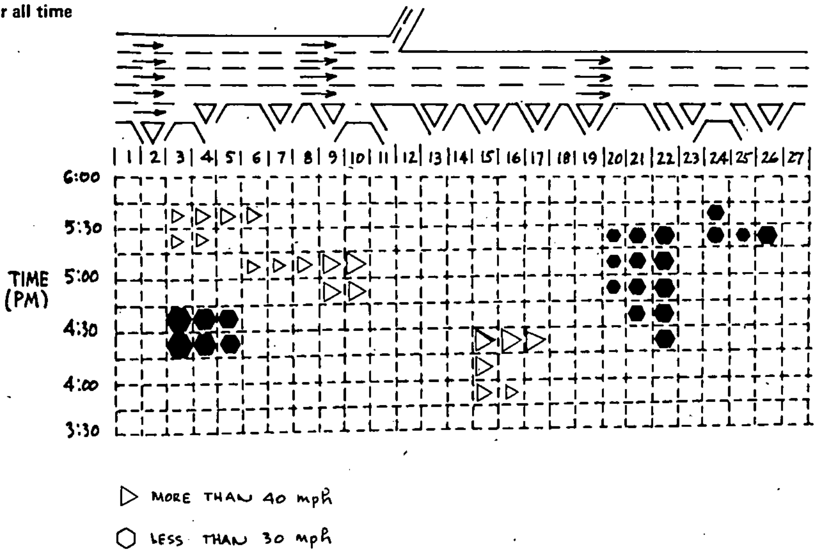
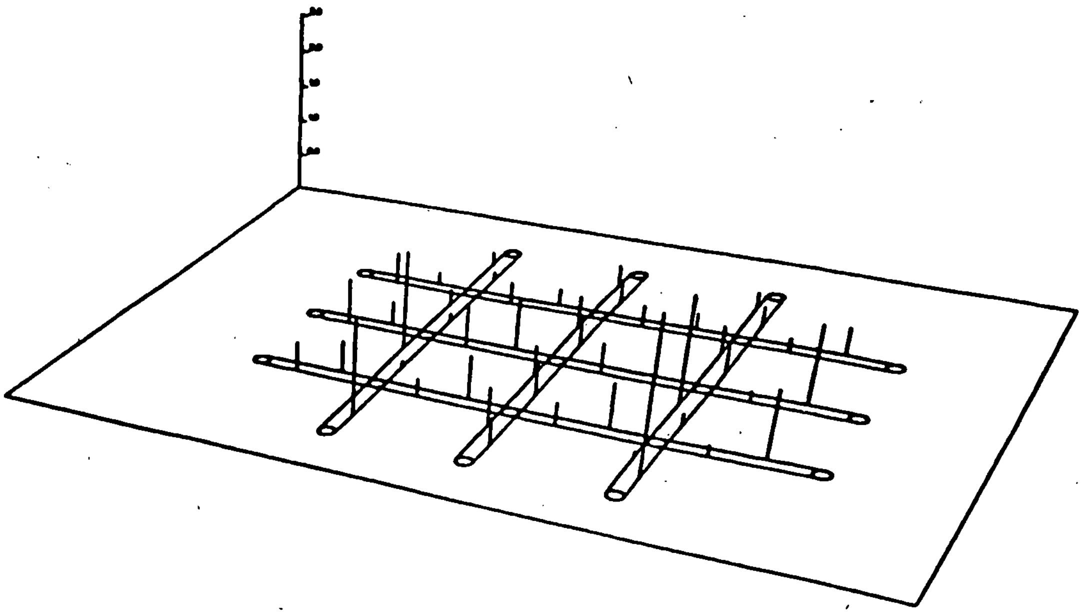
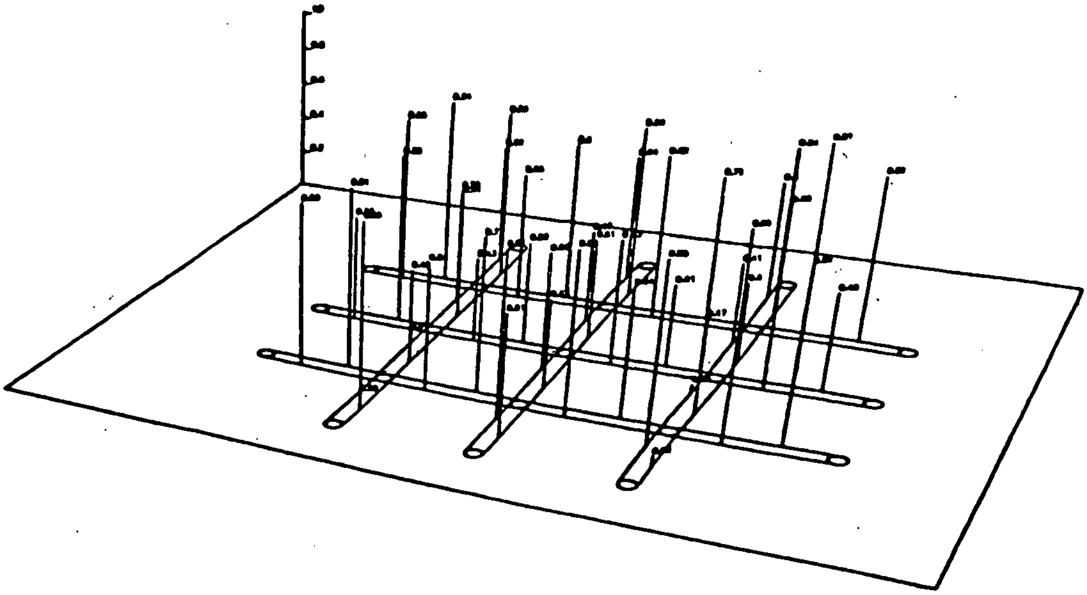


Figure 8. Perspective plot of MOE generated by NETSIM/ICG.

FUEL CONSUMPTION IN GALLONS FOR COMPOSITE AUTOMOBILE



RATIO OF MOVING TIME TO TOTAL TIME



both real-time and passive three-dimensional display of link-specific MOEs as generated by the NETSIM model (Figure 8). Such displays provide the user with more easily assimilated information with which he or she can comprehend the operation of the network.

Graphics-Aided Data Preparation and Debugging

The major and most interesting feature of the NETSIM/ICG is that the program provides an alternate method for preparation of input data required by the NETSIM model. The program uses the interactive computer graphics capabilities that allow the user to work on a physically meaningful link-node diagram. The interactive data input, both graphically and through the keyboard, is in free format that also follows a systematic procedure without referring to the user's manual. The program also provides the capability to graphically display, to as great a degree as possible, the input data. When preparing the signal time information, for example, the user actually works with both link-node diagrams and signal-phasing diagrams. The link-node diagram shows overall intersection orientation and phasing diagrams show detail and tedious signal-timing information. For the actuated signal, the user in effect graphically 'puts' the detectors on each approach on a lane-detailed network diagram (Figure 9). The graphic displays of input data can also be used in detecting errors within the input data file. The displays would either produce an erroneous or obvious inconsistency (Figure 10). Finally the program allows the user to retrieve and modify

Figure 9. Actuated signal-phasing diagram with detectors in land-detailed plot generated by NETSIM/ICG.

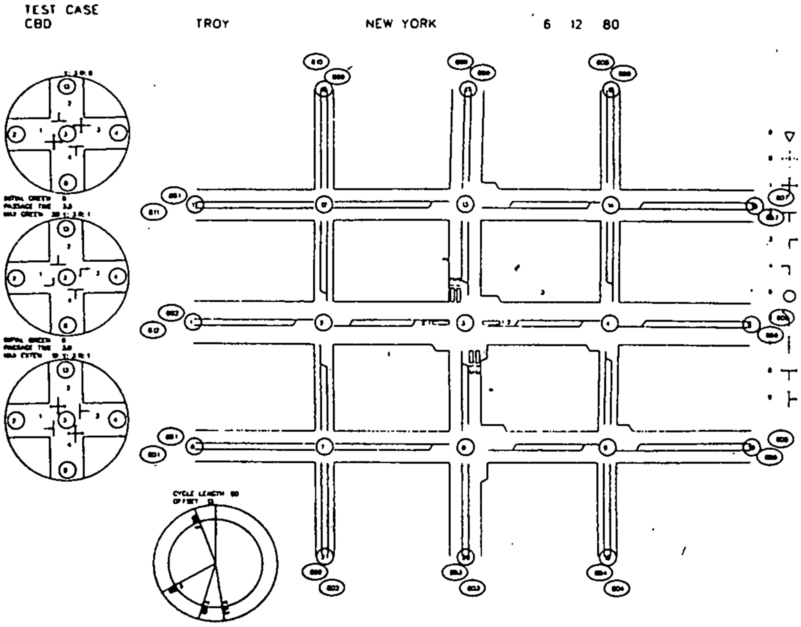


Figure 10. Error messages with associated plots generated by NETSIM/ICG.

```
**** CANNOT LOCATE LINK (   2,   6) FROM LINK    4.   SIGI ARRAY-        1        2        3        4        0
**** NON-ZERO TURN MOVEMENT ( 10 PERCENT) FROM LINK    4 TO NON-EXISTING DESTINATION
**** LINK    8 (   2,   5) ENTERS NODE    5 BUT IS NOT SPECIFIED ON SIGNAL CARD.
           UPSTREAM NODES OF ENTERING LINKS ARE              1          801
    **** ALL TURNING MOVEMENTS ARE NOT SERVICED AT NODE    2 FOR LINK    3
    **** ALL TURNING MOVEMENTS ARE NOT SERVICED AT NODE    2 FOR LINK    1
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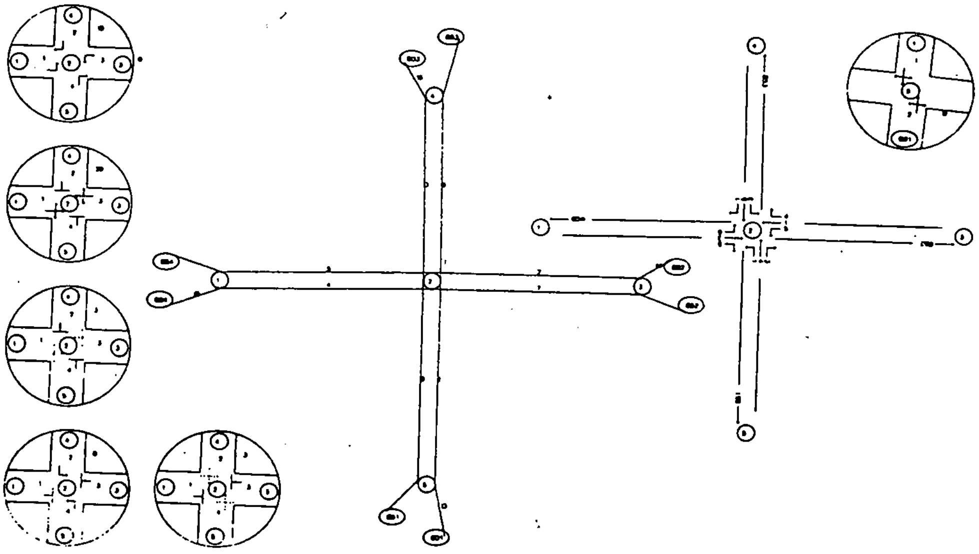

the previously defined data. Consequently, NETSIM/ICG provides the user with an intuitive, direct, and efficient method to prepare and debug the NETSIM input data.

The NETSIM/ICG is easy to operate. Each input step is preceded by a full description of required information. The user can easily code a network without referring to the user's manual. Limited experiences indicate that the costs, both in staff and computer time, associated with using NETSIM/ICG in data preparation vary from network to network. For example, a 20-intersection network with two actuated signals and two bus routes (Figure 9) requires approximately 5 person-hours and $50 worth of computer time. However, a 27-intersection network with only fixed-time signal and no buses (Figure 11) requires approximately 3 person-hours and $25 worth of computer time. The five-intersection network (Figure 10) requires 0.5 person-hour and $5 worth of computer time.

SUMMARY AND CONCLUSION

Recent developments of interactive computer-graphics user interface for traffic simulation models are discussed. Each developed interface is using the capability provided by computer graphics to graphically "translate" the alphanumerical information needed and/or generated by the digital simulation program into a display with a more easily assimilated format. Such graphic capability enables the traffic engineer to reduce, or on occasion even

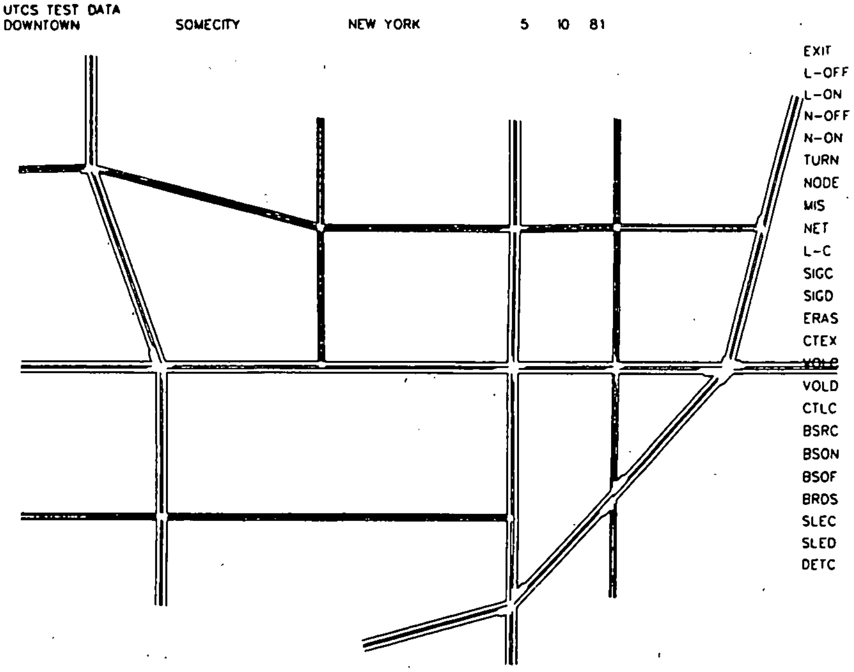

Figure 11. A-27 intersection land-detailed network plot generated by NETSIM/ICG.

eliminate, some of the difficulties associated with traffic simulation models such as extensive data preparation, tedious debugging, and voluminous printouts. It is my hypothesis that computer graphics aid in input data preparation, and debugging would achieve a greater benefit for the traffic engineer compared with applications like animation of traffic flow or output information display. Therefore, future research efforts should concentrate on the development of algorithms that use as little additional geometry data as possible and to generate sufficient network diagrams as needed by the simulation model. A typical example of this is to design an algorithm that would generate the lane-detailed urban street network mixed with freeways and their on-and-off ramps.

Most of the interactive computer-graphics user interface systems discussed in this paper, unfortunately, are not production-level softwares. In some cases this is because of the proprietary nature of the work. Some systems need further testing and contain several errors that are as of yet uncorrected. In addition, the overall potential utility of these user interface systems has yet to be assessed. The lack of opportunity to test these programs is probably due to the lack of availability of computer-graphics hardware, the lack of portability of the computer-graphics language, and the fact that most practicing traffic engineers are not graphics-oriented people. An effort should be made, within developing future interface situations, to use as few machine-dependent graphics subroutines as possible. Furthermore, all graphics subroutines should be grouped into a simple, basic subroutine library such as MOVE, DRAW, OPEN (subpicture), CLOSE (subpicture), etc. In this way, only a few changes are needed when the program is being transferred to another machine. Emphasis on the use of computer graphics should be placed at the college level. Prospective traffic engineers should be exposed to the computer-graphics environment and realize the potential benefit of such technology. Subsequently, computer graphics will become an integral part of their engineering task when they graduate.

The use of interactive computer-graphics user interface with traffic simulation models is relatively recent. Substantial efforts are still needed in research, development, and implementation of such a new technique.

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Part 6
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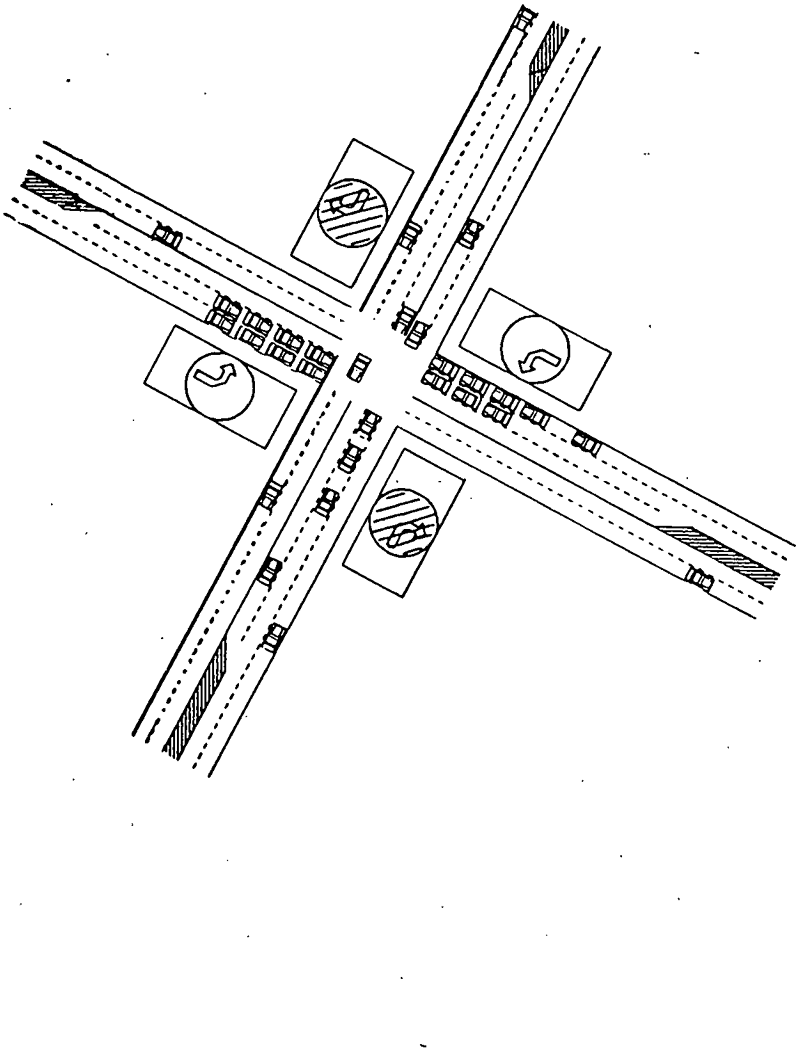

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