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.

REFERENCES

1. E. Lieberman and others. NETSIM Model. Federal Highway Administration, Vols. 1-5, 1977.
2. S.L. Cohen and G. Euler. Signal Cycle Length and Fuel Consumption and Emissions. TRB, Transportation Research Record 667, 1978, pp. 41-48.
3. C.S. Bauer. Some Energy Considerations in Traffic Signal Timing. Traffic Engineering, Feb. 1975.
4. K.G. Courage and S.M. Parapar. Delay and Fuel Consumption at Traffic Signals. Traffic Engineering, Nov. 1975.
5. J.W. Hurley and R.P. Ball. Energy Savings for Fixed Time Traffic Control: Vol. 9, Modeling and Simulation. Proc., Ninth Annual Pittsburgh Conference, 1978.
6. J.W. Hurley and R.P. Ball. Evaluation of Energy-Based Signal Settings for Traffic Actuated Control: Vol. 10, Modeling and Simulation. Proc., Tenth Annual Pittsburgh Conference, 1979.
7. A.E. Radwan and D.A. Benevelli. Evaluation of the Effect of Different Optimization Schemes for Open Urban Networks: Vol. 11, Modeling and Simulation. Proc., Eleventh Annual Pittsburgh Conference, 1980.
8. G. Radelat. Bus Priority Systems Supplement to the Subroutine Documentation of the MITRE Version of the Original UTCS-1 Model. Federal Highway Administration, 1973.
9. D.E. Hill. An Energy Investigation of Signalized Networks Optimized by TRANSYT 7. Virginia Polytechnic Institute and State University, Blacksburg, master of science thesis, 1980.
10. E.B. Lieberman and S.L. Cohen. New Technique for Evaluating Urban Traffic Energy Consumption and Emissions. TRB, Transportation Research Record 599, 1976, pp. 41-45.
11. P.J. Claffey. Running Costs of Motor Vehicles as Affected by Road Design and Traffic. NCHRP Rept. 111, 1971.
12. J.W. Hurley, A.E. Radwan, and D.A. Benevelli. Sensitivity of Fuel Consumption and Delay Values from Traffic Simulation. Presented at the 60th Annual Meeting of the Transportation Research Board, Washington, DC, 1981.

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.

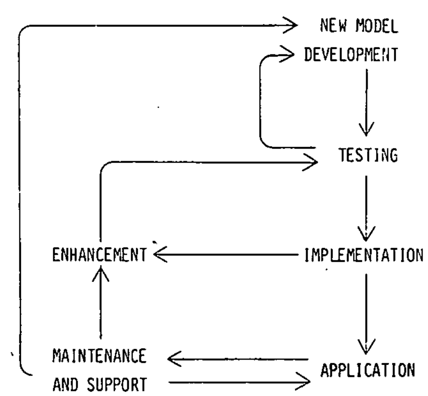
Very often, the implementation or the maintenance and support activities are omitted. This omission places an excessive burden on the application activities.

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

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

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

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.

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

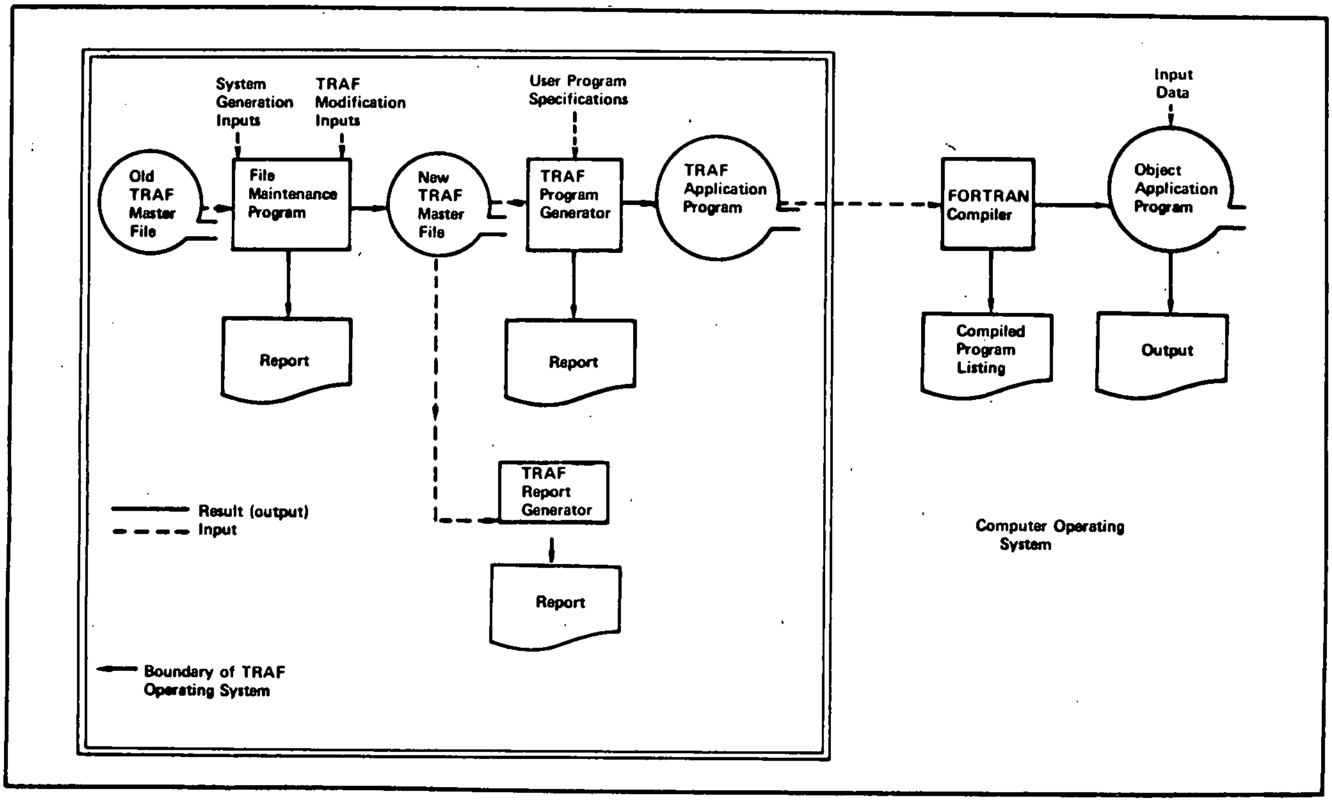
At present, there are no plans at FHWA for developing new traffic simulation models. A survey of the computer technology and prediction of computer developments in the near future is considered necessary before the needs for new models can be determined and plans for their development formulated.

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.

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REFERENCES

1. G. Radelat and G. Tiller. A New System for Traffic Simulation. Public Roads, Vol. 45, No. 1, June 1981, pp. 19-26.
2. Integrated Traffic Simulation Model--Phase I: Vol. 1, Executive Summary. Federal Highway Administration, Rept. FHWA/RD-80/086, Sept. 1980.
3. Traffic Network Analysis with NETSIM: A User Guide. Federal Highway Administration, Implementation Package FHWA-IP-80-3, Jan. 1980.
4. Development and Testing of INTRAS--A Microscopic Freeway Simulation Model: Vol. 2, User's Manual. Federal Highway Administration, Rept. FHWA-RD-76-77, June 1977.
5. A.D. St. John and D.R. Kabett. Grade Effects on Traffic Flow Stability and Capacity. NCHRP Rept. 185, 1978.