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.

REFERENCES

1. Traffic Network Analysis with NETSIM--A User Guide. FHWA, Implementation Package FHWA-IP-80-3, Jan. 1980.
2. E. Lieberman. Macroscopic Simulation for Urban Traffic Management--The TRAFLO Model: Vol. 1, Executive Summary. FHWA, June 1980.
3. E. Lieberman and others. TRAF I.5 Users Guide. FHWA, June 1981.

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.

REFERENCES

1. Transportation Research Center. Signal Operations Analysis Package. Univ. of Florida, FHWA Implementation Package 78-9, Jan. 1978.
2. Arterial Analysis Package Test Analysis Report. Transportation Research Center, Univ. of Florida, Gainesville, 1981.
3. F.V. Webster and B.M. Cobbe. Traffic Signals. Road Research, Technical Paper No. 56, London, 1966.
4. C.J. Messer and others. A Report on the Users' Manual for Progressive Analysis and Signal System Evaluation Routine--PASSER II. Texas Transportation Institute, Texas A&M Univ., College Station, Aug. 1974.
5. D.I. Robertson. TRANSYT: A Network Study Tool. Road Research, Rept. LR253, 1969.
6. D.I. Robertson and P. Gower. User Guide to TRANSYT Version 6. Transport and Road Research Laboratory, Crowthorne, Berkshire, England, Supplementary Rept. 255, 1977.
7. P.P. Jovanis and A.D. May. TRANSYT6C Model Workshop, Student Workbook. Institute of Transportation Studies, Univ. of California, Berkeley, July 1977.
8. P.B. Hunt and J.V. Kennedy. A Guide to TRANSYT/7. Transport and Road Research Laboratory, Note UN78/11, 1978.
9. C.E. Wallace and others. TRANSYT-7F User's Manual. Transportation Research Center, Univ. of Florida, Gainesville, 1981.
10. E.B. Lieberman and J.L. Woo. SIGOP II: Program to Calculate Optimal, Cycle-Based Traffic Signal Patterns. FHWA, 1974.
11. D.B. Fambro. A Report on the Users Manual for Diamond Interchange Signalization--PASSER III. Texas Transportation Institute Texas A&M Univ., College Station, Rept. ITT-2-18-76-178-1, Aug. 1977.
12. K.G. Courage and others. Arterial Analysis Package Users Manual. Transportation Research Center, Univ. of Florida, Gainesville, 1981.
13. PASSER II-80. Texas Department of Highways and Public Safety, Austin, Dec. 1980.
14. J.D.C. Little, M.D. Kelson, and N.H. Gartner. MAXBAND: A Versatile Program for Setting Signals on Arteries and Triangular Networks. TRB, Transportation Research Record, 1981 (in press).
15. R.A. Vincent, A.I. Mitchell, and D.I. Robertson. User Guide to TRANSYT Version 8. Transport and Road Research Laboratory, Crowthorne, Berkshire, England, Rept. 888, 1980.

NETSIM: A User's Perspective

Bradley R. Hagerty and Thomas L. Maleck

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