The NETSIM Graphics System

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Described in this paper is the development of an interactive computer graphics (ICG) system, named GTRAF, that provides users with a new and highly efficient methodology for analyzing results generated by the NETSIM microscopic traffic simulation program. This tool may be executed on microcomputers (PCs) with graphics capabilities or on any larger computer that supports Fortran and graphics. Portability of the software is assured through the adherence to ANSI Fortran and the Graphics Kernel System (GKS) standard. Following a discussion outlining the need for and use of ICG systems for the traffic engineering profession, an outline is provided of the concepts and objectives guiding the design of GTRAF, as well as a description of its logical structure. The reader is then walked-through an ICG session with GTRAF. Photographs of the displays are provided to illustrate the process.

Described in this paper is the development of an interactive computer graphics (ICG) system that provides users with a new and highly efficient methodology for reviewing the user inputs to the NETSIM model and for analyzing the results generated by the NETSIM traffic simulation model *(1)*. Although this system is limited to the NETSIM model, the technology and much of the graphics application software can be employed for other traffic simulation models embedded within the FHWA-sponsored TRAF System *(2)*.

NETSIM, which is probably the most popular and widely used traffic simulation model in the United States, is a Fortran-coded software program that describes the operational performance of vehicles traveling over a network of surface (nonaccess controlled) streets. The internal logic of this microscopic model describes the movements of individual vehicles responding to external stimuli including traffic control devices, the performance of other vehicles, pedestrian activity, transit operations and driver behavioral characteristics. Statistics are gathered that provide detailed traffic performance measures (e.g., speed, volume, density, delay, stops, intersection spillback, queueing, turn movements, fuel consumption, emission pollutants) on each network link over specified time intervals.

A description of NETSIM follows and more information is provided elsewhere (2, Vol. 2–4). NETSIM is perceived as an engineering tool, both for research and for practical application. The need for NETSIM and for other computer-based tools is discussed.

THE NETSIM TRAFFIC SIMULATION MODEL

The basic approach in the NETSIM model is the application of an interval-scanning, microscopic, stochastic simulation to describe traffic operations. The physical street system is represented as a network comprised of one-way links with the intersections represented as nodes. The traffic stream is modeled explicitly; each vehicle on the network is treated as an identifiable entity. Furthermore, each vehicle is identified by category (automobile, carpool, truck, bus) and by type. Up to 16 different types of vehicles with different operating and performance characteristics may be specified defining the four categories of the vehicle fleet. In addition, a driver behavioral characteristic (ranging from passive to aggressive) is assigned to each vehicle. A vehicle's kinematic properties (position, speed, acceleration), as well as status (queued or free-flowing) are determined in each 1-sec time step. Turn movements are assigned stochastically, as are free-flow speeds, queue discharge headways, and other vehicle-specific behavioral attributes. Consequently, each vehicle's behavior can be simulated in a stochastic manner, reflecting real-world processes.

Each time a vehicle is moved by the program logic, its position (both lateral and longitudinal) on a network link is determined, as well as its relationship to other vehicles nearby. This approach allows the program to simulate the detailed, vehicle-specific, traffic processes so that actuated signal control may be simulated and bus–automobile interaction can be explicitly modeled. In general, most conditions experienced on an urban traffic environment can be realistically described.

As an interval-scanning simulation model, each vehicle is moved each second according to car-following logic and in response to traffic control devices and other conditions that influence vehicle behavior. The onset of congestion could result in queues extending throughout the length of a link to block the upstream intersection, thus impeding traffic flow there. The effects of such blockage are modeled realistically; vehicles on cross streets recognize when they are physically blocked by spillback and cannot move. Pedestrian traffic can delay turning vehicles at intersections.

Many other examples describing the factors that are prevalent in urban environs and that are explicitly treated by NETSIM can be given. Most of these microscopic treatments are transparent to the user whose prime concern is the bottom-line description of traffic operations provided by the model in the form of link-specific, detailed, operational MOEs.

A wealth of information is provided as output by NETSIM. The following list is a sampling of what is available:

- Vehicle miles of travel
- Number of vehicles discharged from link
- Total vehicle minutes of travel time
- Total delay time (computed as the difference between the total travel time and idealized travel time for each link based on a specified free speed)
- Ratio of moving time to total travel time
- Total travel time for link
- Average travel time per vehicle
- Average delay time per vehicle

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- Average delay time per vehicle mile
- Percentage of stopped delay
- Average traffic speed
- Average occupancy
- Average number of stops per vehicle (expressed as the percentage of vehicles stopping at least once within the link)
- Average storage percentage (expressed as a time average of the length of the link occupied by vehicles divided by its total storage capacity)
- Cycle failure (defined as the number of times a queue present at the beginning of the green phase fails to clear the stop line by the end of the green)
  - History of queue lengths by lane
  - History of intersection spillback

The ability to replicate individual vehicle trajectories allows NETSIM to simulate the data accessed by individual passage and presence (long loop) detectors.

NEEDS OF TRAFFIC ENGINEERING PROFESSIONALS

Historically, the sharply decreasing costs of computation over recent years has been matched with an increasing cost of professional services *(3)*. These divergent trends are taking place at the same time that there is a growing need for extracting improved productivity from a highway infrastructure of severely constrained growth, which must service a continually growing traffic demand. As stated by Rothenberg *(4)*:

> . . . a consensus in the highway profession is that with the limited highway funding program, a resurgence in the economy, stable fuel prices, and continued growth in most urban areas, traffic congestion is a serious problem which will increase in the future and must be dealt with.

Specifically, studies indicate that traffic demand is growing at a rate of 4 percent per year, while construction of new facilities to accommodate this increased demand is increasing at a rate of much less than 1 percent per year. With 40 percent of urban travel already operating under congested conditions, at an annual cost of 37 billion hours, it is imperative that new and more productive tools be aggressively utilized to assist the engineer to improve traffic performance. In this environment, the engineer must achieve superior results in less time, with greater accuracy and reliability, and at lower cost, than ever before.

Techniques and procedures that have served adequately in the past, which were based largely on empirically derived procedures documented in handbook formats, are often no longer acceptable. Problems today often take the form of interrelated systems that must be treated as such and not partitioned into smaller, unrelated elements. For example, many arterials are actually embedded within larger grid networks. Although a signal control timing plan for the arterial could be developed by using manual bandwidth procedures, such a solution may be significantly inferior to one that is, for example, obtained by using TRANSYT 7F applied to the surrounding grid network.

However, many practitioners are still reluctant to use computerized tools. This may stem from a lack of experience and understanding, inadequate access, or a concern over dependence on a "black box." Quite possibly, the greatest barrier to the use of these more powerful and productive computer-based tools is the substantial effort involved in preparing the data needed, entering these data into the computer, and in wading through extensive output statistics to gain the necessary insights being sought.

Such perceived impediments combine to dissuade the professional from using more powerful tools and to encourage favoring the simpler procedures that provide "reasonable" answers. Consequently, the results obtained are often of less value than could otherwise be realized.

Fortunately, advances in computer technology and in available software systems offer the potential for eliminating, to a major extent, the impediments limiting use of computerized tools. These are described next.

RESOURCES PROVIDED BY TECHNOLOGY

Until 5 years ago, many engineers who explored the possibilities offered by computerized tools had limited access to mainframe or mini computers. Often, the costs associated with such computer usage exceeded available budgetary resources. In addition, it was often necessary to employ personnel who were computer specialists with little or no knowledge of the problem to be solved, which added to the cost. Finally, the entire procedure of preparing input data, checking it, submitting the computer run, and awaiting and analyzing the voluminous results was tedious and time consuming, as well as costly.

Several advances have since radically altered the computing environment for most public and private agencies:

- The introduction of microcomputers with powerful 16-bit processors available at relatively low cost.
- The availability of FORTRAN compilers, which enable the user to transport software designed originally for mainframe computers, for use on microcomputers.
- The widespread proficiency attained by traffic engineers in the use of such microcomputers, thus obviating the need for computer specialists.
- The emergence of a graphics standard known as the Graphics Kernel System (GKS), which accommodates the development of Interactive Computer Graphics (ICG) application software that is largely hardware-independent.

These developments have, in turn, prompted FHWA to sponsor the development of software to greatly improve the user accessibility to these computer tools, which have been "ported" from mainframes to microcomputers. The ITDS *(5)* and INTRAF *(6)* software enables users to enter data to the NETSIM and Transyt models in a "friendly" interactive mode. Other tools have also been developed to exploit the intrinsic benefits of terminal and microcomputer-based access to most computers.

The use of graphics has spread rapidly in recent years as a preferred method of displaying and assimilating statistical data. Probably the most dramatic examples of the popularity of graphics are the emergence of computer-aided design (CAD) and engineering (CAE) systems, the graphics presentations

associated with such spreadsheets as Lotus 123, and the explosive growth of graphics work stations designed expressly to service the engineering community. This transformation, which expresses results in a pictorial format instead of statistical tabulations, has led to impressive gains in engineer productivity.

The adoption of the GKS standard by the American National Standards Institute (ANSI) offers the opportunity for developing applications software designed expressly to present the results generated by powerful computer tools in a graphical format and in an interactive mode. That is, the user can select the displays to view on a screen at any time during a session while seated at a microcomputer or terminal.

Furthermore, the user need have no computer expertise whatever in order to access these tools and need not learn a command vocabulary or undergo any formal training. The displays themselves are often in color and are designed to provide all the information—plus more—that would normally be extracted from robust listings of statistical tabulations.

The initial development of an ICG system sponsored by FHWA was designed for presenting NETSIM results. This system is described in the following section.

THE NETSIM GRAPHICS SYSTEM

The NETSIM model provides detailed statistical data describing traffic operations on each network link at specified points in time. The analyst must then perform a detailed review of this extensive statistical output in order to abstract the information that is sought.

This effort to convert data into information can be time consuming and sometimes requires considerable skill. Consequently, this effort is often the most costly aspect of an investigation employing the NETSIM model. Because of this cost, and the need for skills that are in short supply, many agencies have not used the NETSIM model and have adopted less useful procedures.

Another problem with NETSIM is the issue of credibility. Many managers are reluctant to depend on a "black box," particularly if they feel uncomfortable—due to a lack of knowledge or understanding—with the simulation approach. It is often difficult for many to accept the idea that a computer tool can actually describe the complex processes of traffic flow at an acceptable level of accuracy and reliability.

The NETSIM graphics software, named GTRAF, is designed to provide information rather than data, and insight rather than statistics alone. The interactive mode of operation frees the user completely from any dependence on a knowledge of computer technology. The system does not require a voluminous user's guide replete with technical jargon; instead, operating instructions consist of a few lines displayed on the monitor at the start of a session. Finally, the displays vividly demonstrate NETSIM's ability to represent the traffic environment, thus solving the credibility problem.

Design objectives were realized by postulating well-defined concepts that exploit current technology, and then translating these concepts into software. The concepts are as follows:

1. Elimination of an extensive user's guide and substantive training by

    a. Developing simple, user-friendly procedures for communicating with the graphics application software;

    b. Providing all guidance on line in the form of brief messages (prompts or cues);

    c. Using menus from which the viewer can select the next display, using either a mouse or keys; and

    d. Providing guidance to the user in the form of an online help feature, which explains how to apply GTRAF to analyze the problem at hand.

2. Use of color to transmit graphical information.

3. Interleaving text (numbers and words) with pictorial graphics to provide both qualitative and quantitative information.

4. Guiding the viewer in identifying the problem areas in the traffic environment, quantifying their extent and analyzing the underlying cause-and-effect relationships.

5. Use of animations that impart to the user the dynamic traffic flow processes expressed in terms of operational measures of effectiveness (MOE).

6. Use of animated displays of individual vehicle movements as an option.

7. Performance of all data management functions, which transform NETSIM output into GTRAF inputs, in a manner that requires no action on the part of the user.

8. Integrating NETSIM and GTRAF software to form a coherent system that enables users to perform all necessary functions in a single session.

9. Use of a graphics package that conforms with the GKS ANSI standard and developing all software exclusively in Fortran. Thus, the software can be implemented on any computer that supports an ANSI Fortran compiler and a GKS package, and that has a color monitor.

10. Provision of hard copy of many graphical displays using a color plotter. These displays can be used for documenting a case study.

GTRAF was developed on an IBM PC AT equipped with the IBM Professional Graphics Controller and color monitor. The software can also be executed on a PC AT or XT equipped with the Enhanced Graphics Controller and color monitor. Two Fortran compilers were needed: Microsoft for the GTRAF software and Ryan-McFarland for NETSIM. The need for two compilers was dictated by certain limitations of each. The GKS package used is a product of Graphics Software Systems, Inc.

As shown in the system configuration diagram in Figure 1, the NETSIM simulation program and the GTRAF graphics software are two independent pieces of software. NETSIM must be executed first to generate the data needed by GTRAF for the graphics display. When executing NETSIM, a "case" name identifier must be specified as part of the input stream. The graphics data produced during the NETSIM execution are then stored in files associated with the given case and the case name entered in the case log. This way, a library of case studies can be established and stored on disk. The results of any case entered in the case log can subsequently be viewed graphically using GTRAF.

The logical structure of the GTRAF display hierarchy is shown in Figure 2. On entering the system, the viewer will review the welcome display, which contains instructions on how to use the mouse (or cursor positioning keys) to select menu items and how to browse through the display hierarchy. Next, the user then is provided with a menu listing the various
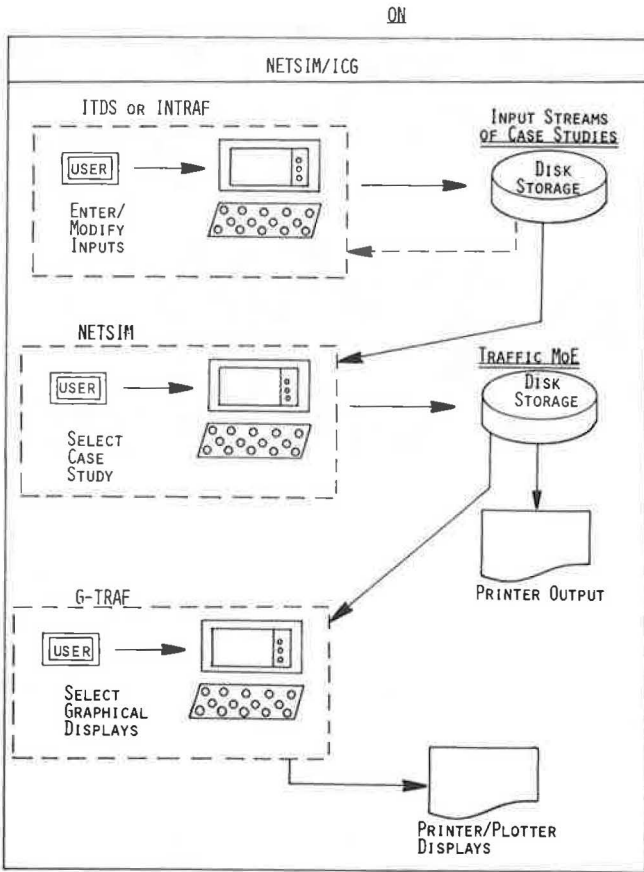
FIGURE 1 System configuration.

NETSIM output files that have previously been stored on hard disk and is prompted to select one. At this point, the software retrieves the selected file from disk and prepares the data for the ICG session. Note that the user must specify in the NETSIM input stream that an ICG session using GTRAF is contemplated and that the appropriate data files are to be generated by the NETSIM software.

The following section is a step-by-step guide through a session using GTRAF.

GUIDE TO AN ICG SESSION USING GTRAF

It is not possible, within the confines of this paper, to demonstrate the uses of all the GTRAF features. Instead, a walk-through of a portion of an ICG session is presented here in order to illustrate the underlying procedures and, it is hoped, to stimulate the reader's interest in this system.

The network schematic and the master menu, which comprise the first display to appear after the viewer selects a NETSIM case study, are shown in Figure 3. The cross-hair cursor (not shown) can be moved using the mouse or cursor keys to any menu item. If the view input data menu item is picked (selected by depressing the mouse after the cursor is positioned over the selected menu item), then a new menu appears offering a choice of displays. At this time the viewer could also elect to view the NETSIM output data, select another NETSIM case study, or end the session.

Note that the prompt message at the bottom of the screen guides viewer responses. These messages, the menus, and the viewer responses (in the form of menu option selections) con-
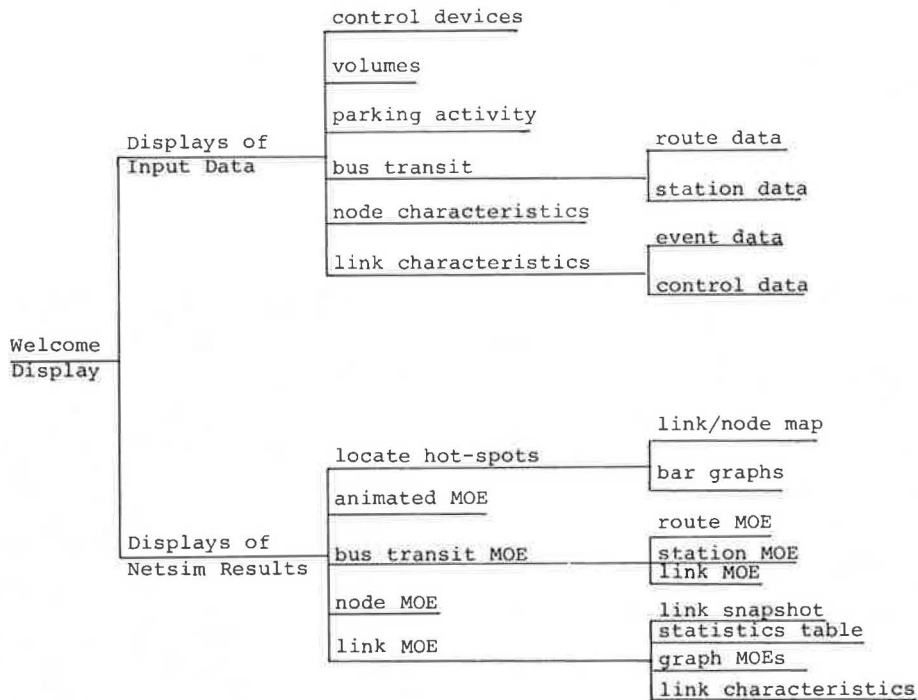

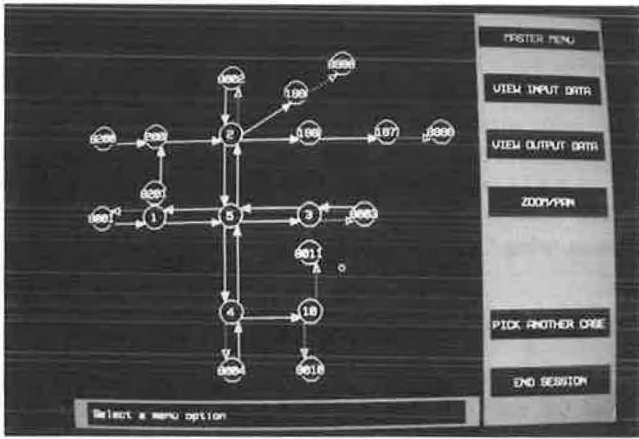**FIGURE 2 GTRAF display hierarchy.**

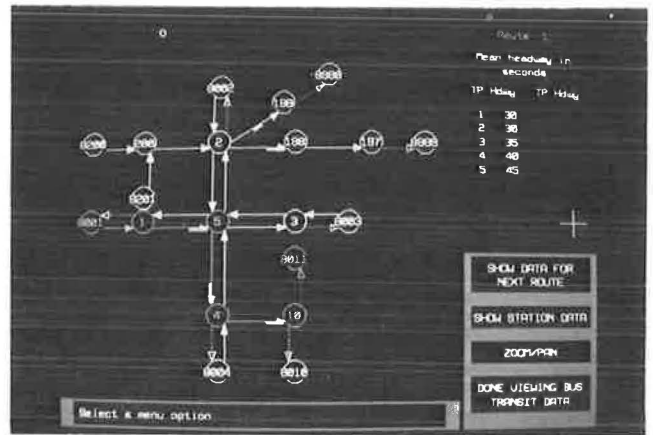FIGURE 3 Network schematic and master menu.

FIGURE 5 Bus route schematic and specified headways.

stitute the mechanics of the man–machine interaction. The GTRAF software retains a display until action (a response to a prompt message) is taken by the viewer. This succession of viewer menu-selection actions and GTRAF responses projecting the requested display on the screen enables the viewer to browse through the NETSIM data base to extract the information desired.

Whenever a display includes the network schematic, as in Figure 3, the zoom/pan menu option is provided. The option enables the viewer to study sections of the network on a magnified scale or to view more of a network on a smaller scale, at any time. If this menu option is selected, a new menu appears that enables the viewer to pan left, right, up, or down and zoom in or out, repeatedly. The viewer can pan and zoom in any sequence desired.

One of the displays available to a viewer wishing to review the NETSIM input stream is shown in Figure 4. Here, the display presents the specified traffic demands at all entry nodes at the periphery and all internal source/sink nodes representing parking facilities. The different types of nodes are distinguished by different colors. At this time, the viewer can request a display showing these data for the following time period, select a particular entry link to obtain a time history of

specified traffic demand, zoom or pan this display, or return to the next higher menu to select another type of display.

When the viewer wishes to review the information specified for bus routes the display shown in Figure 5 appears. Here, the display highlights those links defining the bus route (and the stations serviced by that route) in a different color (orange) from the rest of the network links and stations, which are shown in white and yellow, respectively. The bus headways specified for this route, for all time periods, are also shown. At this point the viewer can request this display for the next bus route, request more detailed information for one of the stations serviced by this route, zoom or pan, or return to the next higher menu to examine other displays. Note the cross-hair cursor positioned above the menu.

In Figure 6 the locations of all curb parking zones (see links 1,5; 5,4; and 4,10) are identified, and parking activity for a particular zone requested earlier by the viewer is also provided. Because this display is at the bottom of a logical tree of GTRAF, the viewer can only continue by moving up to the next higher level.

Shown in Figure 7 is a more detailed display of the links approaching and departing a viewer-selected node. This display indicates the lanes on all these links, a link-node sketch as a
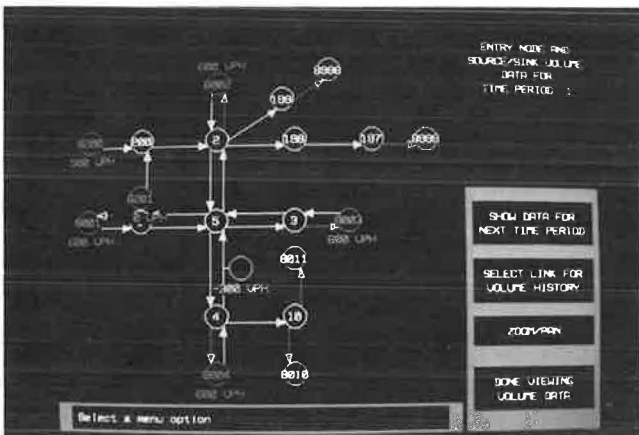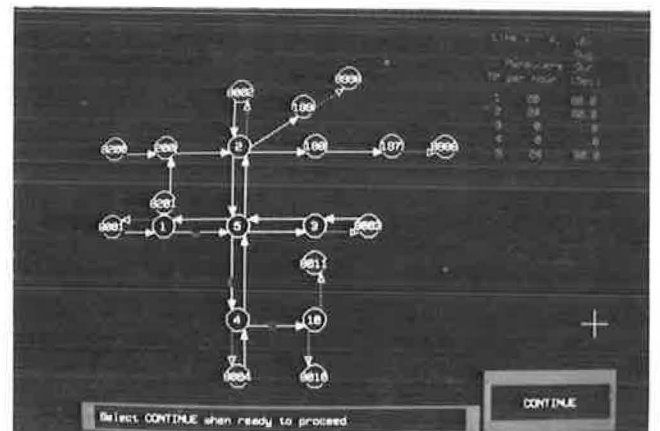

FIGURE 4 Specified demand volumes.

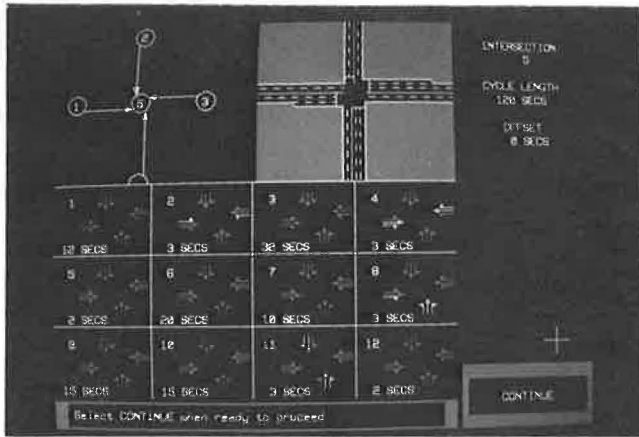FIGURE 6 Display of curb parking zones.

FIGURE 7 Node display with specified control and link geometrics.

FIGURE 9 Hotspots display of link-node format.

reference, and the movements serviced during each signal interval. Each arrow depicting a traffic movement on an approach to the intersection is colored in red, green, or yellow, defining the applicable control for the indicated signal interval. The signal cycle length, reference offset, and each interval duration are also indicated.

Figure 8 is a detailed link configuration showing the lane channelization, right-turn-on-red treatment, pedestrian volume, applicable signal control, specified turn movements, and receiving nodes for each time period. Color is used extensively to distinguish the various features and signal control.

The following illustrations are of some displays showing NETSIM results (output) in formats selected by the viewer. One of the most valuable features of GTRAF is the "hotspots" menu option. Under this option, the viewer can request GTRAF to present displays identifying links that exhibit extreme conditions, relative to the network as a whole. For example, the viewer can ask the system to identify links with the lowest speed, or greatest delay, or highest volume or highest density, and so on. This feature permits the viewer to immediately identify and analyze the trouble spots within the network with no loss of time.

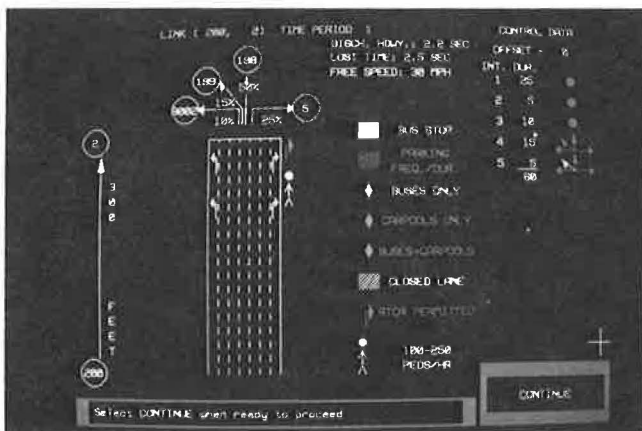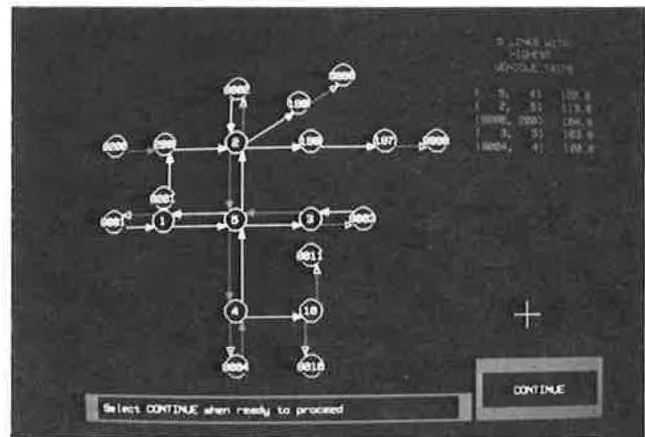In Figure 9, five links with the highest discharge volume in a link-node format are shown. These links are highlighted in red and the values of vehicle trips for these links are presented numerically. Hotspots information in bar-graph format is also shown in Figure 10. Here, the five links identified on the basis of lowest speed are specified. The viewer has the option to request up to two additional MOEs to be presented in the same format for the five links. The values of the selected measures are also given in numerical format.

Another feature of GTRAF is shown in Figure 11. Here, the user has requested a graph depicting the variation of selected MOE (vehicle trips) over a selected time frame (12:30 to 12:40) for a selected link (200,2). Each curve is drawn in a different color (red, yellow, green, blue) representing total, left-turning, through, and right-turning traffic, respectively. The duration of any queue spillback on this link over this time frame is also displayed (none in the figure). All scaling is done internally. After reviewing this display, the user can change the time frame or the MOE to return to select another display.

Vehicle movements into a selected node (intersection) from the approaches at a specified point in time are displayed as shown in Figure 12.

One format for presenting animation is shown in Figure 13. Here, the links are colored according to the number of vehicle-
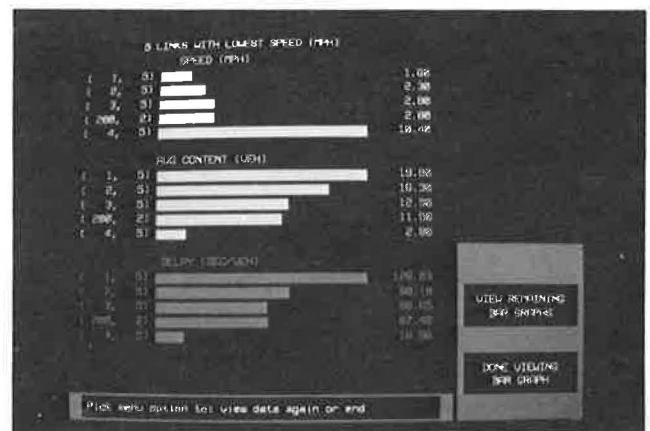

FIGURE 8 Detailed link display.

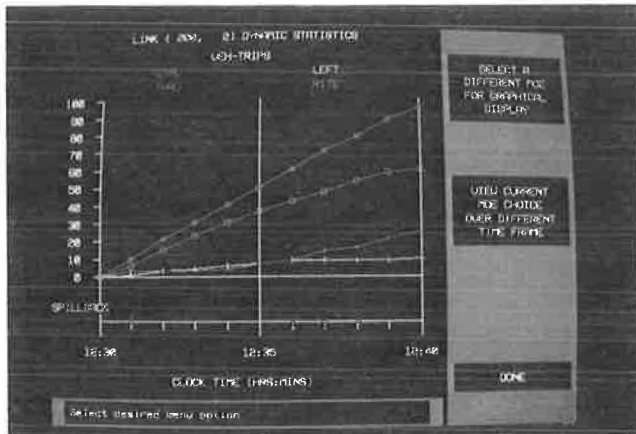**FIGURE 10** Hotspots display—bar graph format.

FIGURE 11 Graphical display of link dynamic statistics.
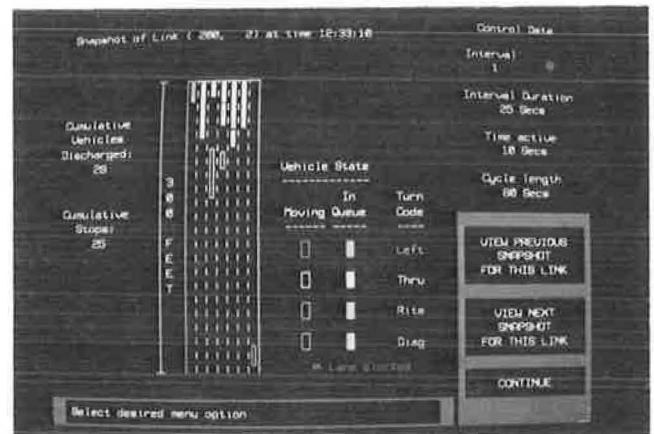

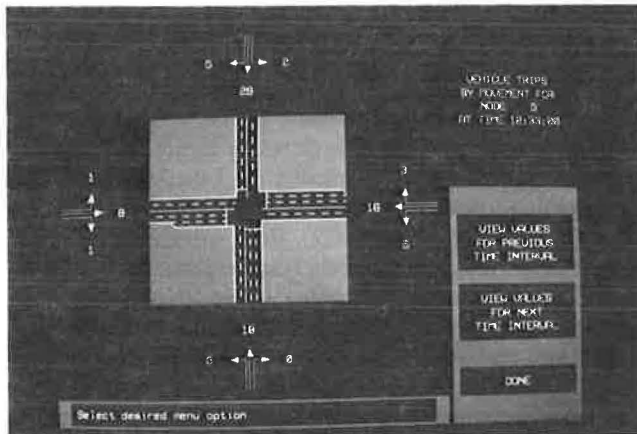FIGURE 14 Step-wise animation of vehicle movements on a selected link.

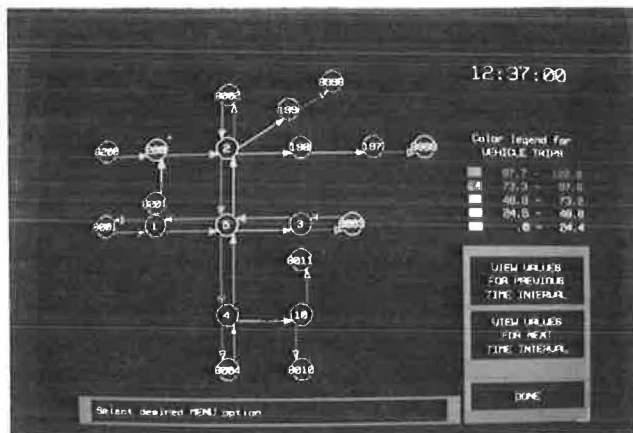FIGURE 12 Intersection traffic demand.

FIGURE 13 Step-wise animation of selected MOE in link-node format.

trips serviced at the indicated clock time. The legend is colored to indicate the associated range of values. The viewer projects ahead (or back) in time to observe how the traffic environment changes with time. The viewer can perform this review with any of several available MOEs. Note the time at which this "snapshot" is taken.

Another animation display is shown in Figure 14. Here, the viewer can observe the detailed movement of vehicles on a selected link at specified (e.g., 10-sec) intervals.

Each vehicle is color coded according to its intended turn movement through the downstream intersection: orange, white, blue, and violet for left, through, right, and diagonal movements, respectively. At each snapshot, the display identifies the time, the signal indication, number of vehicles discharged and stopped, as well as the position of each vehicle on the link.

For those users with appropriate computer hardware, GTRAF offers the additional option of presenting vehicle animation at 1-sec (or less) time steps, without viewer interaction, over a selected portion of the network. That is, the viewer can get the same visual inputs from the screen as though traffic flow were being observed from a stationary helicopter hovering overhead. The animation is performed on a schematic display of the network drawn to scale and shows curb lines, stop-lines, lane lines, median lines, turn pockets, and signal indications. Thus, the vehicle movements and changing signal indications provide a graphical representation of the dynamic traffic environment. The user can control the animation to suit his objectives.

As a minimum, an IBM PC AT (or clone) with the Professional Graphics capability is required for the animation displays. At this time, this portion of the GTRAF software is not generally portable to other hardware configurations.

In general, a session will begin with the viewer reviewing the specifications of the traffic environment (that is, the displays of the NETSIM inputs) to check for errors. Following a successful review, the viewer will focus on an examination of the NETSIM outputs. First, extreme conditions (hotspots) will be located and the extent of any associated problems quantified. It is also likely that the viewer would seek an overview

of the dynamics of traffic flow on the network (Figure 13). After using the hotspot feature (Figures 9 and 10), the viewer may then choose to examine individual links and nodes in detail (Figures 11, 12, and 14). There are many other displays, not included here, that will also serve to provide the viewer with the insights and understanding of traffic operations on the test network. Those with appropriate computers can also view the entire dynamic process of traffic flow using the vehicle animation feature.

At the conclusion of a session, the viewer may decide to modify the traffic environment in a manner which, in his opinion, may improve traffic performance. The viewer need only specify these changes to the NETSIM input stream by using the ICG input processing software, then repeat the analysis process. In this way, several detailed studies can be undertaken in a day.

CONCLUSIONS

All transportation planning and traffic engineering tools require significant amounts of information in the form of input data. In addition, as outlined earlier, NETSIM provides the user with an extraordinary amount of invaluable, detailed information on traffic operations over space and time. In the past, potential users were discouraged by the labor-intensive effort of preparing and processing the input data, and by the effort needed to sift through extensive statistical output listings in order to extract the required information.

These concerns have now effectively been eliminated by the development of ICG tools on both ends of the information spectrum. Input data may now be entered by technician personnel with no knowledge of computers or of traffic engineering. This rate of data entry is rapid and is subject to the quality assurance features of the software, which check all input data. The NETSIM input data and results are presented in many attractive ICG formats, all easily accessible to users, and requiring no background in computers. The GTRAF design permits the user to immediately identify the problem areas in the traffic environment and to rapidly determine the causal factors contributing to these problems. In this way, the perceived impediments to the use of NETSIM are removed and the usability of this tool is greatly enhanced.

Based on limited experience with GTRAF to date, it appears to provide users with an efficient, almost entertaining, medium for gaining a level of insight into traffic operations and for achieving a level of productivity that cannot be matched. Use of ICG is anticipated to grow rapidly as an increasing number of agencies become aware of its benefits and as more PCs and work stations with graphic capabilities are procured.

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