Computer Displays for the Traffic Engineer

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This paper describes and demonstrates the application of visual display techniques generated by a digital computer to the problem of evaluating alternative traffic-engineering improvements in congested urban networks. Stanford Research Institute has developed a tool to be used by the traffic engineer in such evaluations. It is a computer simulation called the Dynamic Highway Transportation Model (DHTM). Problems arise when a user tries to analyze the large amounts of multidimensional simulation output produced by DHTM. To make the DHTM method practical for the traffic engineer, cathode-ray tube display equipment, in conjunction with a CDC 3100 computer located at SRI, and a computer programming language designed for use by a traffic engineer are applied to the evaluation problem. Maps with overlays of volumes, speeds along streets, delays at intersections and routes between selected origin-destination pairs can be called for from the display console and shown instantaneously. Plots of demand and delay for all or selected elements of the traffic networks can be called. A number of measures of the quality of traffic service can be specified and evaluated easily while the traffic engineer is sitting at the console.

Technical feasibility of the display concepts is demonstrated. The cost of operating the CDC 3100 display system located at SRI is about $80 per hour. With the technical and economic feasibility in hand, further demonstrations with practicing traffic engineers using the tools of the evaluation methodology should be forthcoming.

•DHTM (Dynamic Highway Transportation Model) is a computer model that dynamically simulates traffic flow in a network. The inputs to this simulation and the resulting outputs involve large amounts of data. The quantity of these data makes it difficult for the traffic engineer to evaluate the outputs and to reduce them to a usable form. For example, a San Francisco test network is divided into 100 origin or destination zones. In general, each origin has demand to about 60 destinations. DHTM generates up to 10 routes between each O-D pair where demand exists and thus an array that contains about 60,000 routes, each involving 4 to 7 links, is used in the simulation. The output of these routes in numerical form (or conventional computer output) would require over 1000 pages of printing. Evaluating these routes for logic and completeness is not practical when they are left in numerical form. The resulting communication problem is alleviated through the use of computer display techniques.

DEMONSTRATION OF COMPUTER DISPLAYS

The displays presented here are the results of an internally sponsored Stanford Research Institute (SRI) project (1), using data gathered as part of a U.S. Department of

Paper sponsored by Committee on Quality of Traffic Service and presented at the 48th Annual Meeting.

Transportation research project (2, 3). The displays were generated from output of SRI's DHTM (4), and from field studies of traffic parameters representing the morning rush hour in a large test network in San Francisco.

Map Display

Figure 1 shows a computer-generated display of a map of approximately one-fifth of San Francisco (2, 5). About 400 links and 100 signalized intersections of the test network used in DHTM are included. Each line represents one arterial street, that, in general, consists of two links. A link is defined as a single direction of a street in the network connecting two intersections. Links and intersections are assigned reference numbers that are not reproduced on the display. A total of 100 O-D zones has been defined relative to the test area.

The map is a common tool for the traffic engineer. This two-dimensional representation of a network provides a frame of reference for evaluating various traffic parameters such as demand and travel times, and gives relative distances, physical barriers, and orientation at a glance. To plot such information from conventional hard-copy computer output would be a time-consuming and costly process. Since the map display is based on computer input numbers, it also provides a cross-check for the inputs used. For example, if a street is input with an incorrect length, a localized section of the map will become skewed, thus indicating the error. The error can be corrected immediately by using the bug to relocate the intersection.

Peak-Hour Volume

Maps of peak-hour volume have (Fig. 2) been used extensively in traffic engineering and transportation planning evaluations (6, 7). The DHTM generates flows, travel times, delays, routes, and other data on traffic conditions throughout the network. Flows and travel times are broken down for short time intervals (of the order of 15 minutes) to

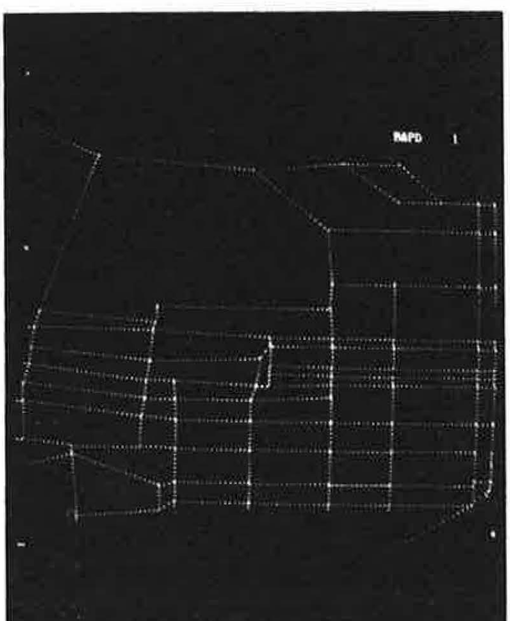

Figure 1. Computer-generated display of arterial street network in western section of San Francisco.

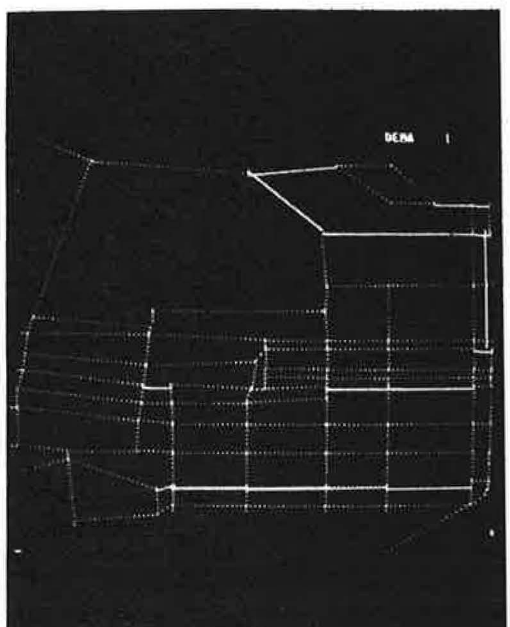

Figure 2. Heavy lines show streets with average volumes greater than 3000 vehicles in two hours (i.e., 0700 to 0900).

treat peaking in the demand patterns. Information for each time period is available for each iteration of the simulation. Peak 2-hr or 1-hr summaries or even a 15-min performance of a network can be shown on the display. A 2-hr representation of volume was chosen for Figure 2, with a threshold concept of presentation used. Links with volumes above 3000 cars in two hours are shown by a heavy line. Similarly, links with more than 6000 cars in two hours are accented by two heavy lines. Using this display the traffic analyst gets a feel for which links are major carriers, to what degree, and where they approach capacity. The value chosen as a threshold, the 2-hr time period, or simple functions of the volume (e.g., straight-, right-, or left-turners) can be designated from the console.

Peak Hour Delay

Travel time and/or delays along streets and at intersections are important traffic operational parameters. With the map as background the user can analyze these parameters from the display console. Figure 3 shows time parameters in the San Francisco network. Average delays of 30 sec per vehicle or more over a 2-hr period are represented by solid lines. The average shown is a summary of the straight, right-, and left-turn delays associated with each intersection. This display is useful in identifying trouble. It should be noted that trouble spots can be caused by an input data error or a simulation error, depending on the source of the data being used to generate the display. On the other hand, an actual physical problem may exist at an intersection. Thus, the total system map can be used to indicate the overall quality of traffic service as a function of travel time and/or delay.

Field Data Comparison

The previous displays are generated by using simulated volume counts and delays. A comparison with field data shows the user how well the simulation is performing. Figure 4 shows a magnified map of the central section of the test network. Offset

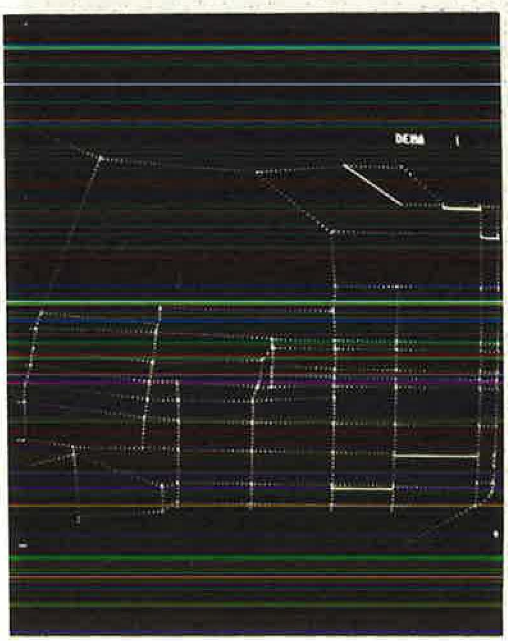

Figure 3. Heavy lines show streets with average intersection delay per vehicle of 30 sec or more.

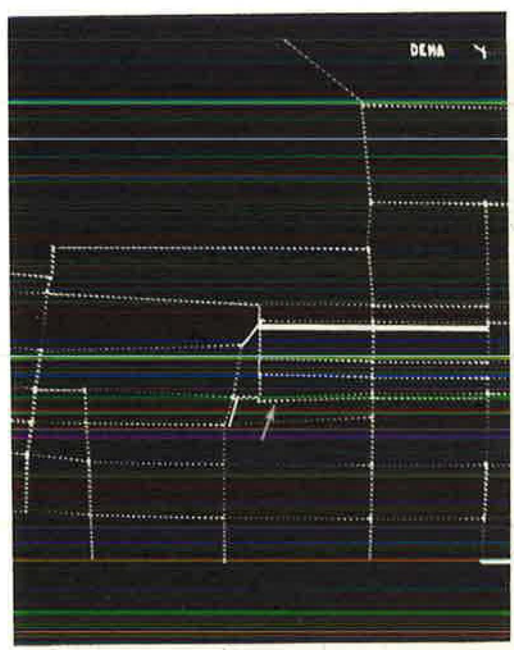

Figure 4. Magnified map display showing differences between simulated and field-measured volume data; offset lines show differences greater than 500 veh in two hours.

dotted or solid lines are used to indicate differences between simulated and field measured data; a solid line represents modeled volumes that were 500 veh less than the field volumes during a 2-hr period; an offset dotted line (arrow) represents modeled volumes that were 500 veh greater than the field volumes during a 2-hr period. A shift of simulated vehicles between two parallel links in the center would make the modeled data fit the real world more closely. Obviously this display is valuable in determining how to improve the simulation.

Magnification

Figures 4 and 5 both demonstrate the ability of the display to magnify a map. In the case where the user wishes to display the actual numerical differences between modeled and field volumes over two hours, the desired section of the map is magnified by a factor of three. The resulting display is shown in Figure 5, where it seems that for some reason the simulation has underestimated the number of vehicles on the northbound links.

Magnified Map Showing Delays

After looking at Figure 5, the user may well ask why the differences in volumes exist. Figure 6 demonstrates the ability to display average vehicle delays at each link intersection in a magnified area. Each delay is given in seconds per vehicle. In this case the delays shown on the display seem reasonable based on traffic engineering experience with the intersections being considered. Thus the analyst may conclude that the fault lies in some step in the simulation process that took place before generating delays from volumes.

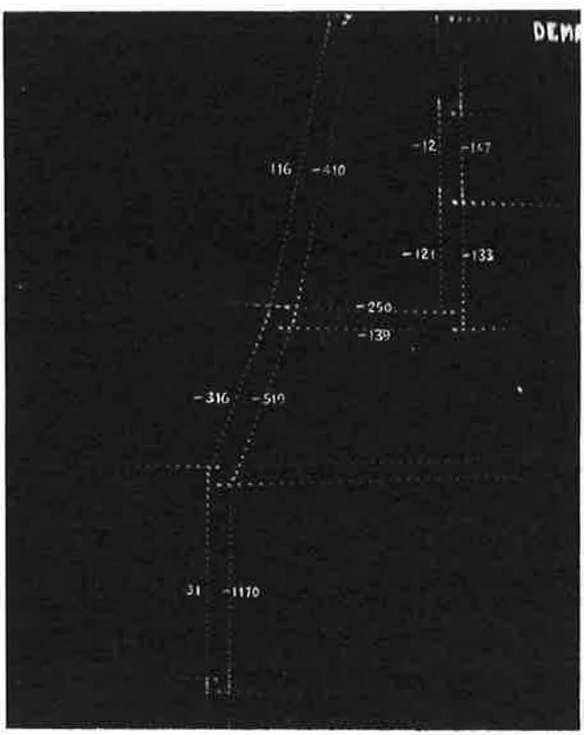

Figure 5. Magnified map display showing numerical values of the difference between simulated and measured volumes.

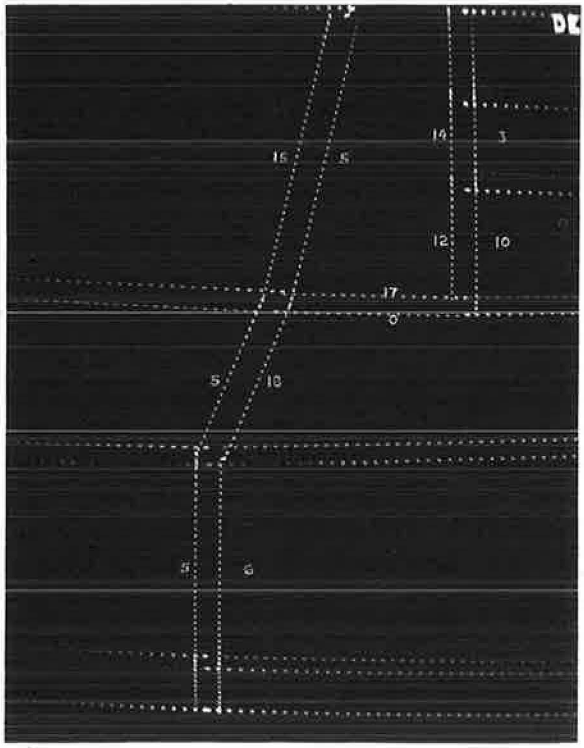

Figure 6. Magnified map display giving values of average delay (seconds per vehicle) for all links.

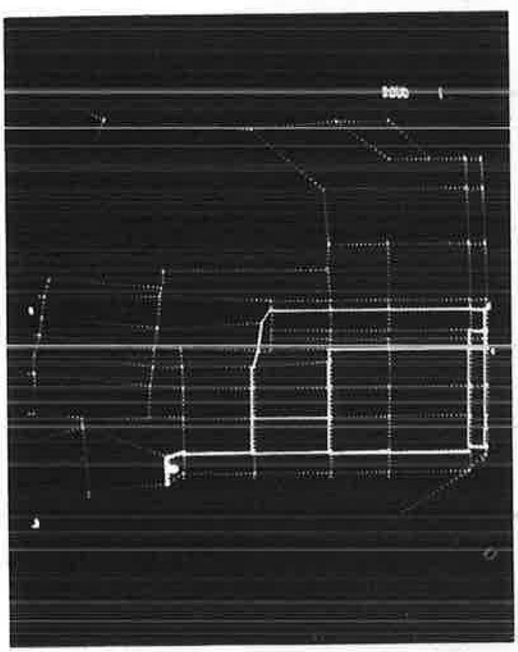

Figure 7. Alternate routes from origin zone 100 to desitnation zone 9, based on shortest distance, minimum delay, and minimum travel time.

Routes

Figure 7 demonstrates the ability to display alternate routes from origin zone 100 to destination zone 9 in downtown San Francisco (i.e., the financial district lying to the right of the picture). A traffic engineer familiar with the area would note that an important alternate has been omitted. This route is one that has a right turn at the intersection approximately at the center of Figures 5 and 6. In a later analysis of the problem, a hand calculation of the route selection algorithm shows that this route was about as good as any of the others. Thus a provision was made to include this route as one of the alternates for this O-D pair. On rerunning the simulation with the new route, a display like Figure 5 indicated more favorable simulation results.

Link and Intersection Demand And Delay

In addition to general information on the trouble spots in the network or on possible data inconsistencies, further de-

mand-delay information may be desirable. Figure 8 demonstrates how a system of graphs can be displayed to allow the traffic engineer to compare the computer description of a particular intersection or link with his intuitive feel or knowledge of how it should function. The graph shows average delay in seconds per vehicle versus demand or volume for all traffic on link 181 at its associated output intersection. The principal demand at this intersection is for a left turn. Each demand level given for link 181 was produced as the number of vehicles being routed through the link changed as a result of more routes being generated between all O-D pairs in the network. Changes in demand level indicated by the numbers 3 through 9 on the display were produced after routes 3 through 9 had been generated. Using the physical description of this link and intersection, the traffic engineer can determine if the delay generated by the simulation is of reasonable magnitude. The plot shown is for average delay over a 2-hr period. The delay values from the plot can be output on the line printer. The straight-line portion of the plot represents a delay of about 30 sec per vehicle. The maximum delay is about 195 sec per vehicle, and the knee of the curve occurs at about 1450 veh in two hours with over 95 percent left-turners. Of course intersection performance in general is affected dynamically by all 12 flows (i.e., four directions with three turning movements each) at the intersection. Any one of those flows can change as new routes are generated. Similar plots for travel time and delay for each turning movement through the intersection can be overlayed. Obviously, many insights can be gained from these plots, such as the extent to which capacity should be increased, demand decreased, or signal parameters changed to achieve better service. One of the more important capabilities is that of determining critical demand for a particular intersection. At this point other displays, describing the cross street and opposing traffic, should be called to evaluate a possible physical change at the intersection.

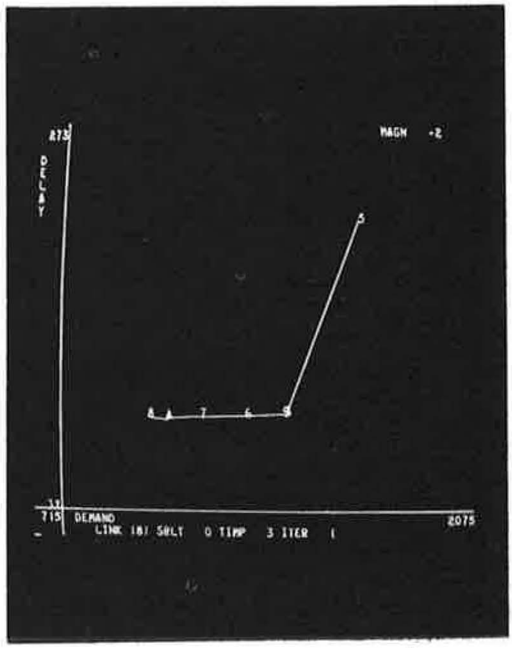

Figure 8. Computer-generated plot of delay (seconds per vehicle) versus demand (vehicles in two hours); the number of alternative routes available between each O-D pair is given for each point.

Network Demand and Delay

Figure 9 demonstrates a method for evaluating total network performance from the display console; it shows a plot of delay versus demand averaged over all intersections and links of the network. Each new point on the plot represents the demand and delay associated with increasing the number of alternative routes in the network. The results indicate that with 8 or 9 routes the simulation predicts a delay of about 19 sec per vehicle and a demand of about 800 veh on an average link of the network. The traffic engineer can use this display to evaluate measures of the quality of traffic service that include total travel time, average delay, average speed, and total vehicle-miles per hour. Sitting at the console he can define and evaluate any one of the measures in all or any part of the network. This allows him to look at only those intersections and links with demand near capacity or satisfying some other criterion or point of view taken in the evaluation.

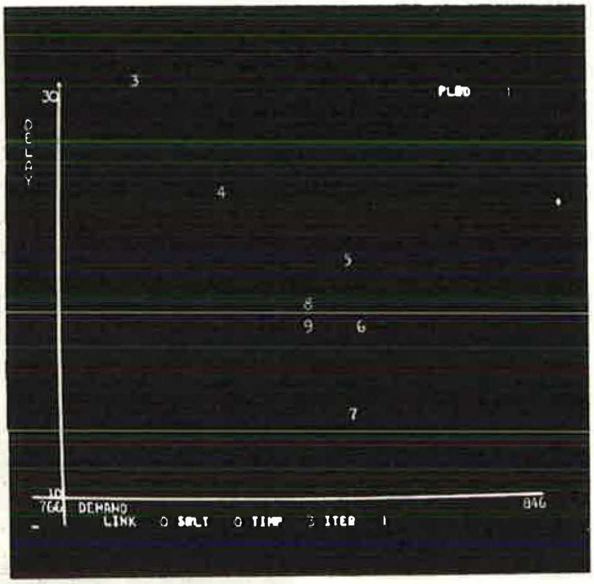

Figure 9. Plot of average delay per vehicle versus demand per link for all links of the network; the number of alternative routes available between each O-D pair is displayed as a label for each point.

THE DISPLAY SYSTEM

Physical Characteristics of the Display

The requirements for computer hardware are an important consideration to the potential user of a display system. The configuration at SRI consists of a CDC 3100 computer with three magnetic tape units, a line printer, a card reader, a 700,000 word disk, and a display system including a 512- by 512-point cathode-ray tube, a keyboard, and a cursor. The present system costs about $80 an hour to operate. Figure 10 shows the work station on the CDC 3100 system and Figure 11 shows a schematic of the computer hardware and its function. For the San Francisco example, disk memory of approximately 400,000 words was used to store 9 routes between each O-D pair, volume counts and delays on 400 links during 8 time intervals, and 10 iterations of the simulation. Any word of data can be accessed by the system in less than one-half second. This capability coupled with efficient retention of frequently referenced data in the computer core, provides the operator access to any form of the data with no discernible delay while a display is generated.

Operating the system is a simple task. Pressing three buttons on the computer console initiates the program. The traffic engineer may then sit at the keyboard before the display and make requests or write a program. Anything he types in from the keyboard appears immediately on the display. He may backspace and retype characters, delete a line, or request that the line be executed.

A "bug" is used as a pointer on the screen; it can be moved about the screen by using the "mouse" on the console table. The operator can press a button on the mouse to indicate that he is pointing to something he wishes to identify. For example, while a program is displayed on the right side of the screen, the operator may wish to change one of the instructions. To do this, he points at the instruction. The identified instruction will light up and he may type in the new instruction. The flexibility this affords is obvious: the operator can correct his mistakes and add or delete instructions—making the programming process quite simple.

Similarly, the bug can be used to identify an area of any display for magnification, to reposition links or intersections on the map, or to adjust other parameters. Data from the disk in numerical form can be displayed directly. During analysis of the

Figure 10. CDC 3100 display system work station.

routes, the link numbers making up a route can be printed. The traffic engineer can generate a new route by typing in STRAIGHT, RIGHT, or LEFT at intersections to select successive links of the new route. When he wishes to save a particular display, he can store it on magnetic tape for future plotting by a Cal Comp plotter. The operator can also interrupt a program he has written when it is no longer useful or when he desires more detail about an event that has been observed on the display.

The principal difficulty that a traffic engineer will have is remembering what instructions are available and how each should be used. To alleviate this problem, a

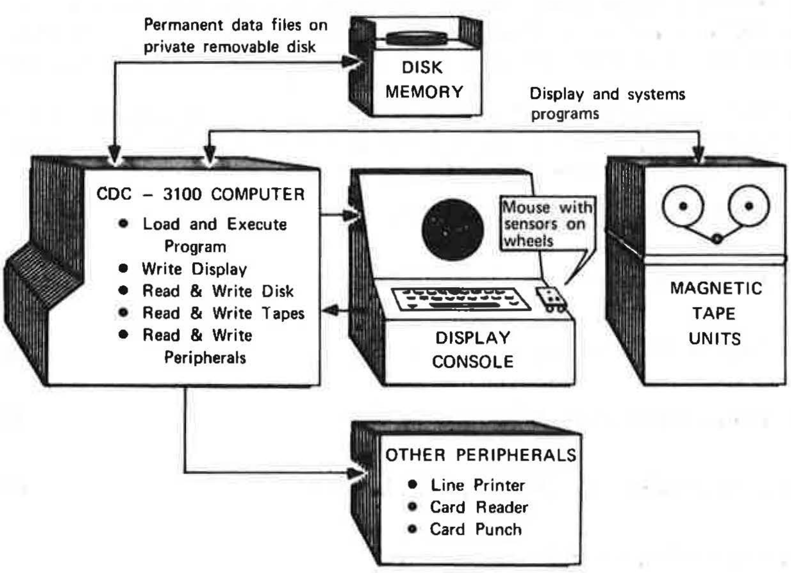

Figure 11. Schematic of CDC 3100 computer and display console.

description of each instruction is stored on the disk and may be displayed any time the operator needs to refresh his memory.

A Traffic Engineer's Display Language

A system of computer logic has been developed to provide the user with his own computer programming language for display of measured traffic networks. Display of a Measured Traffic Network (DMTN) is a computer program that implements the language. Simply defined, a language is a system for representing and communicating information or data between man and machine. As the user types at the keyboard in front of the display screen, various characters are shown. These characters can form names, numbers, or pictures. Names are strings of characters that have special meaning to the computer. For instance, in the language of DMTN, MAPD 1 typed in and executed will cause a map to be displayed. It will be displayed in the area of the screen defined as display number 1; MAPD is the name of a subroutine built into the program to perform this function.

In general the display language consists of strings of characters that have some predefined meaning (8). Remembering these meanings presents some difficulty for the user, but this difficulty is offset by his ability to write unique sequences of instructions and thus to broaden the use of the display. For convenience and ease of operation, the result of each instruction that is typed in and executed is shown on the display. Furthermore, the instruction can be added to a saved program, and a sequence of saved instructions can be executed repeatedly without the user having to retype them. Through this feature the user can look at a list of words that belongs to the language, type one in as an instruction, and see what happens. If he does not like the results, he can cancel that instruction and try another or a different sequence of instructions.

During execution of a program, branching to some alternative series of instructions may be desired. Before proceeding along a new branch, the language interpreter restores variables to their original condition. This is a definite contrast to the usual computer-programming language that consists of a series of instructions executed one after another by the computer, after which variables are left as they were at the end of each branch. The purpose of developing the display language in this unique way is to simplify programming. While programming at the keyboard of the display, the user has to remember only the higher ordered instructions above the branch being programmed. The program as it is developed at the keyboard is stored as a tree with branches and nodes. When a branch has been made, it is impossible to execute another branch of the tree at the same level without returning to a starting branch. The inability to branch to any node of the instruction tree has not proved to be detractive to the language since the user can consider each path through the tree as a logical entity in itself.

Perhaps the above description of the basic features of the language is a bit difficult to follow. For further clarification, an example has been worked out. A program to display nine routes between a specified O-D pair follows:

The first two lines represent a branch label:	III- 2
The next two set the line type for the map to dotted:	LINE 1
The next two display the link map on the display defined as 1:	MAPD 1
The next two read a value into ORIG as the origin zone:	ORIG 95
The next two read a value into DEST as the destination:	DEST 5
The next two are a branch label:	1 - 21

The next two initialize the iteration number as zero:	ITER 0
The next two call for nine repetitions of every instruction below that is part of the current branch:	DO 9
The next two increment the iteration number by one:	ITER + 1
The next two change the label so that simultaneous displays can be shown on display number 1:	LABE + 1
The next two display the route between the origin and destination zone specified on display number 1:	ROUD 1
The next two set delays of 15 seconds for keeping the display on the screen:	TIME 15
The next two lines represent a new branch with a higher number than 1 and so terminate the DO:	2 - 0
The last indicates the end of the program:	END-

Figure 12 is an actual display of the program, and the display resulting from the program is very similar to that shown in Figure 7. Various routes from origin 95 to destination zone 5 are displayed in the order they were chosen (i.e., on each iteration of DHTM). A new route is shown every 15 sec unless the operator interrupts the program.

In summary, a language for communicating with a computer on the problem of traffic on urban street networks has been developed and illustrated. The language has a unique feature of tree storage of instructions with a self-restoring feature that makes use of the display language from the console quite easy. The real utility of the display language can be proved only when analysts and engineers can use the display in a network evaluation. To date, the language and associated equipment have demonstrated many of the qualities necessary to make computer display a practical tool for these potential users.

TOWARD A PRACTICAL METHODOLOGY

The objective of developing the computer display techniques is to demonstrate the technical and economic feasibility of using these techniques as part of a practical method of measuring and evaluating traffic engineering improvements in urban street networks. The methodology requires two specific tools: a dynamic simulation model of an urban traffic network and a set of computer display techniques to be used in conjunction with the simulation. Both of these tools go beyond the present state of the art in traffic engineering.

The DHTM has been developed as a tool for comparing alternative highway improvements in terms of user benefit and cost. The model has been refined and is in the process of being calibrated by using input data gathered in a large test network in San Francisco (5). The model

Figure 12. Program to display nine routes between origin zone 95 and destination zone 5.

is unique in that it treats the dynamics of demand and delay in a congested street network at rush hour and has sufficient component detail to allow the evaluation of many of the important parameters of interest in an urban traffic network. These parameters include signal timing, signal progression, turn channels, signal phasing, and parking restrictions.

In the model, origin-destination-time (O-D-T) inputs are treated for short periods (on the order of 15 min) to account for peaking at various points within the network. A number of alternative routes between O-D pairs are developed so that the decisions available to the population of drivers making the route choice can be represented. Traffic is assigned to these routes on the basis of time, distance, and comfort; then the resulting travel times, and other quality of traffic service measures throughout the network are calculated. During the process, a submodel calculates dynamic delays at each intersection and along each street of the network. This submodel is DHTM's most rigid tie to the real world and contains much of the detail required to make the overall model responsive to the decision variables of interest.

The problem of making the results of a computer simulation model, such as DHTM, usable to the traffic engineer has been addressed here. Computer displays (DHTN) and the resulting man/computer relationship have been demonstrated to allow the traffic engineer to interpret visually the effects of changes in his network. Using this tool in conjunction with DHTM, the traffic engineer can sit at a display console and call for basic data and/or descriptive (i.e., a representation of the existing situation) simulation results from his network for use as a basis in designing and evaluating improvements. When he postulates practical network modifications, he can use the predictive simulation results to evaluate rapidly the effect of changes on network performance.

Research on a traffic-engineering evaluation methodology offers new tools to the urban traffic engineer. As envisioned, the application of the SRI methodology in an urban area will consist of the following steps:

1. Obtain a complete description of the network, including existing demand patterns.

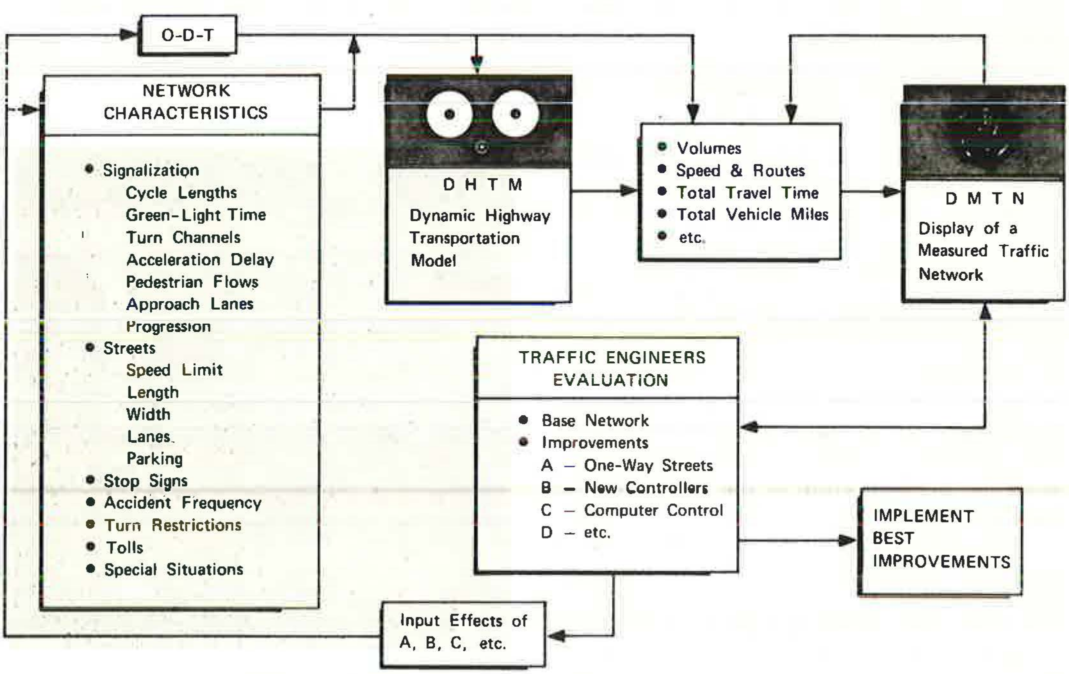

Figure 13. Methodology for traffic systems evaluation.

2. Simulate (DHTM) the existing traffic flow over the network and isolate the major problem areas by means of computer-generated displays (DMTN).

3. Develop sets of network improvements, such as one-way streets, signal timing, and parking restrictions, by using judgment and DHTM and DMTN.

4. Use DHTM to estimate the effects, appropriately measured, of each proposed set of improvements.

5. Choose a good set of changes based on the predicted improvements in traffic flow, the associated costs, and other important constraints.

6. Implement this set of changes and then measure the new volumes, delays, and demands in the network.

Steps 3 and 4 will probably have to be repeated several times to insure the consideration of all improvements of highest potential. For further clarification, Figure 13 presents a diagram of the overall process. Examples of the types of input information required and the interaction of the man and machine during the evaluation process are illustrated.

It should be emphasized that this procedure is carried out not just once but is a continuing program of improvement to the traffic network, subject to such factors as political, fiscal, and long-range planning constraints. The method has the advantage of enabling the analyst to consider a wide range of alternative solutions and to choose the best one without repeating extensive field work. The technical and economic feasibility of these tools has been demonstrated. Refinement and actual application are presently under way.

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Discussion

GORDON A. SHUNK, Alan M. Voorhees & Associates, Inc.—The computer display technique presented by the authors is yet another example of the beneficial spinoff from modern space age technology to improve the capabilities of more conventional practitioners. The concept of such displays is proving to be exceedingly valuable in many applications. The implications for the practicing traffic engineer are every bit as profound. Here is an opportunity to conduct cause and effect analysis of traffic engineering improvements without having to construct and disrupt. Here is an opportunity to examine and perturb networks and their loadings without the waiting and plotting formerly required. The effectiveness of the traffic engineer and planner can be greatly enhanced by such a technique.

The greatest asset of such a technique is the capability of immediate display. An analyst can examine and evaluate the basic system visually and decide upon measures to improve problem areas he sees. He then can make changes to effect these improvements and immediately observe the true results of his proposal. In traffic engineering, of course, such a procedure obviates costly and time-consuming construction or other trial and error solutions. The situations for which this approach is most useful are those for which standard traffic engineering analyses are not applicable or effective.

The effectiveness of the graphic display technique is a function of the simulation model or other source which supplies input to the process. The model generating input to the display must be capable of rapid response to perturbation of initial conditions. Unless such a response is possible for use with the graphic display, its greatest contribution is negated and one might as well examine printed plots output from the simulation. The model should also be capable of producing for simultaneous display several service parameters necessary for adequate system evaluation. Any display should contain such service measures as speed and delay, in the mean or on selective links, and in some cases volumes. Dynamic simulators can provide these service parameters for specific time periods. The authors' technique displays such parameters using overlays.

The previous comments regarding the requirements or desirable attributes of graphic display capabilities have been somewhat general. Specific comments were avoided because they would have borne more directly on the capabilities of the simulation model, which was not the primary element of this paper.

The authors' comments regarding cost did not deal with the economics of setting up an operating display system for a traffic engineering department. Eighty dollars per hour is certainly a reasonable figure as long as the price need be paid only when the system is in use. However, a computer facility to generate inputs and feed the display unit is not likely to be readily available to many traffic engineers outside of large cities. And even in large cities, the out-of-shop residence of the unit is sure to detract from its greatest utility. Certainly the system presented could be converted for use on other types of computers.

One solution to the problem of access to a computer facility could be using remote terminals. The traffic engineer could rent a CRT and control unit which would be connected by telephone line to a central computer, perhaps in the state highway department. The simulation display programs would be stored for direct access at the central computer facility. The traffic engineer would then merely have to call his programs and control the display from his office, using the equipment only when necessary. The non-processing cost would be nominal and the ready access would encourage more extensive use.

A centralized processor with remote display and control capability could handle input from traffic engineering agencies in many locations throughout an area.

The language provided in the subject technique to control the display program may prove difficult to use. The abbreviated commands can be referenced in tables to aid operators. But if the commands could be at least full English words, operation would be facilitated. Such a change should not prove too difficult although a translater might have to be included in the program. Display of the commands for checking is an excellent feature. The error checking of displays permitted by use of the "bug" pointer also is a valuable attribute.

In summary, the technique proposed by the authors represents a valuable contribution to the practice of traffic engineering. Using a good simulation model, graphic displays can prove a time saving tool that readily returns their cost. They can improve the effectiveness of the practicing traffic engineer by concentrating his efforts on analysis and evaluation. They can improve city traffic flow by leading to implementation of truly effective improvements. They can help to apply funds in the place and manner which will best utilize resources available.

WILLIAM C. TAYLOR, Wayne State University—The authors have described some traffic engineering functions which can be conducted utilizing computer displays as an aid. The report clearly demonstrates that the technology is available, and at a reasonable cost, to consider the benefits which one might derive from these techniques. I think the authors should be commended for the thorough presentation of some possibilities for increased use of computer displays.

I would take exception to the authors' statement that it is more difficult to evaluate the quantitative data from a standard computer output than it is to do so from a visual display. In the final evaluation, an analysis of the quantitative values is required. I do not necessarily agree that searching photographs of a visual display which is heavily laden with numbers is less difficult than the analysis of standard computer output. The potential for establishing threshold values exists in tabular data presentation as well as visual data presentation.

I do not feel that we have arrived at a standard definition of the quality of traffic flow or service, nor do I envision that we will in the near future. This implies that there are more than one, and in fact, several objectives to be considered in the selection of alternative network configurations or control strategies. The information presented in the paper illustrates the potential use of the technique for the analysis of "tradeoffs" between the satisfaction of a set of objectives.

The selection of the final set of quantitative data to be presented can be made with the use of the visual display. The iterative procedure necessary to reduce the myriad of possible combinations of system configuration, control strategies and measures of performance to a reasonable number of combinations for consideration, can be done quite readily without the necessity of quantifying all the possibilities.

The same capability exists on an operational level as exists on the broad planning level. We are all aware of the time and resource demands of a quantitative sensitivity or parameter analysis. The example of the program languages flexibility in isolating individual elements of the network for study illustrates a possible use. If we consider an individual intersection with a range of possible design features, another range of possible control strategies and are interested in the operation of the intersection as measured by a different criterion for a specified volume range, the parameter analysis requirement is already four dimensional.

The simulation procedure of fixing three of these variables and allowing the fourth to assume all the values in its range, then repeating the process for each of the other variables, and then iterating this procedure to determine the optimal set of values is quite involved. The alternative, which is constructing a model that accurately describes the relationships among all of the variables, is not always possible. The use of a visual display technique combined with the command language developed in this study offers a third, and in many cases perhaps far more attractive, alternative. The procedure would be to narrow the range of the variables qualitatively instead of quantitatively, thus reducing the matrix of possible decisions to a manageable limit. This could then be followed by a quantitative analysis of the remaining variable values.

The third possibility which occurs to me for the use of the visual display techniques is possibly the most important. The major disadvantage of tabular data is its static nature. The tables depict the status of the system at a given instant, and cannot indicate what precedes or follows that instant. Unfortunately, there is no such thing as steady-state flow in a street network. The demand flow is known to increase to some peak value in the rush periods, but the time, location and magnitude of this peak are dynamic. If we take a time slice from the system, we can portray the peak at only one location and magnitude. Likewise, a locational slice can depict only one time period and one magnitude of demand.

The simulation of flows through the network could be accomplished with the DHTM as described by the authors, with the value for some selected performance measure shown on the display. Let us assume that this performance measure is the level of service as defined in the Highway Capacity Manual. The threshold concept could be

used to readily identify any link which reaches level-of-service D. This can be accomplished by tabular methods also, but there are two advantages of a visual display: (a) the operator could stop the simulation and call for level-of-service characteristics of alternative paths, and (b) the system could be continued and the duration of the low service level could be determined.

If the results must be on tabular displays, the ability to recreate the instant when level-of-service D was reached on a link would require the initializing of the complete simulation up to that point. This is the property of a dynamic system, and cannot be avoided. This is often impractical from a cost point of view. With the visual display, immediate knowledge of alternatives available allows decisions to be made without starting the simulation run again.

The duration of the low level-of-service may be just as important in the decision-making process as the fact that the level exists at all. Once again, tradeoffs can be considered at the decision-making level. In this case the decisions are between various values of the same measure of performance, where before the decision was between alternative measures.

I feel the authors have developed a tool which will be very helpful to the profession. I consider its greatest benefit to be in the role of an aid to the decision maker rather than to the analyst. The concept should be continued, as I am sure will happen at Stanford Research Institute.

RICHARD C. SANDYS and JOHN L. SCHLAEFLI, Closure—The authors would like to thank Mr. Shunk and Dr. Taylor for their favorable discussions of this paper. Through these discussions a number of important points of interpretation have become evident. The following paragraphs attempt to clarify these points.

The display language (DMTN) enables the user to communicate and program directly from a display console. To date, the interaction that takes place is with data collected in the field or with simulation (DHTM) data produced on a larger computer. In order to attain immediate interaction with simulation data, a subset of the DHTM is being considered. This simulation would run on a small computer such as the one used for the DMTN program. If this is accomplished, immediate interaction with simulated data can take place and the traffic engineer will be able to see the results of his proposal in real time.

Experience indicates that the display console can be used to manipulate data and present the most interesting results. This capability is extremely important and has been accomplished using data generated by a complete cycle of the DHTM simulation. The ability of the display language to allow the traffic engineer to sift through enormous amounts of data without pre-specifying the order or the format of the search is new and powerful. For example, a certain intersection may operate below capacity and with no large queues for all but one 15-min time period during rush hour. If a hard copy approach is used, intersection performance for all time periods must be printed out. Using the display, the particular time period of interest can be isolated and then the print out can be limited to the relevant information. This capability is very powerful in itself; when immediate interaction with simulation and/or field data is achieved, the displays become even more powerful.

The feasibility of using remote (time-share) terminals for display has not been assessed directly. However, it seems that most existing operating systems on medium- to large-scale computers are rather static as far as data retrieval and allocation of computer core storage are concerned (1). A user cannot demand the whole computer when he wishes, but must always share with other users. Also a user must pay for the maximum amount of computer storage used during the running of a program. Thus, it is very expensive to pause in the execution of the simulation to display intermediate results. What is required is an operating system that will permit dynamic core allocation. Then the simulation/display user could store the simulation program and results on a disk, while he retains the display program in core and looks at intermediate results.

Research and development on text manipulation systems have been extensive (8). Expanding DMTN commands that full English words be straightforward. One technique used at SRI is to have the computer recognize and complete a word as soon as the first characteristic letters have been typed. Thus, when the user wishes to display a route on a map he types in R and before he can type further computer responds with ROUTE, the completed English word.

A final comment on the iterative nature of the DHTM—the simulation predicts volumes on streets and the resulting delays at intersections throughout the network for a 2-hr period and then repeats itself using predicted delays to generate new volumes. Interruption during an iteration of DHTM will not prove useful to the traffic engineer because the simulation is at some intermediate point in its solution process and some of the internal data files will be for time period, i, and some time period, i + 1, and the user would have difficulty identifying which. On the other hand, interruption of the program after an iteration is complete allows the user to see vehicles avoid or become attracted to a previously "improved" element of the network. This capability would be of great value to the traffic engineer in his evaluation of a particular improvement alternative.