Applications of Interactive Graphics in Urban Transit Analysis

G. BRUCE DOUGLAS III

Recent experience with interactive graphics programs has demonstrated the advantages of these methods over traditional travel demand analysis methods and has led to interesting approaches to network construction and market segment analysis. In particular, reduced analysis time per alternative and enhanced planning decisionmaking through increased accuracy and accessibility have been demonstrated in recent transportation studies in Baltimore, Jacksonville, Washington, D.C., and Buffalo. The benefits derived from this process are a direct result of the increased interaction between the computer and transit planners and operators, many of whom do not have extensive computer experience. For these four transportation studies, the interactive graphics battery of programs in the Transit Network Optimization System, based on work by Rapp, were integrated into a planning process for analyzing operations and estimating patronage on proposed transit facilities and a pedestrian walkway. This method was chosen for its ability to provide probabilistic, multipath assignments, rapid testing of alternatives, and graphics output for use by citizens and a multidisciplinary project team. This paper provides an overview of the procedures used and the capabilities of this new and relatively unknown technique.

The use of the Transit Network Optimization System (TNOP) battery of interactive graphics programs, an enhanced version of the interactive transit assignment model (ITAM) developed by Rapp (1,2), marks a milestone in transportation planning techniques. By combining easily understood graphic presentation with conversational user friendly command language, this process brings the power of computer simulation into direct interactive contact with the transportation planner and transit service operator who may have little or no computer experience. In this way the selection of parametric values and the interpretation of interim results may be accomplished without the need for translation from the world of computer simulation to the world of transportation operations. The need for manual plotting or tabulation of large amounts of data from computer printouts is also reduced.

An important benefit anticipated from the application of TNOP and its graphic capabilities is the enhancement of the planning process by facilitating more direct feedback from planning professionals and citizens who are not familiar with computer programming. The visual representations increase accuracy and greatly reduce the time required for editing networks and demographic data bases because visual displays are much more easily comprehended than printed tables. With the rapidly increasing processing speeds of present computers and their attendant reduced computational costs, TNOP and similar batteries of programs will soon be within the reach of all planning agencies. They will provide them with more comprehensible planning tools than have previously been available.

RECENT APPLICATIONS OF PROCESS

Although applicable to all forms of transportation planning and transit operations analysis, these methods are particularly well suited to simulation of travel that involves a large proportion of pedestrian trips such as for downtown people mover (DPM) and second-level walkway projects. Travel in center cities frequently includes choosing from among multiple paths between a trip's origin and its destination. Not all people will select the identical, or even the shortest, path. The ITAM probabilistic assignment algorithm, based on work by Dial (3), allows trips between two points to be assigned to multiple paths rather than to the single path that results from all-or-nothing assignment methods commonly found in transit planning models. This method is not only intuitively more appealing but also is supported by empirical evidence.

From 1978 to 1981 an interactive graphics analysis methodology using TNOP or ITAM was developed and applied to four projects that represent diverse transportation planning challenges. In Baltimore, TNOP was recently used to estimate patronage, revenues, and operating costs for a proposed center-city DPM. In Jacksonville, first ITAM, then TNOP, were used to assess the feasibility of building an automated guideway transit (AGT) facility proposed for ultimate use as a 20-mile long regional facility. An analysis of travel on a pedestrian and transit mall and second-level walkway system was performed in Buffalo, New York. In Washington, D.C., these methods were used to examine a crosstown transit connector for which three transit modes were considered--light rail, bus, and AGT. Examples from these projects are used throughout this paper.

A number of U.S. cities, including Jacksonville and Baltimore, have investigated the feasibility of implementing an AGT to improve transportation within the densely developed central business district (CBD) and as part of an overall program to stimulate development and provide improved access to activity centers. AGT systems usually employ small- to medium-sized, automatically controlled, driverless vehicles that operate on exclusive guideways, which are often elevated. Potential applications were under intensive study in Miami, Detroit, Los Angeles, Jacksonville, and Baltimore in 1981.

PROCESS OVERVIEW

The overall analysis method involves the use of a combination of programs developed specifically for the process, with programs from the Urban Transportation Planning System (UTPS) and TNOP, as shown in Figure 1. The specific process shown analyzed travel by using five modes: walking, automobile driver, bus, rail rapid transit, and automated guideway transit. Although the applications discussed in this paper are all microscale and cover small study areas such as the CBDs of cities, the techniques are applicable to all areas and are constrained only by the level of detail and consequent network sizes required. Large subregional or even regional areas may be simulated if the level of detail is reduced. For AGT and pedestrian studies, it is desirable to keep the unit of analysis at the block or block-face level for maximum accuracy and sensitivity to CBD development patterns.

As is commonly done in transportation analyses, a physical representation of the transportation system starts with a street network. For certain detailed urban studies the CBD is incorporated into a study area, and activities are allocated to zones that are frequently equivalent to one city block in size, as shown in Figure 2. In the simulation process used for Baltimore, the street network and activities were then transformed through keyboard entry of coordinates into the TNOP programs, where they can then be displayed. Figure 3 illustrates the Balti-

Figure 1. Travel demand methodology.

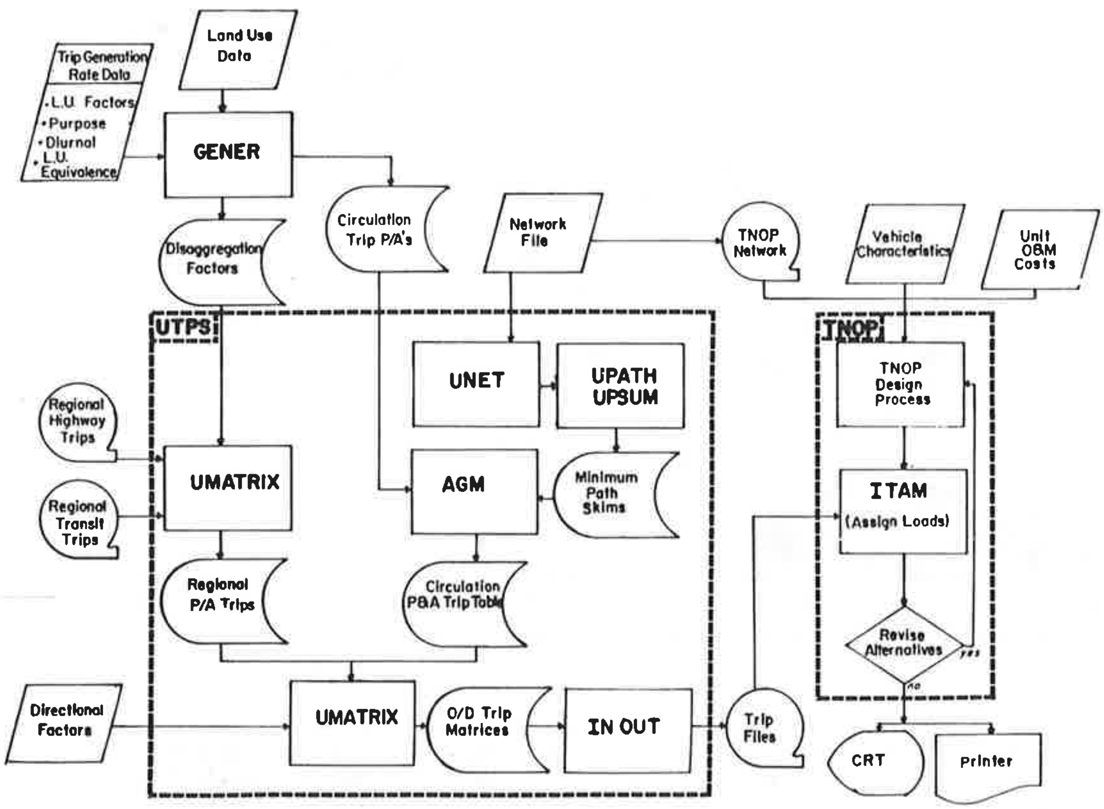


Figure 2. Baltimore CBD with DPM zones.

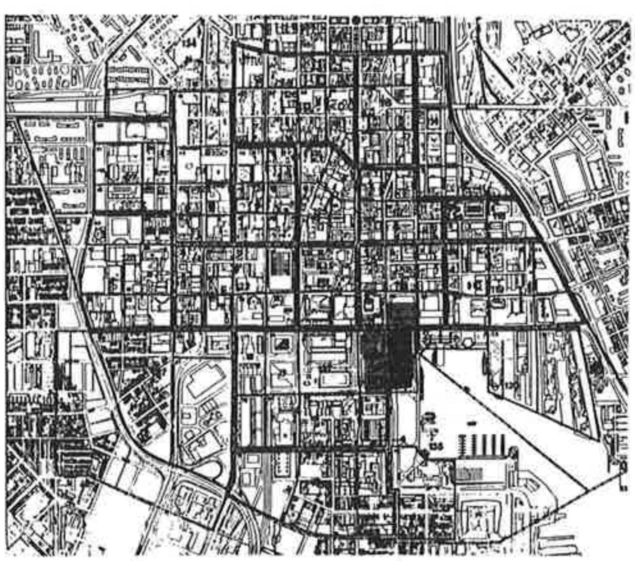
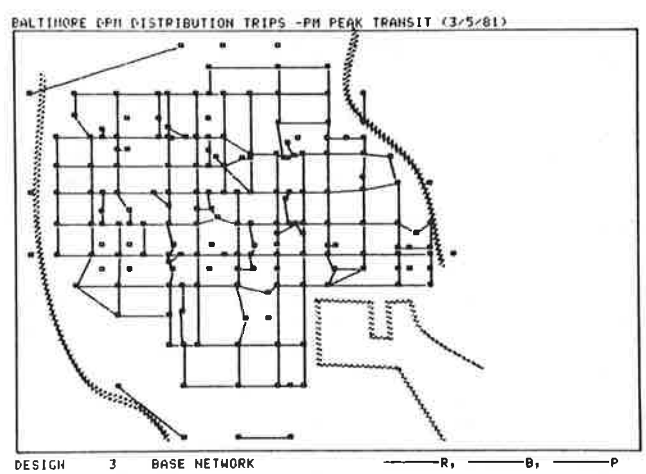


Figure 3. Baltimore DPM study area street network.

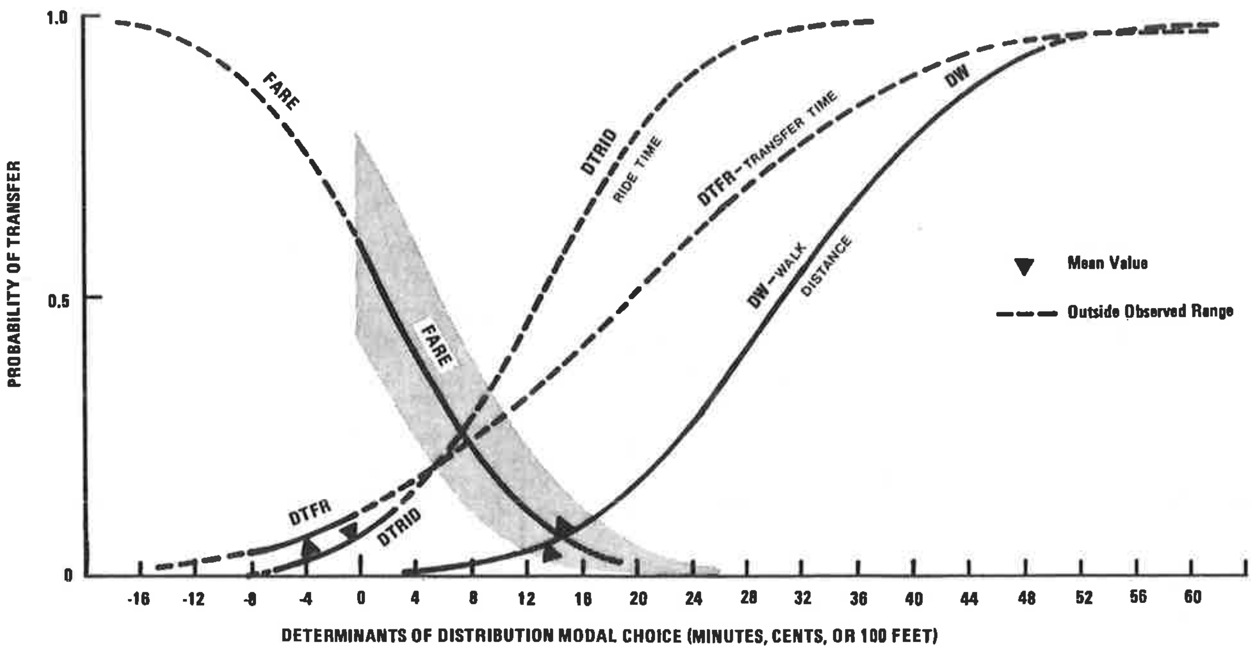


more sidewalk network as depicted on the CRT screen. Networks have also been developed for a proposed Buffalo Skywalk and the Jacksonville Transit Authority's bus network as part of recent alternatives analyses and AGT feasibility studies.

The data input needs for the AGT and pedestrian studies are not different from other transportation planning analyses, but the microscale nature of the study area and the interactive relation between development and travel increases the need for accuracy and reliable estimates. This is particularly true as the results may be easily seen, understood, and questioned by study participants who are not computer-oriented. Consequently, data preparation is an important and time-consuming activity. The most time-consuming and complex problems involve the following:

1. Preparation of an accurate and detailed land use inventory;
2. Determination of trip generation rates and the diurnal distribution peculiar to the particular city under analysis;
3. Determination of the particular decisionmaking

Figure 4. Determinants of choice between walking and transit.



characteristics of the population under study; and

4. Preparation of reliable development forecasts related to the individual transportation alternative being examined.

These data are essential for obtaining accurate trip files, estimating the coefficients and relative weights for the assignment model (ITAM), and selecting parameters for the various UTPS programs. They are generally developed through field surveys and interviews and/or trip diaries when possible. For those data not available at the site, it is possible to use information from the Pedestrian Planning Procedures Manual (4) and the work on distribution modal choice by Douglas (5). Several determinants of distribution modal choice are indicated in Figure 4.

NETWORK ANALYSIS USING COMPUTER GRAPHICS

For the applications described in this paper, the battery of TNOP programs [as supported by General Motor's Transportation Systems Center (6)] was mounted on a Prime 400 host computer system and operated through a Tektronix 4051, which emulates the 4010 and 4012 terminals. The graphics displays are an integral part of all stages of the analytical process from data input through service design, display of the results, timetable optimization and preparation of presentation graphics for steering committees and citizen groups. Examples of the use of these various graphic capabilities are presented in the following sections.

Menu

The graphic elements of the overall planning process are indicated in Figure 1 by the heavy line labeled TNOP, a battery of programs that are driven by commands in response to a menu, which is displayed at the completion of each task. The menu items fall into an organization of seven general task groups: (a) entering input data into the system and creating the storage file structure, (b) displaying the input data such as networks and the origin-destination matrix data, (c) defining the level of service in terms of transit lines and their attributes, (d) assigning the origin-destination matrix to the system as defined for a particular alternative, (e) displaying the results of the assignment in terms of the volumes by using each of the transit and nontransit links in the network, (f) comparing alternatives and performing the file management, and (g) performing schedule optimizations and investigating congestion on the various transit lines.

The analysis and display programs available to the user are listed below and are described in the following sections.

1. Input base network
2. Input trip demand matrix
3. Input vehicle characteristics
4. Input model parameters
5. Input titles and geographic reference lines
6. Display data files
7. Plot base network
8. Plot trip desire lines
9. Plot productions and/or attractions
10. Display vehicle characteristics
11. Interrogate origin-destination matrix
12. Plot trip-length distribution
13. Define transit lines
14. Input/modify transit line attributes
15. Print line structure
16. Execute trip assignment
17. Display network loads
18. Display transit line loadings
19. Display transfer volumes
20. Display design summaries
21. Print line segment loads
22. Display travel time contours
23. Compare line loadings
24. Compare performance of alternatives
25. Store/erase alternative
26. Input and display timetable
27. Display transfer characteristics
28. Display transfer movements
29. Timetable optimization and
30. Display vehicle positions

Data Preparation and Display

The data required to analyze a transportation network include the network attributes and consist of links and nodes, an origin-destination matrix, vehicle characteristics, and geographic features. For the current design applications, the origin-destination matrix has been developed through a combination of trip generation and UTPS programs by using conventional batch processing. When the data have been read into the TNOP system and the files initialized, graphic representation of the data will reveal the characteristics of both the network and the travel patterns to be served. These results are presented below with examples from Baltimore and Jacksonville.

Network Editing

As can be seen in Figure 3, the display of the network will quickly reveal errors in specification and coordinates. In addition, the capability for windowing (i.e., the selection of a small rectangular subarea of the total study area) allows for detailed examination of the links and their relation to nodes. The presence of geographic feature lines such as the harbor and freeways in the Baltimore example provide orientation for the viewer.

Origins and Destinations

By summarizing the row and column totals from the origin-destination matrix, TNOP is able to display the activity graphically, expressed as trips, at each zone centroid. For example, in Figure 5 the transit trips from the CBD to the rest of the region are shown graphically by zone. The width of the rectangle represents the number of people who leave a zone (i.e., an origin or production), and the height of a rectangle indicates the number of travelers who enter a zone. As will be seen in Figure 5, the three rectangles at the right side of the study area represent the remainder of the region and indicate that most of the transit trips during the evening peak period are leaving the downtown for destinations outside the study area. The various bus lines are also shown graphically in Figure 5. In this way the planner may visualize graphically which combination of links will best serve the major activity centers.

Desire Lines

A common representation of travel patterns is the desire line, a straight-line connection between two points that has a band width equivalent to the number of trips. Just 25 years ago the production of a desire line diagram similar to Figure 6 by using a Cartographatron would have required several days rather than the several seconds required with current technology. In addition to the desire lines, Figure 6 contains points that represent the various city blocks or zones, a proposed AGT system, and a serpentine geographic reference line that represents the St. John's River in Jacksonville.

Trip Length Distribution

An alternative means for examining the network and origin-destination matrix implications is by way of a trip-length distribution as shown in Figure 7. In this diagram the travel time (including riding time and walking time but without transfers and waiting) over the shortest path from all zones to all zones or among selected origins and destinations may be displayed.

Service Design and Trip Assignment

Following the entry of the network and travel data, the interactive elements of the program battery are executed. In actual application new origin-destination matrices were required for each major transportation alternative that would have a significant impact on the land development pattern. This is a technique that has long been missing from traditional travel demand analysis because it has been assumed (usually implicitly) that a future land use pattern would remain static regardless of the type and level of transportation development taking place in a region. Because of the interactive nature of transportation and land use (particularly for rail facilities and CBDs) it is desirable to be able to reflect the impact of the location of a transit facility on the shape and form of development.

Transit lines are defined by the location of their stops or stations and the frequency of their service. A traditional map of such an alternative is shown in Figure 8. This diagram was used to review preliminary alignments with citizen committees prior to simulation on the computer. After defining service levels and performing an assignment of the origin-destination matrix to the selected alternative, the results are displayed and analyzed, and the service is revised if a more-efficient alternative appears possible. The results of the trip assignment process are generally expressed in terms of line loadings, network link loadings, and comparisons among the various alternatives as described below.

Line Loadings

Transportation planners and transit operators are generally interested in the number of riders to be expected on each link in a transit system--particularly the critical links that determine the level of service required. This information may be displayed for a single line such as that shown in Figure 9, which is the DPM alternative originally drafted in Figure 8 with minor modifications.

Network Loads

In addition to the performance of individual lines, transportation planners are frequently interested in the behavior of the entire network. The heavily loaded freeway that bounds the west side of the Jacksonville CBD is obvious is Figure 10 and helps to indicate points of possible traffic congestion. Because of the complexity of the networks, it is frequently desirable to examine a subarea of the network such as the small window in Figure 11 where the street network and bus lines near the Harborplace on the Baltimore Harbor are shown at an enlarged scale, including pedestrian travel volumes on sidewalks and through intersections.

Design Comparisons

During the evaluation process it is helpful to know whether changes in the service level produce a significant impact on transportation system patronage. This may be accomplished by displaying the difference in link volumes for alternative transit lines graphically, as shown in Figure 12. In Figure 12 the heavy shading indicates a major shift in traffic that results from the choice of one design (no. 6) over a second design (no. 7), which thus indicates that the designs are significantly different in terms of travel parameters.

Travel Time Impacts

An additional measure of transit service performance is whether a significant change in travel time results from implementation of a change in service. As can be seen in Figure 13, the isochrons (equal time lines) clearly indicate the impact of implementing a transit line by the shorter travel times from the center of Jacksonville to the new development areas north of the CBD and south of the St. John's River.

Figure 5. Evening peak transit trip origins and destinations.

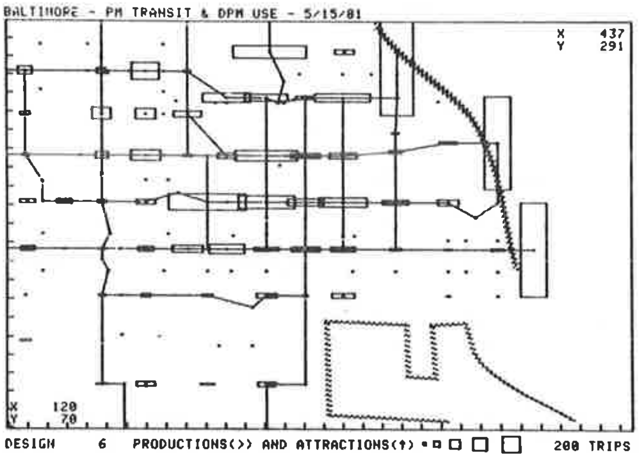


Figure 6. Transit trip desire lines.

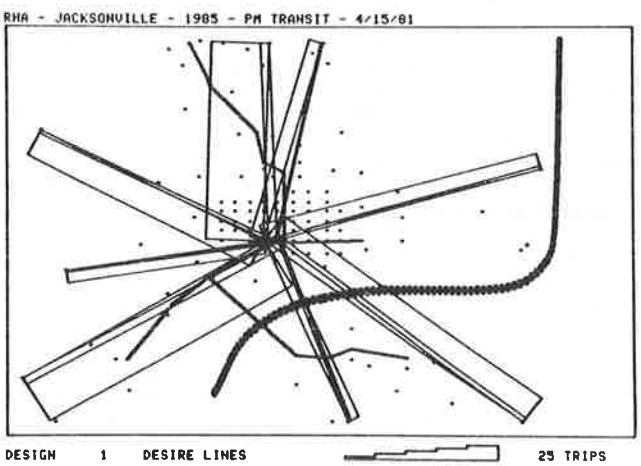
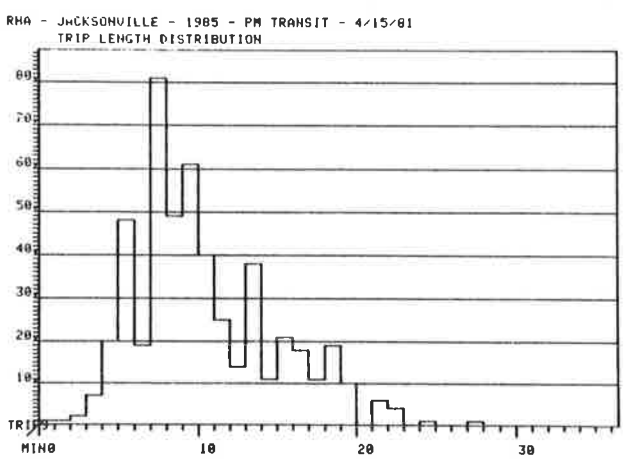


Figure 7. Trip length distribution.



Transit Operating Statistics

For each design alternative, the program automatically prints all the usual operating statistics necessary to analyze the efficiency of each route, line, and mode. These include statistics on the hourly operating cost, the distance traveled, and the number of vehicles required based on the travel times, route lengths, and terminal layover times necessary to provide the desired service. By reviewing these statistics along with estimates of use (expressed as the percentage of seats and standing places occupied by link) and by the probability of finding a seat, the transit planner may interactively revise the service levels to converge on an improved transit operation.

Timetable Optimization

A powerful feature of the TNOP program is the ability to coordinate schedules of the lines in a transit system based on an objective function that minimizes the systemwide transfer delay (in passenger minutes) by using a simple heuristic (automatic) search procedure to inspect terminal departure times

Figure 8. Proposed Baltimore DPM alignment.

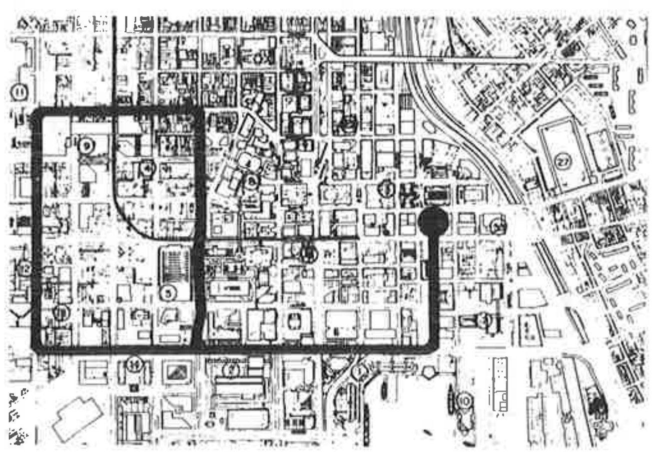


Figure 9. Baltimore DPM ridership.

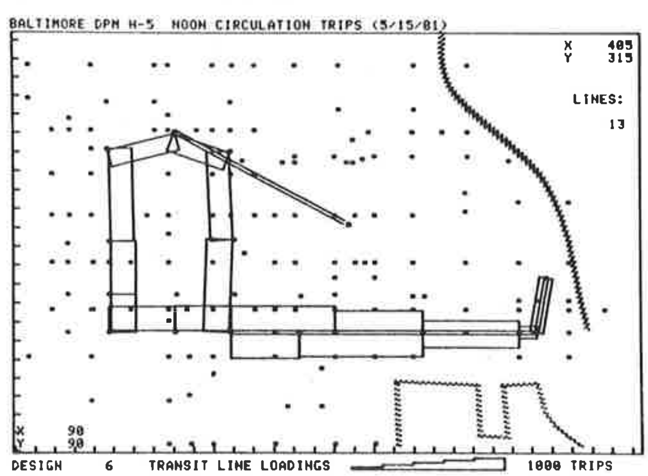


Figure 10. Jacksonville highway network volumes.

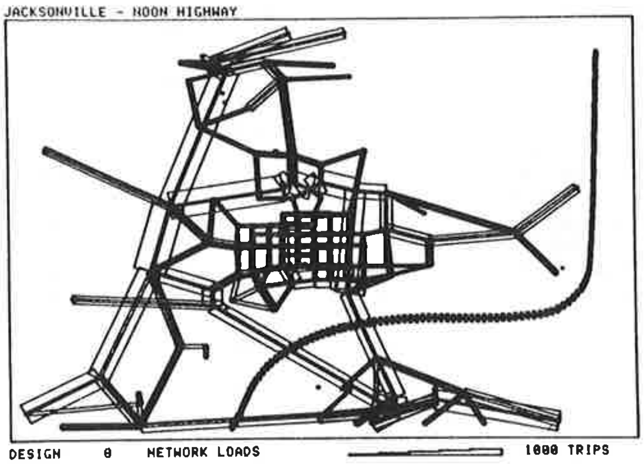


Figure 11. Pedestrian and bus network volumes.

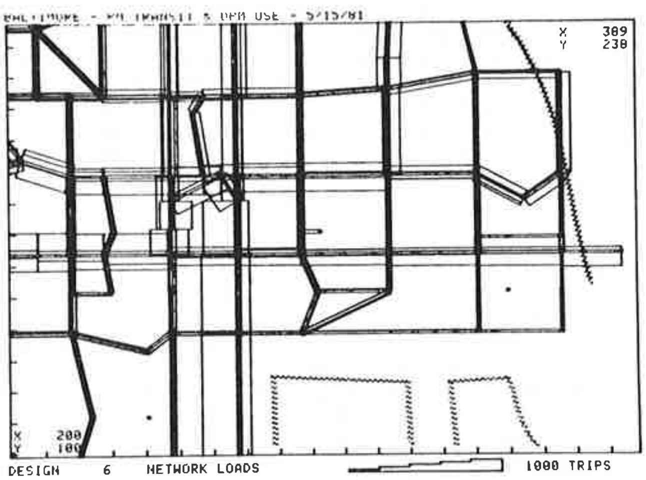


Figure 12. Patronage comparisons—designs 6 versus 7.

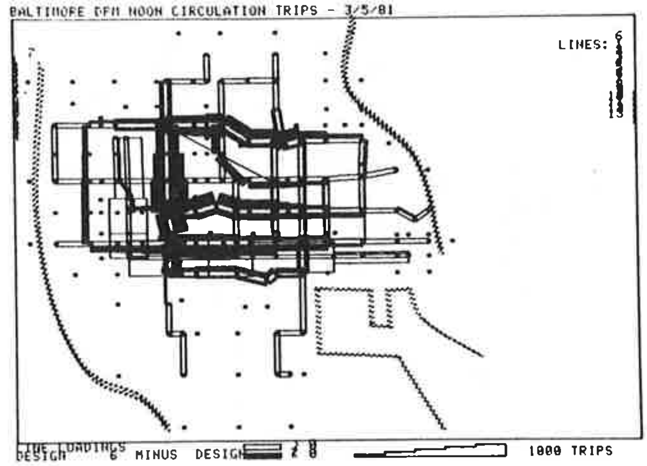
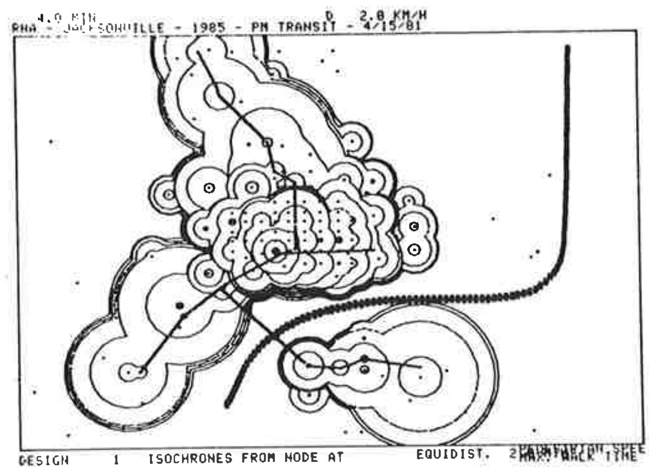


Figure 13. Travel times from Bay and Julia Streets, Jacksonville.



and by adjusting to minimize delay. The results of this process will ensure that a minimum number of transit vehicles is used and that a local minimum of total systemwide transfer delay is achieved. Graphic output associated with this process includes schedules and a map of the vehicle positions.

Graphic Timetable

If desired, a graphic timetable of each line plus parallel lines that use the same facilities may be produced as shown in Figure 14. This figure shows a 30-min time period along the X-axis, the transit stop names along the left Y-axis, and the distance in kilometers along the right Y-axis. The schedule for the selected line (no. 1) is indicated along with all parallel bus lines that share the same street segment. One advantage of this type of schedule is that it indicates the potential for congestion and possible transit delay because of the routing of a number of lines through the same street segment.

Vehicle Positions

Another interesting feature is the ability to display the position of vehicles in interconnecting lines, as shown in Figure 15. In this display the congestion of vehicles (in this case the proposed Howard Street Transit Mall in Baltimore) and possible congestion problems are quite evident. The display is not dynamic but may be repeated for each succeeding minute in the schedule to determine the progress of vehicles along the various transit lines.

Presentation Graphics

The principal graphic presentation medium for TNOP is the storage tube displays on the Tektronix 4000 series terminals. A Tektronix 4631 hardcopy unit produced the majority of the graphics included in this paper.

Additional graphics were prepared by using the 4051 as a microprocessor and a Tektronix 4662 B-size plotter to provide citizen and advisory committee members with summary graphics that illustrated such diverse results as the change in land use due to implementation of an AGT facility, the daily transit ridership for various tested alternatives, and the change in accessibility of employment that result from alternative modal connectors in the Washington, D.C., study. Each of these techniques takes advantage of the inherent capability of graphic presentations to show scale and relative magnitudes of

Figure 14. Graphic transit line schedule.

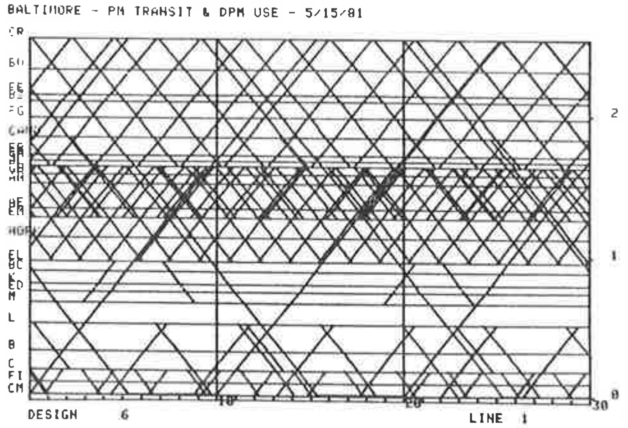
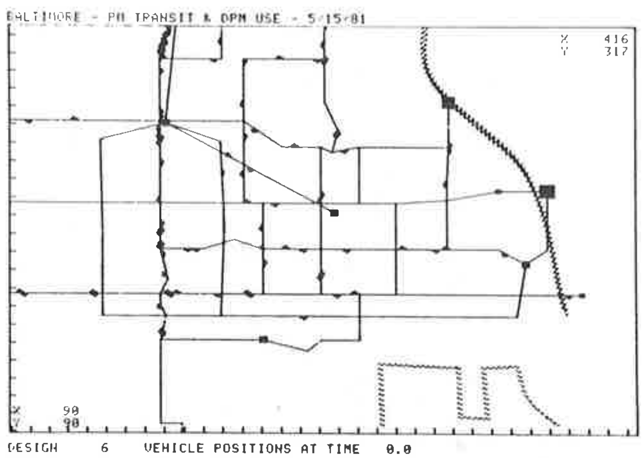


Figure 15. Transit vehicle positions at time 0.0.



change much more clearly than the background tabular data from which the graphics were constructed.

CONCLUSIONS AND SUGGESTED APPLICATIONS

The recent applications of TNOP to transit planning in Washington, D.C., Jacksonville, Baltimore, and Buffalo have confirmed the anticipated benefits to be derived from the use of interactive graphics analytical methods. The accuracy of results has been increased through the availability of visual editing. The number of alternatives that may be tested has been increased dramatically because of the interactive feedback loop capabilities in which a professional observes the results and revises input parameters to converge on an optimal solution. The entire planning and decision process has been enhanced through the ability for direct interaction between the computer program and professional judgment of the planner and transit operator.

A number of potentially fruitful planning opportunities have been suggested by this experience. More research should be directed toward the use of these techniques for the critical analysis of trips within CBDs that involve trade-offs between walking and mechanized modes. From the perspective of the transit operator, routing buses through the dense CBD and optimizing schedules to reduce transit operating costs and minimize transfer time are more important analytical problems. The study of skywalks in Buffalo has indicated that these techniques may also lead to greater understanding of the use of second-level walkway systems and their impact on CBD development, travel, and retail activity.

Recent changes in methods for financing transit deficits have made the question of cost reduction and possible service reductions of current importance. The question of where to reduce service to minimize the impact on transit users is of particular relevance today. Another opportunity for route and overall travel time optimization may be found in the routing of school buses based on minimizing transportation costs, the impact of which may even extend to the selection of schools to remain open as enrollments decline. As the cost for computer facilities is reduced and the speed of processing increases through lowered hardware costs, we anticipate significant increases in software development to address these problems based on TNOP and other interactive graphics programs.

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