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Urban Transportation Planning Using Interactive Graphics

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EMME/2: Interactive Graphic Method for Road and Transit Planning

ANDRÉ BABIN, MICHAEL FLORIAN, LINDA JAMES-LEFEBVRE, AND HEINZ SPIESS

The multimodal equilibrum-equilibre multimodal (EMME/2) system is a multimode urban transportation planning method designed for interactive use. It is more comprehensive than other interactive graphic methods that have been developed to date. It has been developed on the Cyber 173 of the University of Montreal; however, it may easily be adapted for a certain class of micro (or mini) computers. In this paper we describe the general concepts that underlie the design of the EMME/2 system; the structure of its data base; and the possibilities offered by the network editor, the matrix editor, the function editor, the assignment processors, and the modules that produce the results.

During the past 10 years a wide variety of transportation planning methods have become available for various urban and regional applications. Most of these methods have been implemented for use on modern computers in a batch-type environment. Although many successful applications of these methods have been achieved, and the new generation of urban transportation models [such as the Urban Transportation Planning System (UTPS) and Multimodal Equilibrium-Equilibre Multimodal (EMME/1)] go a long way to alleviate the difficulties associated with their behavioral validity and computational efficiency, the dialog with the planner is still rather cumbersome. The transfer of information between person and computer is done via relatively cumbersome procedures, sometimes involving computer analysts who have no interest in planning and are also limited by the management of a given computer installation. The typical situation that requires the use of such computer-based models is the evaluation of future scenarios, which may reflect changes in the road and transit networks or changes in the socioeconomic characteristics of the urban area. Such use requires quick and efficient communication with the computer-based models that evaluate the proposed scenarios.

The approach that has emerged over the past few years, particularly in the context of transit route planning, is to use interactive graphics to enable direct dialog, with real-time graphic or nongraphic response, between the planner and the computer-based planning method. It allows the planner to engage in the planning process by using the terminology that he or she is familiar with and obviates data-processing tasks. Once the data base is set up, the planner need not know or be concerned with the technical details of computer programming or computer systems. It also permits the instantaneous visualization of input data, results of computations, and information retrieved from the data base, all in graphic or list form. EMME/2 is a multimode urban transportation planning method designed for interactive use. It is more comprehensive than other interactive graphic methods that have been developed to date.

GENERAL CONCEPTS THAT UNDERLIE DESIGN OF EMME/2

The data that may be entered, modified, and used for calculations in EMME/2 fall into three main categories: networks, matrices, and functions. Figure 1 gives a schematic representation of the EMME/2 data base and is helpful in clarifying the descriptions that follow.

The network data may be input, modified, and displayed by using the network editor of EMME/2. The

Figure 1. EMME/2 data base.

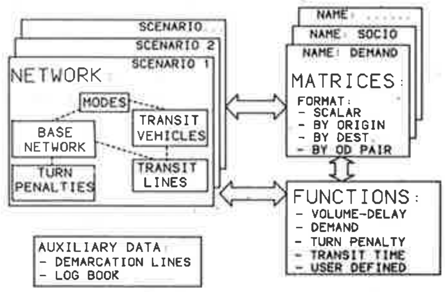
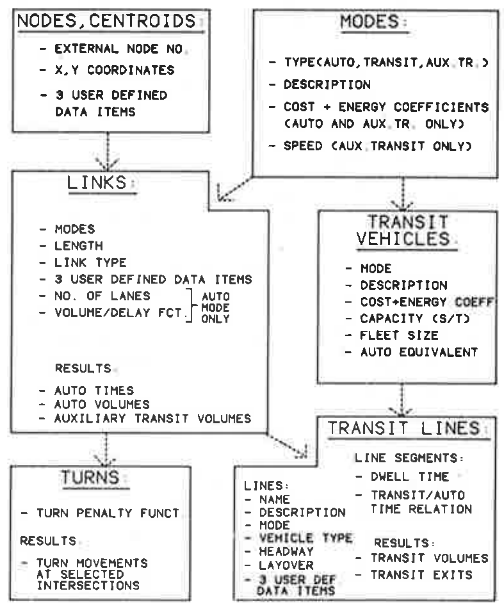


Figure 2. EMME/2 network structure.



matrices of the EMME/2 data base may be entered, modified, and displayed and various matrix calculations may be performed by using the matrix editor. All relevant functions of the EMME/2 data base are entered and evaluated by using the function editor. The EMME/2 data base contains demarcation lines and a log book, which we refer to as the auxiliary data. Demarcation lines may be superimposed on graphic displays to make them more readable and a log book keeps track of the use made of the various EMME/2 modules in manipulating the data base.

Networks

The transportation infrastructure that spans the region studied is represented by a multimodal network. The network descriptors are the modes, base network, transit vehicles, transit lines, and turn penalties. Any of these data may be modified at any time, provided that the hierarchy of the data structure is respected. For example, a transit line cannot use a vehicle type not present in the vehicle table (see Figure 2).

The base network is defined by the list of all nodes, and all the links between those nodes, used by any of the modes. Intersections that are described at the level of detail of turning movements are prepared separately. The turn penalties are indicated only for penalized movements.

The line itinerary is defined as a sequence of nodes. It is not necessary to specify all the nodes along a route. If nodes are omitted, the line is assumed to pass through the nodes on the shortest path between the specified nodes. Dwell time and the transit time function, which correlates the speed of the transit line to that of the automobile mode, need only be specified when their values change. These data are stored by line segment. Up to two layovers are allowed in a line itinerary and they are specified immediately after the nodes where the layover takes place. It is not necessary for a transit line to return to its starting point, such as do certain services during the peak hour. The base network is defined by the unit of all nodes and all the links between those nodes used by any of the nodes.

The user may specify up to three additional data elements for each node, link, and transit line. Such user data may include observed link flows, observed link travel times, or any other data that the planner intends to use in subsequent analyses. Another example would be accident rates at given nodes of the network.

Each complete network data set (modes, base network, transit vehicles, turn penalties, transit lines) makes up a scenario, and the base year is one of these scenarios. The user may define a new scenario by duplicating the data present in an existing scenario and making the appropriate changes in any one of the network data components. All these manipulations may be performed interac- tively, with graphical output, when appropriate. In EMME/2, the network data that correspond to a base year is not conceptually different from that corre- sponding to a future year configuration.

Matrices

The matrices that are handled in EMME/2 may be full matrices, origin or destination vectors, or scalars. These may contain various socioeconomic data related to the zone subdivision of the urban area studied, such as origin-destination demand matrices or origin-destination travel times by mode. A matrix may be both an input to or an output from a computational procedure.

The matrix editor has been designed in a way that permits the user to choose a matrix format appropriate to his or her data in order to avoid duplication of data in the data base. For instance, if a full matrix has the same value in all its cells, then the user may specify a scalar matrix, give the value, and the matrix editor will use only the space required to keep the scalar in the data base. However, when a full matrix is requested in an EMME/2 module, the matrix editor will automatically expand the scalar value to a full matrix with that value in all of its cells within the module at execution time. The same concept applies to given values for origins or destinations.

The matrix editor does not define any matrices by default. The definition of a matrix and its contents are left to the user. Thus, if an assignment routine expects the availability of an origin-destination matrix, the user defines this matrix and ensures that it contains the correct data. This provides great flexibility in evaluating a given scenario that has different origin-destination matrices.

Any network scenario created by the network editor may be used with any of the matrices present in the data base. The user identifies the relevant matrices that he or she wishes for a given scenario. The matrix editor of EMME/2 also contains matrix balancing procedures in two and three dimensions. Their judicious use, with the appropriate matrices, permits a user to scale matrices or to implement some versions of classical spatial interaction models.

Whenever the matrix editor expects a zone number, a zone group can be specified, which indicates that the operation applies to all zones within the group. A zone group is a set of zones. A set of zone groups that includes all the zones is called an ensemble. Within an ensemble, a zone may be in only one group. The user of the EMME/2 system may specify up to 26 ensembles, each containing up to 100 zone groups. The advantage of using zone groups is that for many applications it is necessary to select subsets of the zones, and the use of zone groups allows this selection to be accomplished efficiently.

The matrix editor includes a module that permits the user to perform matrix calculations. The user specifies the operations that he or she wants to perform as an algebraic expression. Such algebraic

Figure 3. EMME/2 program structure.

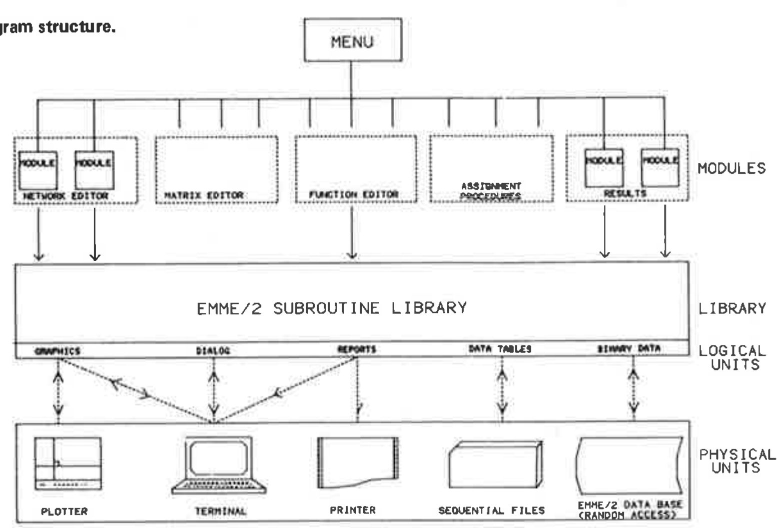


Figure 4. Menu that displays available EMME/2 modules.

```
1.  U T I L I T I E S

1.11 DIRECT DATA BASE MANIPULATIONS
1.21 LOG BOOK CONSULTATION
1.22 SCENARIO MANIPULATIONS
1.23 MODIFY TITLES AND UNITS
1.31 I/O FILE MANAGEMENT
1.41 INPUT / MODIFY / DISPLAY DEMARCATION LINES

2.  N E T W O R K   E D I T O R

2.01 INPUT / MODIFY / OUTPUT MODES
2.02 INPUT / MODIFY / OUTPUT TRANSIT VEHICLES
2.11 INPUT BASE NETWORK USING BATCH ENTRY
2.12 INPUT / MODIFY BASE NETWORK INTERACTIVELY
2.13 PLOT    BASE NETWORK
2.14 OUTPUT  BASE NETWORK
2.15 PLOT SHORTEST PATHS ON BASE NETWORK
2.21 INPUT TRANSIT LINES USING BATCH ENTRY
2.22 INPUT / MODIFY TRANSIT LINES INTERACTIVELY
2.23 PLOT    TRANSIT LINES
2.24 OUTPUT  TRANSIT LINES
2.31 INPUT / MODIFY / DISPLAY TURN PENALTIES
2.41 INPUT / MODIFY / DISPLAY USEP DEFINED DATA

3.  M A T R I X   E D I T O R

3.01 INPUT / MODIFY / DISPLAY ZONE GROUPS
3.11 INPUT MATRICES USING BATCH ENTRY
3.12 INPUT / MODIFY MATRICES INTERACTIVELY
3.13 PLOT    MATRICES
3.14 OUTPUT  MATRICES
3.15 COMPARE MATRICES
3.16 PLOT HISTOGRAM OF MATRICES
3.21 MATRIX CALCULATIONS AND BALANCING

4.  F U N C T I O N   E D I T O R

4.11 INPUT FUNCTIONS USING BATCH ENTRY
4.12 INPUT / MODIFY FUNCTIONS INTERACTIVELY
4.13 PLOT   FUNCTIONS
4.14 OUTPUT FUNCTIONS

5.  A S S I G N M E N T   P R O C E D U R E S

5.11 PREPARE SCENARIO FOR ASSIGNMENT
5.21 AUTO    ASSIGNMENT
5.31 TRANSIT ASSIGNMENT
5.41 BIMODAL ASSIGNMENT

6.  R E S U L T S

6.01 RESULT SUMMARY
6.11 LIST    AUTO TIMES AND VOLUMES
6.12 PLOT    AUTO TIMES AND VOLUMES
6.13 COMPARE AUTO TIMES AND VOLUMES
6.14 PLOT AUTO TIMES AND VOLUMES ON INTERSECTIONS
6.15 PLOT SHORTEST PATHS ON AUTO NETWORK
6.21 LIST    TRANSIT VOLUMES
6.22 PLOT    TRANSIT VOLUMES
6.23 COMPARE TRANSIT VOLUMES
6.31 LIST    MODAL SPLIT
6.32 PLOT    MODAL SPLIT
6.33 COMPARE MODAL SPLIT
```

expressions may be stated by choosing from 16 logical and algebraic operands and 9 intrinsic functions. The variables that may be used in these expressions are the matrices of the EMME/2 data bank, centroid numbers, and zone groups.

Functions

All the functions that are used in EMME/2, such as volume-delay functions, transit-automobile travel time relationships, turn penalties, and demand functions are specified by the user as algebraic expressions. These functions are not part of the code as user-defined functions or subroutines as in the EMME/1 system or other similar systems. When an EMME/2 module requires the use of a particular function, the function is then evaluated by using the appropriate data that correspond to the variables specified by the user in the algebraic expressions that define these functions.

In addition to the classes of functions described above, the user is free to define and display functions that are not employed in any one of the standard calculations of the EMME/2 system.

Figure 5. Plot of a multimodal base network shows three modes—C (car), B (bus), and A (access); CBD is not displayed; and two rivers serve as demarcation lines.

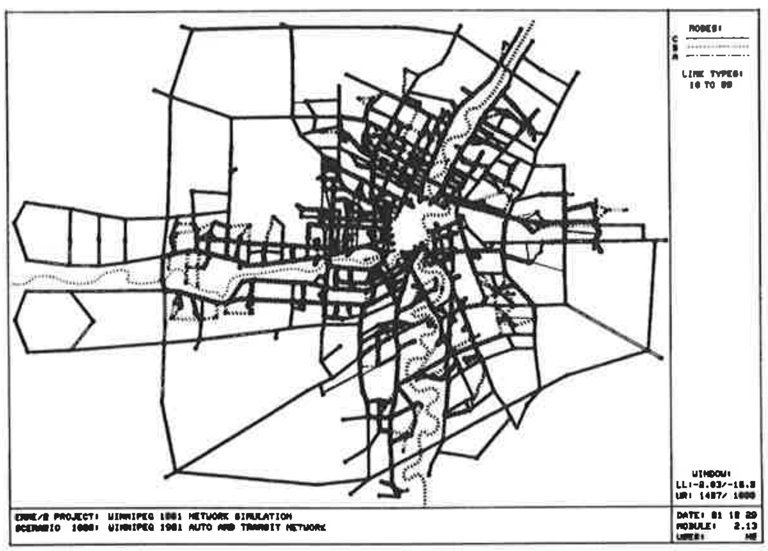
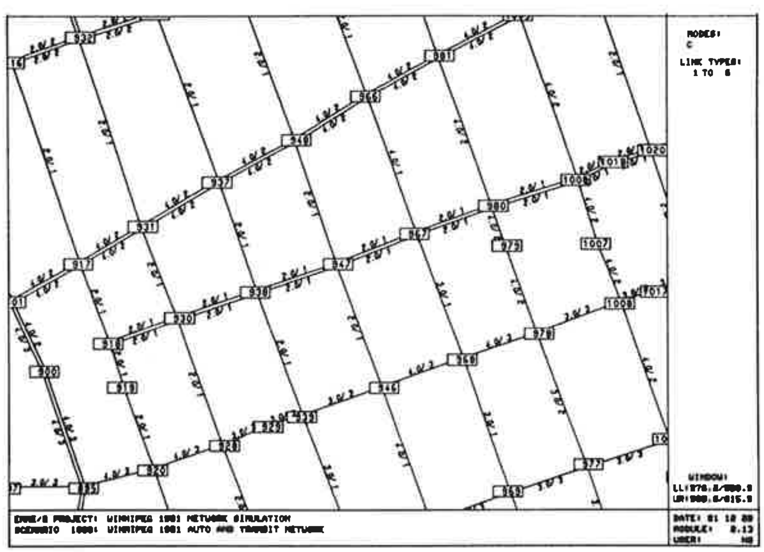


Figure 6. Plotted window of base network displays node numbers and also number of lanes and volume-delay function index for each link.



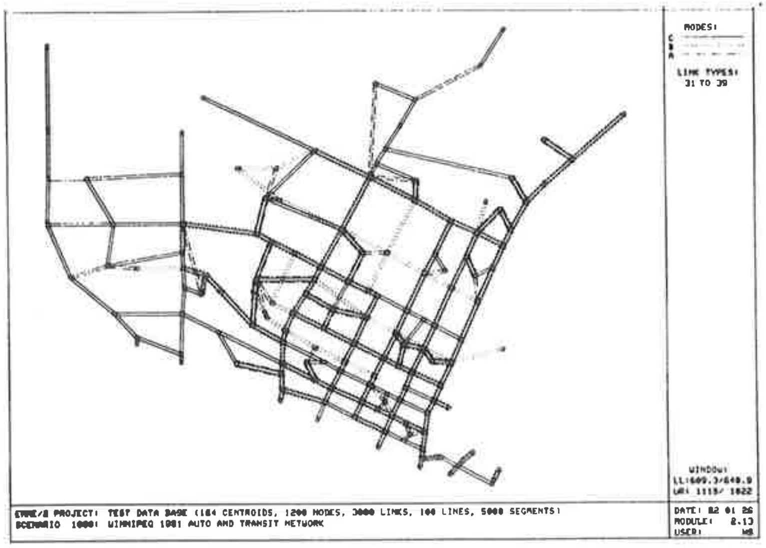


Figure 7. Plot of subnetwork (district 3) of the multimodal base network displayed in Figure 5 is identified by link types 31 to 39.

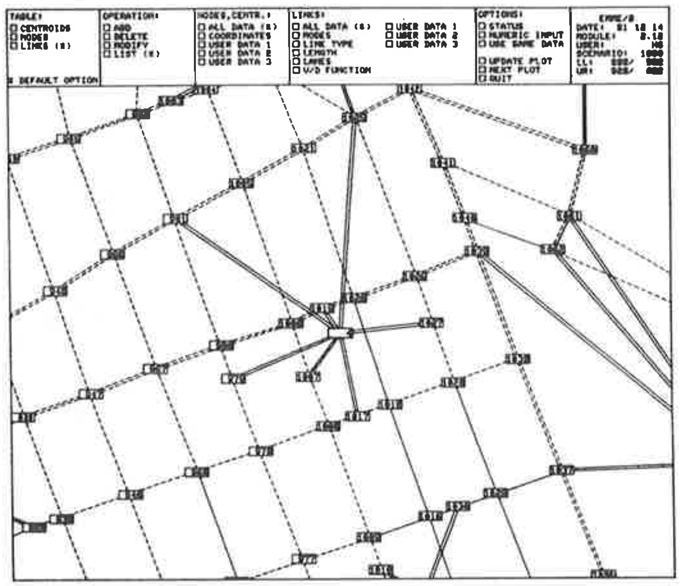


Figure 8. Graphic work sheet used by interactive network editor; window of base network about to be edited is displayed; upper part of graphic work sheet contains command area where user indicates data tables to be modified and operations that will be used in modifications.

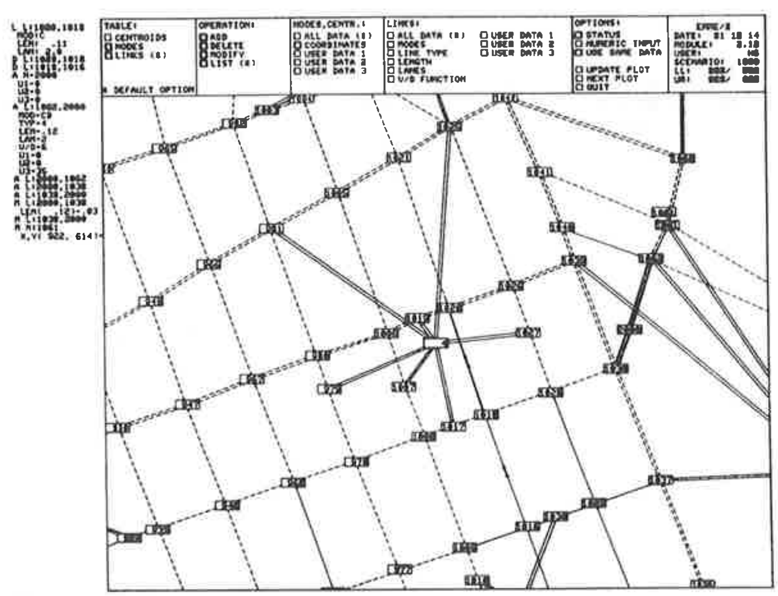


Figure 9. Graphic work sheet after certain modifications of the window in Figure 8 have been carried out; left-hand margin is a pad that records modifications and permits an abbreviated dialog for additions. For instance, the data of link (1020, 1018) were first listed; then links (1020, 1018) and (1018, 1016) were deleted; then node 2000 was added.

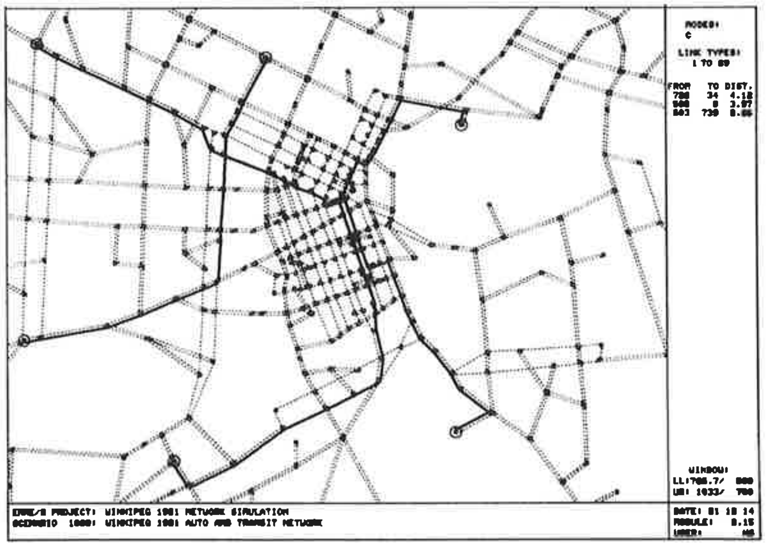


Figure 10. Plot of shortest distance path between two nodes on base network. The two nodes are identified interactively by using cross-hair cursors. The right-hand margin contains from node, to node, and distance in unit length. Shortest path is displayed with a heavy line on the base network.

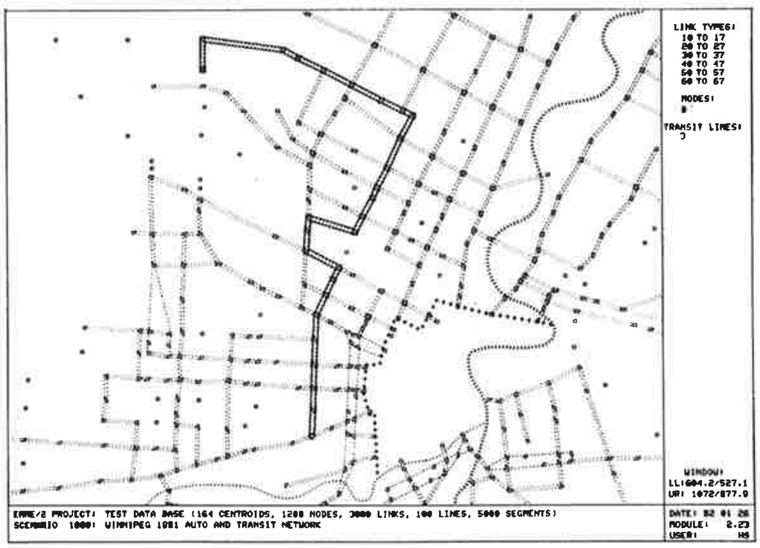


Figure 11. Plot of transit line number 3 on a window of base network that displays only links used by bus (B) mode.

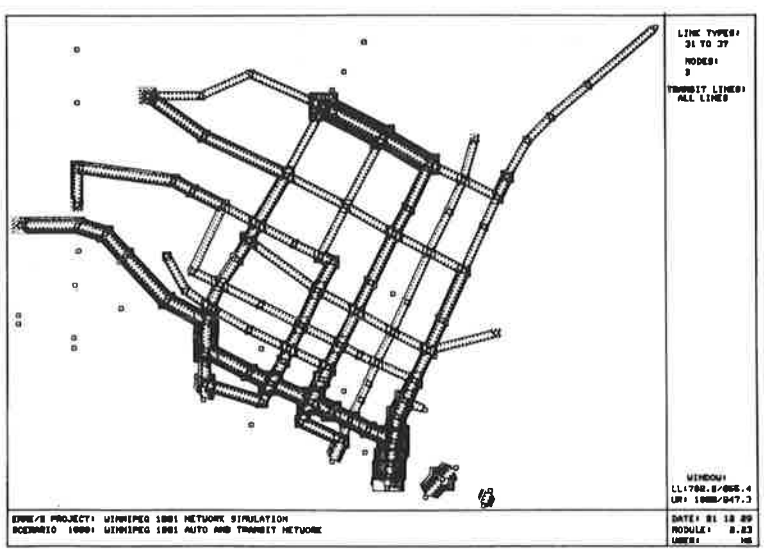


Figure 12. Plot of all transit lines that serve district 3.

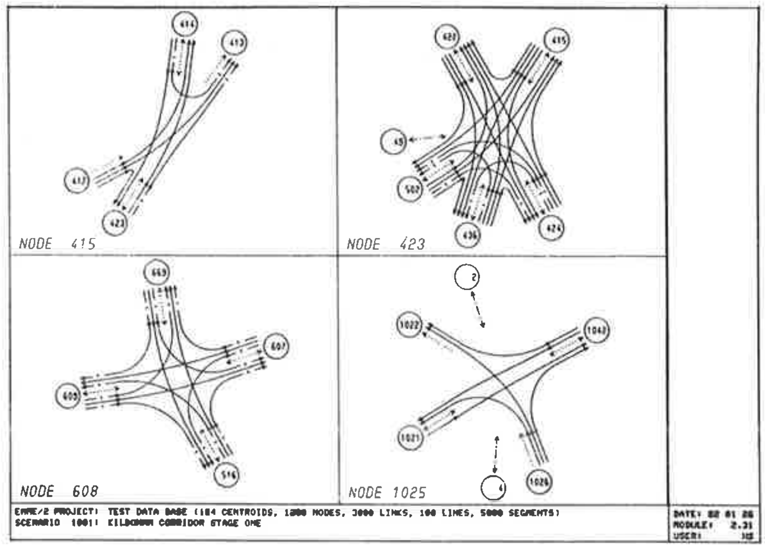


Figure 13. Plot of turning movements at selected intersections; forbidden turns are not shown and penalized turns are indexed with the corresponding penalty function.

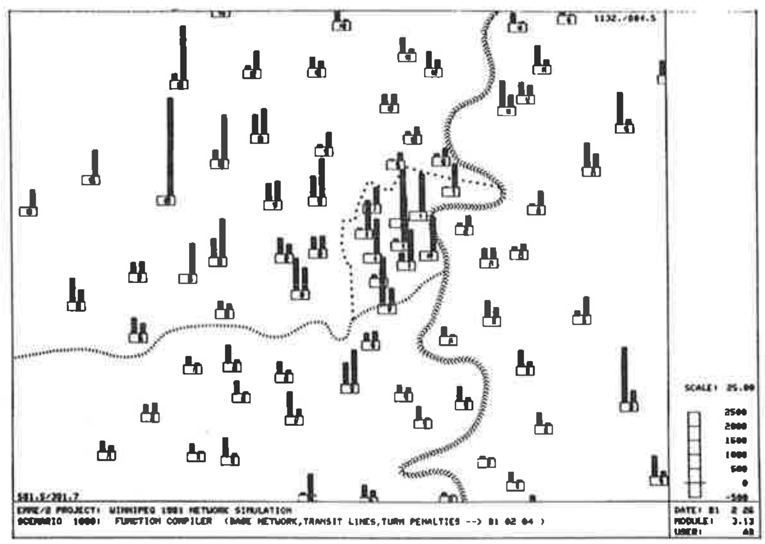


Figure 14. Plot of productions (row totals) and attractions (column totals) of origin-destination matrix; right-hand margin gives scale used for display bars.

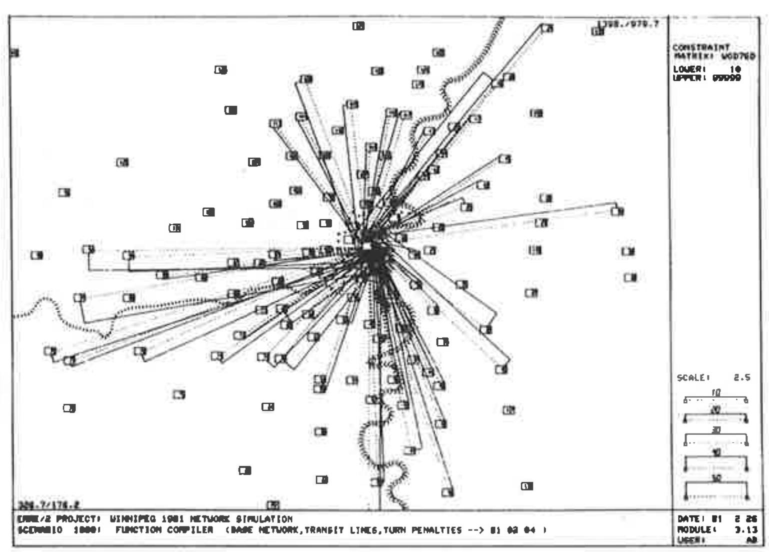


Figure 15. Plot of a column of the origin-destination matrix or desire lines for centroid 4: right-hand margin gives scale used for display bars.

Figure 16. Plot of four volume/delay functions: right-hand margin gives functions plotted (FD1, FD2, . . .) and parameters that were fixed at certain values (VOLTR=0, LANES=2, LENGTH=0.5).

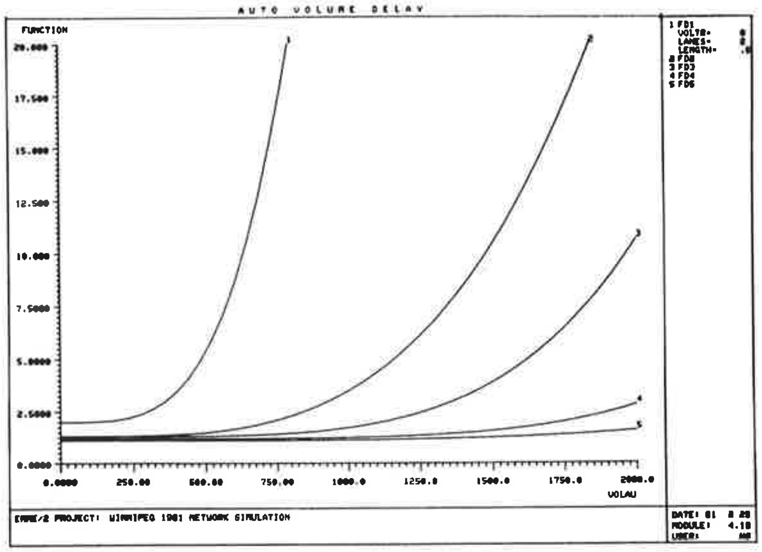


Figure 17. Plot of shortest path tree on automobile network (including penalized turns), based on link times that result from an assignment: right-hand margin gives root of tree, centroid 14.

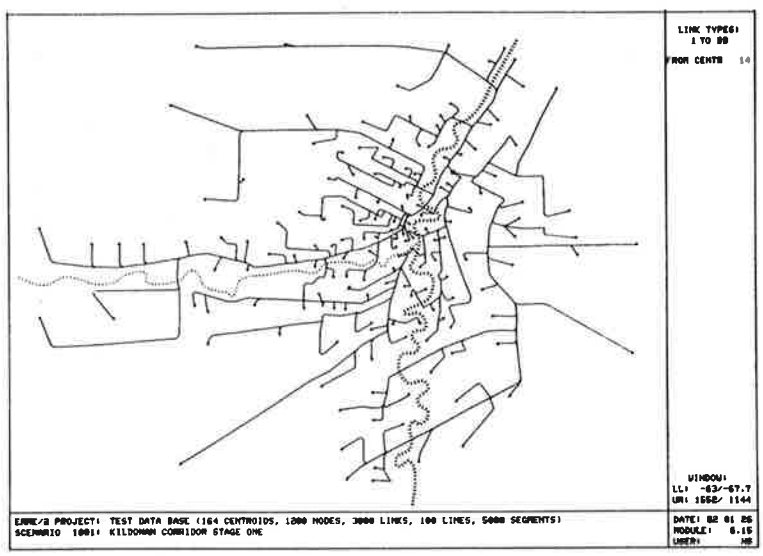
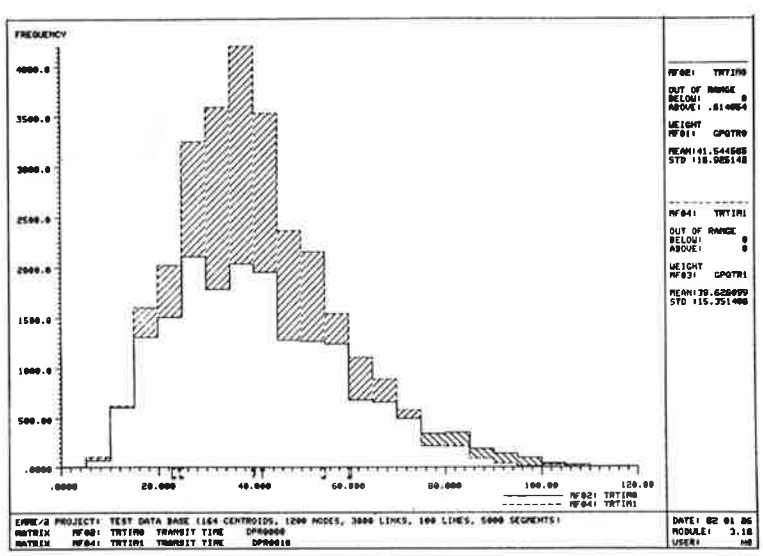


Figure 18. Comparison of two histograms of travel-time distributions: base year corresponds to travel-time matrix TRTIM0 and demand matrix GPQTR0; future scenario corresponds to travel-time matrix TRTIM1 and demand matrix GPQTR1; right-hand margin also contains mean and standard deviation of each distribution.



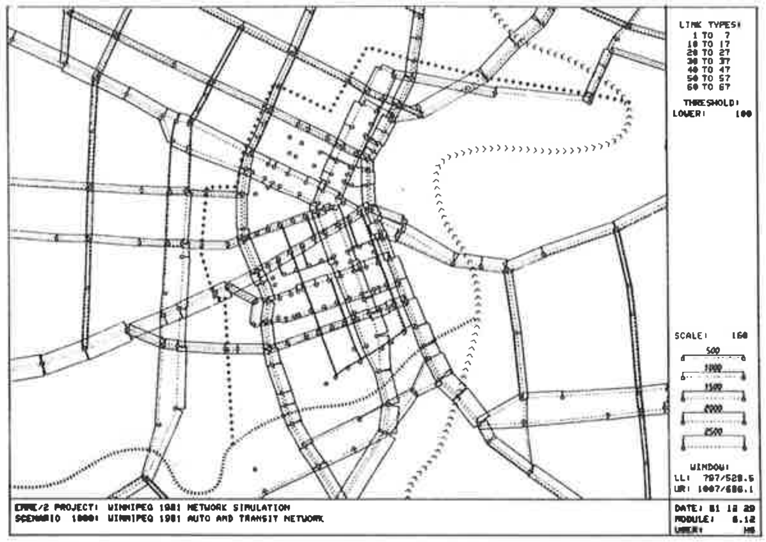


Figure 19. Plot of automobile link volumes that result from an assignment on automobile network: right-hand margin indicates that volumes smaller than 100 are not plotted (THRESHOLD : LOWER : 100) and scale used for display bar width.

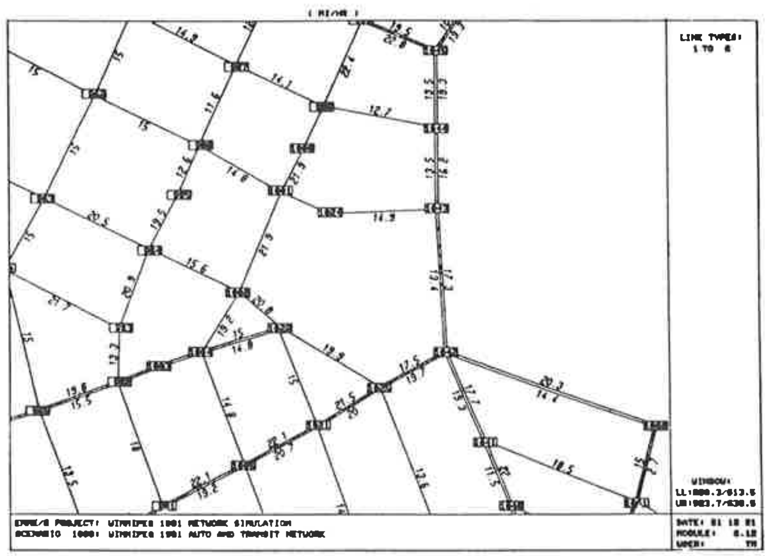


Figure 20. Plot of automobile link speeds as a result of an assignment on the automobile network.

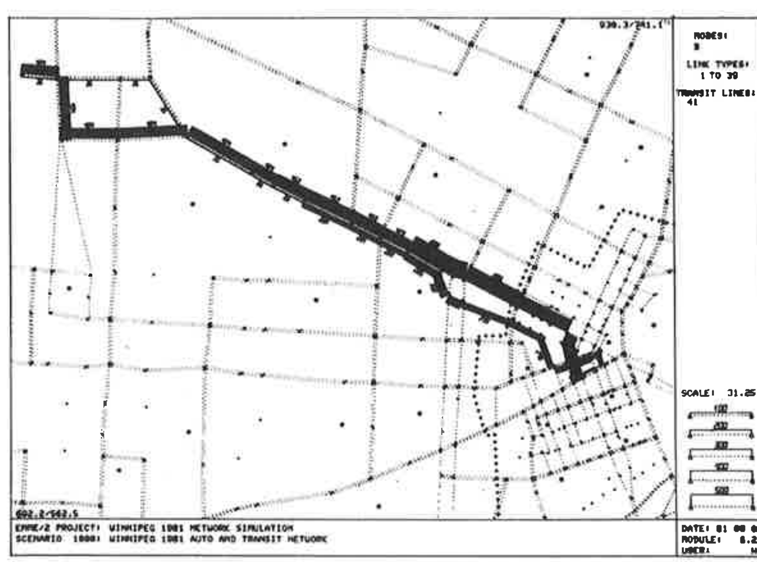


Figure 21. Plot of transit volumes on transit line number 41 as a result of an assignment on transit network.

Assignment Procedures

The most general assignment procedure provided by EMME/2 is a multimodal equilibrium assignment method that has variable demand. It computes the equilibrium demands, flows, and service levels for all the modes considered. Because the assignment procedures have a modular structure, the user may select equilibrium assignment with fixed or variable demand on the road network or variants of shortest path or multipath assignment on the network served by the transit and any or all of the auxiliary transit modes. For variable demand assignment, both mode choice and direct demand functions may be specified.

Results

EMME/2 permits the user to obtain a wide variety of results, both in interactive graphic form and as a printed output. The main feature of the results is interactive comparison of scenarios with accompanying graphical display. Although the main results pertaining to comparison of scenarios are related to link flows, origin-destination demands, and service levels, a wide variety of other results may be obtained by using the user-defined data (e.g., comparison of predicted versus observed flows for calibration).

Worthy of emphasis is that, unlike a batch code, where each successful execution terminates with a particular set of results, an interactive graphic code permits the user to obtain results of different types during a particular EMME/2 session. The notion of result is thus different from that of a batch code and may be considered to consist of the entire gamut of displays, results of computational procedures, data bank queries, and scenario comparisons.

Demarcation Lines and Log Book

For a given urban area the user may define demarcation lines that may be superimposed on a graphical output that covers the area spanned by the zone subdivisions. A demarcation line may identify geographical characteristics of the urban area, such as rivers or mountains or certain regions of the city, such as the central business district.

An automatic log book keeps record of the identity of the user and of the modules and elements of the data base used during all EMME/2 sessions.

EMME/2--THE COMPUTER-BASED SYSTEM

EMME/2 has been coded in standard ANSI Fortran IV and has been designed for easy transferability to various computer makes. It has been developed on the Cyber 173 of the University of Montreal; however, it may be adapted easily for other computers, including a certain class of mini or micro computers.

The EMME/2 code has a modular structure. Each of the modules is an independent program but all the modules share the EMME/2 subroutine library. All data transfers between modules occur only via the data base. Figure 3 gives a schematic representation of the program structure.

At present, EMME/2 is implemented for use on any of the Tektronix 4010 and 4110 series of terminals. Any output displayed on the screen may be copied by using the Tektronix 4631 hard copy unit. The same output may be drawn with a high technical quality by using the Tektronix 4663 digital plotter, when available. EMME/2 may be easily adapted for use with other graphic equipment of comparable resolution.

SOME OUTPUT EXAMPLES OF EMME/2

Figures 4-21 are a sample of the kind of output that is made possible by the EMME/2 system.

Jeffries Freeway Corridor Transit Design Project by Using the IGTD System

LUSIA DENDE GALLIO AND JAMES MASLANKA

This report presents the findings of an experiment in designing bus routes in a regional freeway corridor by using the Interactive Graphic Transit Design System (IGTDS). This project was conducted by the Southeastern Michigan Transportation Authority (SEMTA) in cooperation with the General Motors Transportation Systems Center. As a modeling tool, IGTDS allows the transit planner to study the alternatives and variables of a transit problem in spatial terms. The advantage of the IGTDS program is that it is easy to operate because it was designed for use by persons who have little or no computer background. Several objectives were realized by undertaking this corridor demonstration project. First, SEMTA transit planners were given an opportunity to work with and evaluate the latest computer graphics technology. Second, the IGTDS model was tested in terms of a real world transit planning situation by using existing data. Finally, the IGTDS method was compared with conventional transit planning methods in order to determine the strengths and weaknesses of each technique. This report describes and documents the IGTDS transit design process. It covers the areas of data development, operational characteristics, and alternatives analysis. Problems associated with each of the various steps are discussed. A primary part of the documentation of this experiment is a comparison of the effort involved in solving transit planning design problems by using IGTDS or conventional transit planning methods. Conclusions and recommendations are stated regarding the use of IGTDS as a feasible planning tool.

In June 1979 General Motors contacted the Southeastern Michigan Transportation Authority (SEMTA) pursuant to a proposal for a joint analysis involving Interactive Graphic Transit Design System (IGTDS) 2. IGTDS 2 is the second, advanced version of the transit design system. An agreement was reached and the responsibilities of both parties were delineated. SEMTA was to provide the experimental design, demand by census tract, network modifications, staff time, and preparation of the final report. Training on the use of IGTDS 2, computer time, the existing Detroit transportation node and link data base, and the technical support for allocating census tract demand data set to IGTDS nodes was to be provided by General Motors.

EQUIPMENT

The Department of Civil Engineering at the University of Washington, with the support of the Urban Mass Transportation Administration (UMTA), developed the Urban Transit Analysis System (UTRANS), the predecessor of IGTDS, in the early 1970s. The GM Transportation Systems Center (GM TSC) in 1977 took the UMTA users manual and developed GM TSC Release Number 1 of IGTDS. This was a conversion from the UMTA PDP-10 version to an International Business Machine (IBM) 370/168 version that operates with IBM's time sharing system (TSS). GM TSC continued to refine and improve IGTDS and later developed GM TSC Release Number 2 (1). Three versions of GM TSC Release Number 2 now exist.

In the analysis executed by SEMTA, an IBM version with TSS and the Prime computer version was used. Much of the network editing was accomplished by using the IBM time sharing version, and the data input and analysis were accomplished by using a Prime computer hard wired into the graphics display terminal.

The actual equipment required to use the software includes the following:

1. Tektronix model 4014-1 graphics display terminal,
2. Tektronix model 4631 hard copy unit, and
3. Bell Systems model 212A data communications unit.

STRUCTURE OF IGTDS

The IGTDS program is organized in a modular form. Each module can be manipulated independently but the entire system uses a common data base. A total of 17 modules or menu items form the IGTDS framework. These menu items can be classified into three functional categories: design, prediction, and performance.

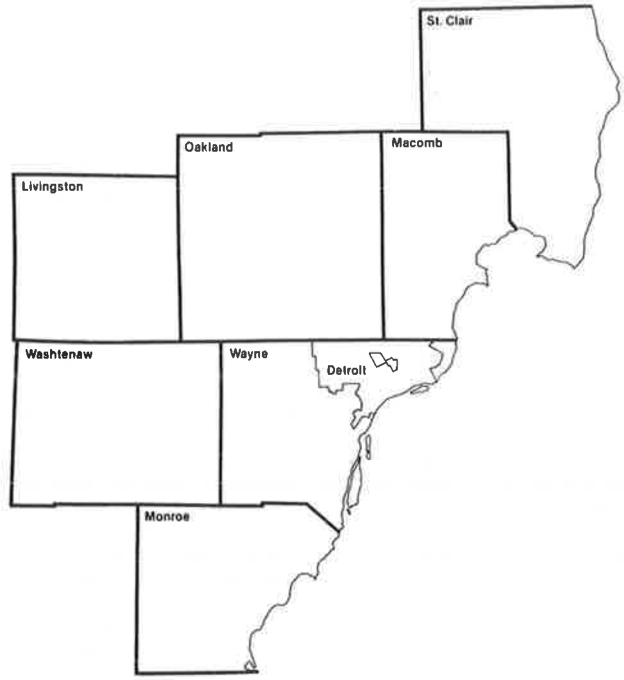
The design and prediction capabilities of IGTDS will be discussed in detail. The description of each component will follow in the order that the data are required to be input. This does not necessarily follow the numerical order of the menu items.

DESCRIPTION OF STUDY AREA

SEMTA's jurisdiction is a seven-county region that includes Wayne, Oakland, Macomb, St. Clair, Livingston, and Washtenaw (see Figure 1). SEMTA serves an estimated population of 4 697 500 in a 4603-mile^2 area. As of January 1981, SEMTA was operating a line-haul bus system of 378 coaches. In 1980, SEMTA carried approximately 11.2 million passengers and operated approximately 11.4 million revenue miles. Formed by the acquisition and merger of four privately owned suburban bus companies, SEMTA provides service between the suburbs and the Detroit central business district (CBD) and other points within the city as well as a variety of local and special services between suburban areas. The greatest volume of SEMTA patronage occurs on bus routes that connect Detroit's CBD and the suburbs. Most of SEMTA's vehicles operate in a closed door fashion on entering Detroit, meaning that SEMTA coaches cannot pick up and discharge passengers within Detroit. Thus, most of SEMTA's routes to the CBD are express in nature for the Detroit portion of the trip.

The environment of the southeastern Michigan region lends itself well to a transit analysis using IGTDS. First, there exist travel corridors that

Figure 1. Southeastern Michigan region.



have minimal current services slated for service expansion. Second, ridership habits on SEMTA services consist of a large percentage of peak-hour riders who go to one destination--the CBD. The specific orientation of the IGTDS program is directed to a many-to-one analysis. Finally, the present closed-door policy simplifies analysis by limiting the service area to be analyzed.

The SEMTA service planning staff decided that the optimum area for analysis would be the Jeffries Freeway corridor. The Jeffries corridor analysis area is principally located in Wayne County to the west of Detroit. The general boundaries of the study area are shown in Figure 2. SEMTA line-haul service in the Jeffries corridor study area is provided through the Wayne division terminal located in Inkster. Currently 18 routes operate from the Wayne division, 6 of which are park-and-ride routes.

The Jeffries corridor analysis included a total of 11 transit routes, 9 operated by SEMTA and 2 operated by the Detroit Department of Transportation (D-DOT).

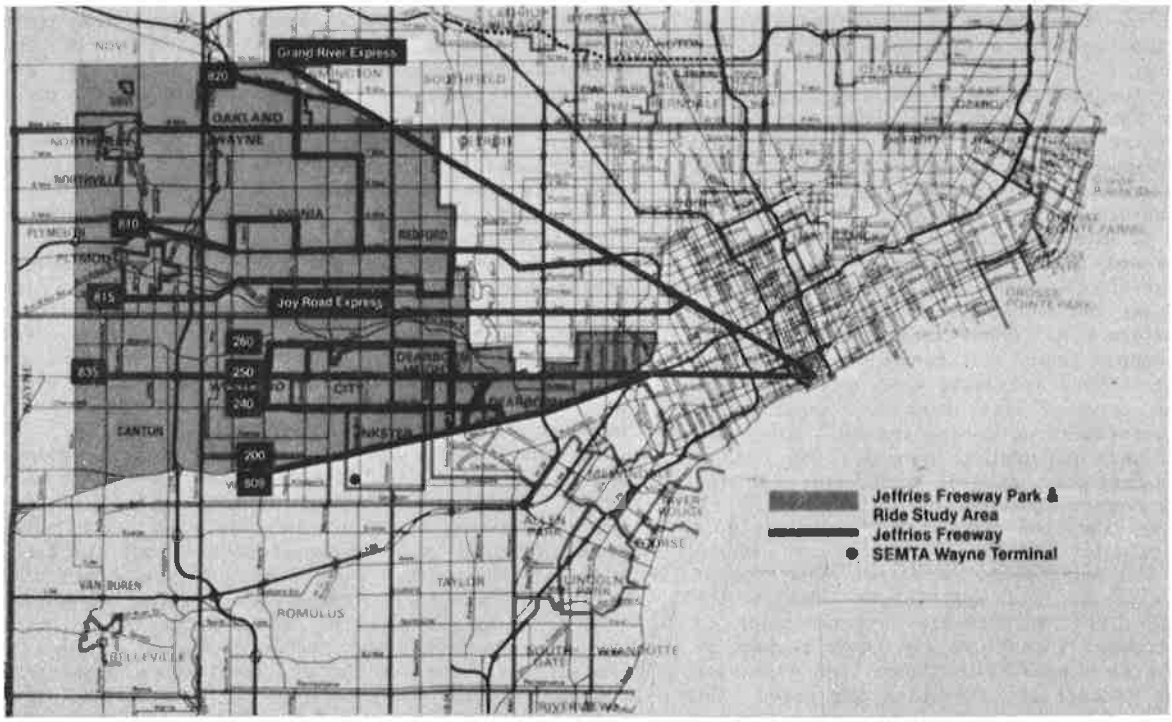
D-DOT provides transit service to the City of Detroit and some adjacent suburbs. The two D-DOT routes included in this analysis were the Grand River Express and the Joy Road Express. Inclusion of these D-DOT routes was appropriate because future plans call for the merger of the SEMTA and D-DOT systems.

All of the transit routes selected for this analysis serve the Detroit CBD. The five SEMTA park-and-ride routes operate during the peak period only and serve the Detroit CBD exclusively. A total of three SEMTA routes travel on the Jeffries expressway for the majority of the trip to the CBD. The remaining six SEMTA routes enter the CBD by traveling on Michigan Avenue (refer to Figure 2 for transit route configurations).

DATA DEVELOPMENT

Three components were required to form the IGTDS

Figure 2. Jeffries Freeway park-and-ride study area.



data base: (a) the base network on which the transit system was designed, (b) the node-oriented trip demand set from the analysis area to a candidate destination, and (c) the various parameters and model coefficients involved.

Base Network

The base network is an abstract version of the regional street system. In IGTDS, the street system is represented in the form of links and nodes. The base network is input and modified in menu item 2, the network editor.

The network editor will input the desired nodes and links by using numeric (keyboard) or graphic input. A network link is a one-way connection between two nodes and is indicated by selecting the beginning and ending nodes. Unless a one-way street is desired, links must be entered for both directions. The length of the link and the travel times for each of the three travel modes are input after the link is entered into the network. The same is true for the node attributes. After the node is entered and assigned x and y coordinates by the computer, the demand value and space cost for park-and-ride facilities are input. The network editor has the capability to delete or modify links and nodes on command.

The TRIMS network was used for the Jeffries corridor analysis project. The TRIMS network was developed by the Southeastern Michigan Council of Governments (SEMCOG) for use as a highway sketch planning network. Several modifications had to be made to this network to adapt it for the Jeffries corridor analysis. Initially, the TRIMS network could only be used as a geographic reference because it lacked sufficient detail.

For example, transit vehicles are capable of traveling on almost every roadway in the Jeffries corridor study area. However, the TRIMS Network consisted of a 2- to 3-mile grid system. To replicate the existing transit environment more accurately, a 1-mile grid system was developed. Also, the coding of the TRIMS network prohibited buses on freeway links. A transit travel time was given to all transit-suppressed links.

Because of the inadequacies of the TRIMS network, the inputting of the Jeffries corridor analysis base network was a slow process. Most of the network editing was done on the IBM computer with the TSS. This also hampered the process because, when the communication lines were interrupted, the editing process would be halted. The network editing process went much smoother with the Prime computer.

Travel time must be assigned to all links in the base network. Three time attributes are required: driving travel time, transit travel time, and walking time. SEMTA staff planners conducted a field survey of Wayne County roads to determine the speeds for the network. It was assumed that transit vehicles would travel at a constant 20 mph on most arterials and 45 mph on expressways. The automobile travel time was assumed to be 5 mph less than the posted speed on all roads. The walk travel time value of 20 min for a 1-mile link remained constant.

Demand Set

Three demand sets were developed initially for the Jeffries corridor analysis. The first demand set consisted of the total number of persons in the Jeffries corridor analysis that are employed in the Detroit CBD. Demand set 2 combined the total number of persons in the analysis area employed in the New Center area, which is approximately 3 miles north of the Detroit CBD. The third demand set included the number of persons in the analysis area employed at one Detroit CBD employer. Although three demand sets are available for use with IGTDS, only demand set 1 was actually tested, mainly because of its large size and Detroit CBD orientations. The following is a description of the methodology used for developing the demand set data. This explanation will focus on the development of demand set 1, but all three demand sets were developed by using the same methodology.

Residential location data for the tricounty SEMTA service area was collected from major employers through the joint efforts of SEMTA's planning and business development departments. The residential location data collected from major employers varied slightly in nature. Some employers have released the addresses of their employees, but other employers have released only the summaries at zip code levels (number of employees who live in each zip code). By using the Regional DIME geographic base file (GBF) and the U.S. Census Bureau's ADMATCH program (2) the census tract that contains each address was identified. Those addresses that were not identified by the program were processed manually to identify the corresponding census tracts. Note that the manual process of address matching was one of the most time-consuming project activities; it required several months of effort by SEMTA staff.

The employee location data, which was only a sample of total demand, were expanded to reflect total Detroit CBD employment. A direct expansion of the sample data was not appropriate because the sample data were not an accurate representation of the total employment in the CBD and their respective proportions for each type of industry. An expansion within similar industrial categories was used. The actual expansion from the sample data to the control totals within each category was performed at zip code level. These data were transferred to the small geographic level of census tracts by using a zip code-census tract equivalency table.

The next step consisted of extracting from the total tricounty employment data set the employment data by census tract for the Jeffries corridor analysis area. It was then necessary to convert these data to SEMCOG's traffic analysis zones (TAZs). This was done to facilitate the conversion of these data to the node-based form required by IGTDS. Since the TAZ's zonal centroids were available and the census tract centroids were not, the conversion was necessary. In order to apply the IGTDS system, the travel demand data in TAZ form were transferred to the nodes of the Jeffries corridor transportation network. The link-to-node data conversion system (ZONOCO) (3) was employed to effect the conversion.

The ZONOCO program operated by creating a three-dimensional surface over the Jeffries corridor study area by using a data-gridding procedure. Demand density at the TAZ centroids was used to approximate density values at the grid intersection. Grid intersections were then assigned to the nearest node. Demand data values were then assigned to the nodes based on the density of each grid intersection in the node service area and the number of the intersections. By this process, the IGTDS demand file was created.

Parameters and Coefficients

The third component of the IGTDS data base consists of the model coefficients and parameters. Calibration values are required for the logit mode choice model and for the cost model. Parameters must be initialized to describe vehicle characteristics, analysis time period, origin and destination walk time, destination parking fee, and transit waiting time. All default values and parameters will require modifications that correspond to the transit environment being analyzed. Any one of these values can be changed interactively. The calibration of the Jeffries corridor model is documented in the explanation of menu item 10, the mode split.

Initially, this IGTDS study obtained the logit model parameters and coefficients used in the Bellevue, Washington, IGTDS demonstration (4) and checked them with previous SEMTA surveys and transit experience. Values were assigned to approximate existing conditions that affect the SEMTA system as of September 1980. These values are initialized in menu item 1 of the IGTDS program.

The variables for the cost model and for the vehicle characteristics are entered in menu item 17, cost model parameters. First the vehicle characteristics table is displayed. Data related to the operation of the transit vehicle are entered in this module. Up to four vehicle types can be used. For each vehicle type the following characteristics are input: number of seats, number of standing spaces, comfort level, operating cost per mile and hour, fixed cost, and the driver cost per hour.

In the Jeffries corridor analysis vehicle types 3 and 4 were used. All local routes in the transit design were assigned type 3 vehicles because a passenger standing situation is likely to occur. Ten standing spaces were assigned to this vehicle type. Park-and-ride routes were assigned type 4 vehicles with zero standing. These routes are considered long-haul, express service, and a situation in which a passenger must stand for as long as an hour is undesirable. The vehicle classifications are input, for each route, in menu item 8 of the IGTDS program. Some problems were encountered in determining the operating and fixed cost data.

Next, the computer displays the table of cost model coefficients and parameters. As mentioned earlier, some problems were encountered in the data and use of the cost model. In most cases the IGTDS concept of specific costs was not compatible with SEMTA's accounting procedures so that some data were unavailable in the form required. This was not considered to be a deficiency of IGTDS, but it did prevent the cost model component of IGTDS from being fully tested in the Jeffries corridor analysis.

OPERATIONAL DATA INPUT

Once the street network is in place, the transit route design may be input. Menu item 4, transit route design, provides for the initial definition of a transit system that serves the destination node, which in this design is the Detroit CBD. The defined transit design can be modified by using menu item 16, the route editor.

First, in designing the transit system a window is selected and the street network is displayed. A route is designed by inputting the first transit stop or lot closest to the destination node and, moving outward, plotting the transit stops or lots until the starting point of the route is reached. Each route in the transit design is input in this fashion. The only constraint that affects the route design is that it must not violate the graph theory definition of a tree, that is, there can be only one possible transit path from a node to the destination.

A good deal of time was spent on the transit design. Problems existing with the original TRIMS network, as transit was suppressed on a number of links and in some cases, additional links were added. To input these modifications required further sessions with the network editor. Additional transit stops were added to the design on the number 810, number 815 and number 820 park-and-ride routes in order for the actual configurations to be represented.

Another problem encountered involved menu item 16, the route editor, which has the capability to correct a wrong input made in the initial design in menu item 4. For example, if a stop was designated instead of a lot, the route editor has the ability to delete the stop and replace it with a lot. When this module was used by SEMTA staff, the instructions in the IGTDS manual were not clear enough to allow the delete line function to be executed successfully. This necessitated the use of menu item 4 for the entry of all route design data, without the assistance that the delete line function of menu item 16 could have provided. Subsequent testing of the route editor by GM staff members, however, reported that the delete line function was operational. Also, because the street network was not labeled, inputting of the transit design was hindered until the operator became familiar with the grid. This situation was somewhat alleviated by referring to a copy of the street network grid that had been correctly labeled. In the Jeffries corridor demonstration project, nine existing SEMTA lines and two D-DOT routes were input (see Figure 3). The transit design included a total of 22 park-and-ride lots, 21 of these were on SEMTA routes. One informal lot serves the D-DOT Grand River express. Also included are 78 transit stops. To simulate the actual service pattern of local routes, which stop frequently, stops are input at each node intersection on the transit line. A total of nine stops were designated on park-and-ride routes, most of which were inserted to correct a route configuration problem.

The function of menu items 5 and 6, parking lot sizes and parking fees, is to input the size of each lot, by number of parking spaces, and the parking fee that is to be charged, if any. All 22 lots were listed in the numerical order that they appear on the transit design network and lot sizes were designated (see Figure 4).

As of September 1980, SEMTA did not own any of the park-and-ride lots. Various agreements are made between the lessor and SEMTA. Payments to the lessor may range from $0 to $2000. These payments are either for the actual lease or they cover fees for maintenance activities executed by the lessor. The daily cost for each lot was listed as $1.00. This reflects the value given the variable operating cost parameter, which was $1.40/day for each lot. The $1.40 figure represents an average cost per day by using the total annual cost for all lots. The computer has rounded off this figure to the nearest one.

Menu item 6 was not particularly significant to this design problem. SEMTA does not charge its patrons for parking at designated park-and-ride lots. A zero fee was entered under the appropriate heading for each park-and-ride lot. No significant problems were encountered in menu items 5 or 6.

Access and egress characteristics for each route are input in menu item 7, transit route deadhead characteristics. The term deadhead is used to describe the time or the distance required for a transit vehicle to travel from the storage facility to the point where revenue service begins and from the point where revenue service ends back to the storage facility.

Both time and distance deadhead access characteristics were entered for each route in the network. Egress deadhead characteristics were given a zero value because SEMTA vehicles do not necessarily return to the bus garage after each run to the CBD. Some vehicles that serve park-and-ride routes will return to the original point of revenue service and make a second trip. Other vehicles may work split runs, or in terms of local service, travel back and forth on that route for the entire time period.

The values for the default return trip and the return trip were calculated by the computer based on the default values in menu item 17 under the heading of transit line deadhead characteristics. No problems were encountered in using this menu item.

Transit operating characteristics are entered into the program in menu item 8. The transit design is displayed. For every transit line, the vehicle type and headway is entered. The IGTDS computer program determines the maximum number of vehicles, by using the assumption that there will be one vehicle for each revenue trip made on the route during the analysis period. The minimum number of vehicles is determined by allowing the vehicles to return to the origin point of revenue service for additional trips. The computer also lists a cost for both the minimum and maximum alternatives. The number of actual vehicles was input in the last column (see Figure 5).

Vehicle type for each route was listed as either a type 3 or a type 4, based on information from menu item 17 under vehicle characteristics. Park-and-ride routes were classified as vehicle type 4 and local routes received a vehicle type 3 designation.

The transit system fare structure is designed in menu item 9. In this module a base fare is input. If zone charges are required, then the transit design appears and fares are input at zone boundaries located with the graphic crosshairs. Unfortunately, the transit design appears on the screen without the aid of the street network grid. Once again a labeled network map must be used as a reference. Also, zone fare designations must be input for each route. When the data input are complete, the fare at all stops is automatically displayed. SEMTA's base fare in September 1980 was $0.60. The $0.60 fare covers zones one and two. The SEMTA service area is divided into eight zones. Each zone thereafter is an additional $0.20. Park-and-ride routes had a base fare of $0.80. That fare applies to travel through zones one and two. Each subsequent zone is an additional $0.20. D-DOT charges a base fare of $0.60. No zone charges applied to D-DOT routes in the study area.

DATA ANALYSIS

After all the required data have been entered into the program, the modal split may be computed. Menu item 10 performs the modal split and public transportation system capacity-restrained assignment computations. This process involves an estimation of the number of tripmakers likely to use either the walk-and-ride, park-and-ride, or drive mode. The computer model will, at the same time, assign potential transit patrons to the transit lines in the design by means of the shortest impedence paths. The probability that a tripmaker will travel to the specified destination is determined by comparing the impedences associated with each mode of travel. By using a series of estimation equations, the IGTDS computer program calculates a mode split value for each node in the network. It then assigns the park-and-ride and walk-and-ride demand to transit routes and parking lots based on the shortest impedence path between the node and destination node. If route and lot capacity is exceeded, the excess demand will be assigned to a route or lot on the second shortest path or to a different mode in the next iteration of the modal split process. The computer will perform as many iterations as the analyst desires, unless 100 percent of the demand has been allocated.

When all demand has been allocated, the computer will display the results in menu item 11, perfor-

Figure 3. Jeffries corridor transit network, 1980.

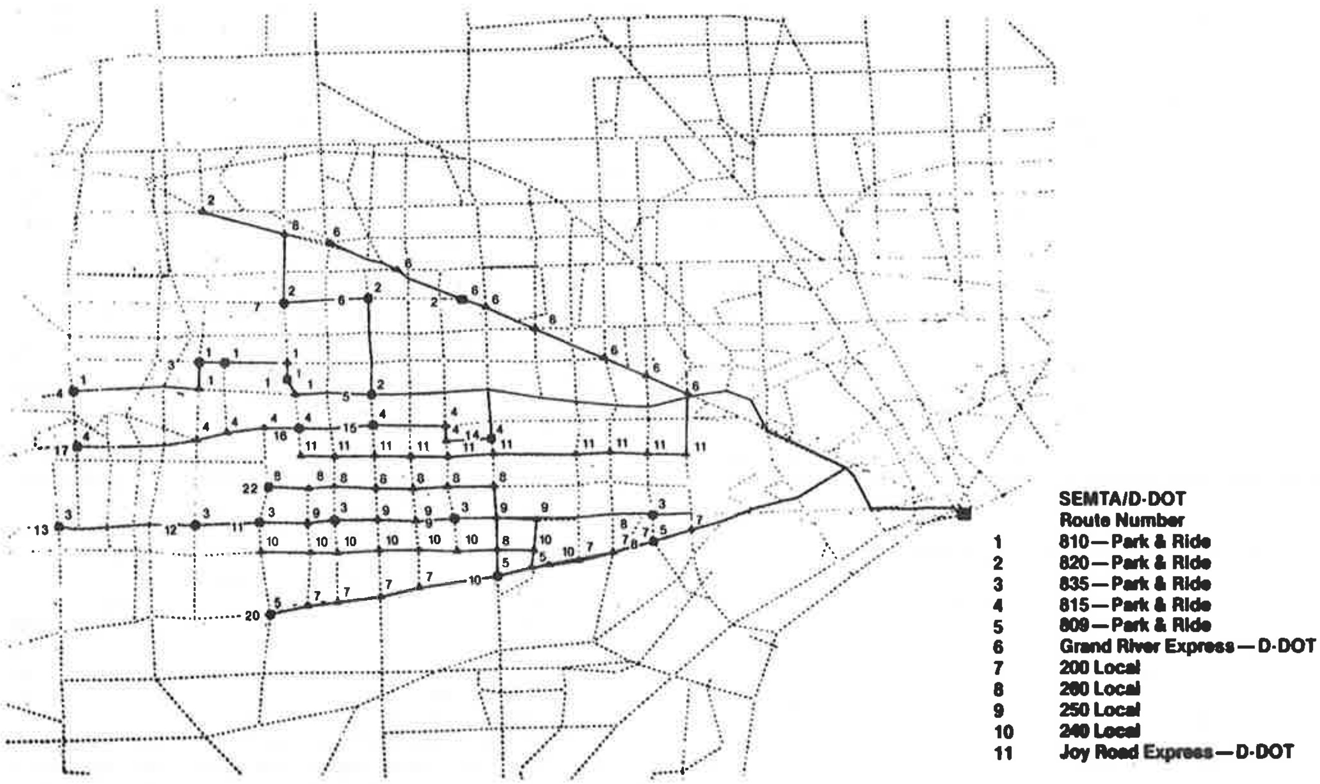


Figure 4. Jeffries corridor park-and-ride lot sizes, 1980.

ENTER NUMBER OF PARKING SPACES AVAILABLE
DURING THE ANALYSIS PERIOD FOR
EACH P-R LOT

LOT	SPACES	DAILY COST (DOLLARS)
1	105	1
2	50	1
3	75	1
4	80	1
5	100	1
6	55	1
7	60	1
8	40	1
9	25	1
10	30	1
11	50	1
12	30	1
13	30	1
14	100	1
15	150	1
16	75	1
17	50	1
18	25	1
19	50	1
20	50	1
21	25	1
22	30	1
0		

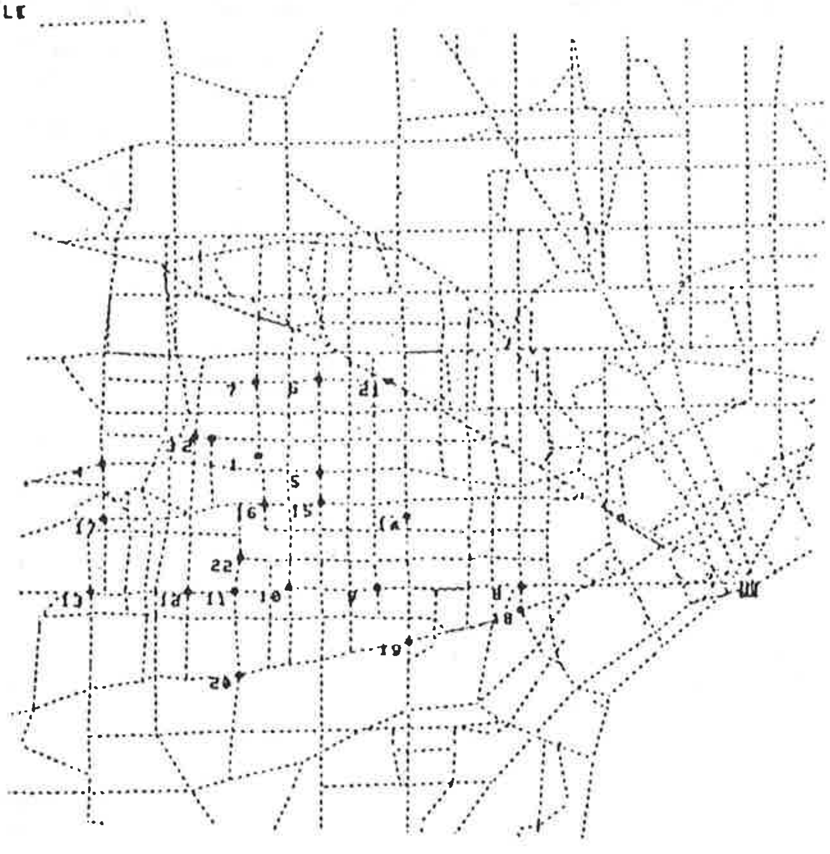
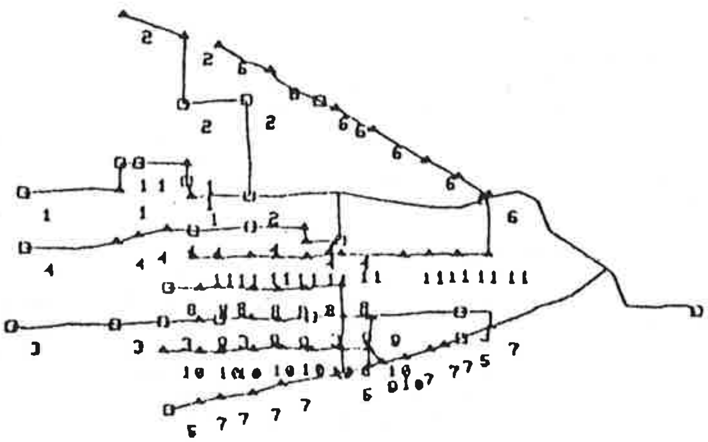


Figure 5. Jeffries corridor transit route operating characteristics, 1980.

HEADWAYS WHICH MINIMIZE LAYOVERS

LINE	R.T. TIME	1	2	3	4	5	6	7	8	9	10
1	106.9120	60	40	30	24	20	18	15	14	12	
2	137.3180	60	40	30	24	20	18	15	14	12	
3	176.4120	60	40	30	24	20	18	16	14	12	
4	164.3120	60	40	30	24	20	18	15	14	12	
5	103.0103	58	36	26	21	18	15	13	12	11	
6	135.6120	60	40	30	24	20	18	15	14	12	
7	106.5107	54	36	27	22	18	16	14	12	11	
8	123.6120	60	40	30	24	20	18	15	14	12	
9	103.0104	52	36	26	21	18	15	13	12	11	
10	111.3112	56	38	28	23	19	16	14	13	12	
11	147.0120	60	40	30	24	20	18	15	14	12	

ANALYSIS PERIOD IS 120 MINUTES



ENTER OPERATING CHARACTERISTICS

LINE	VEH TYPE	HDWY	LAY-OVER	MIN VEHS	COST	MAX VEHS	COST	ACTUAL VEHS
1	4	12	0	10	191	10	191	10
2	4	10	0	12	229	12	229	12
3	4	14	0	9	172	9	172	9
4	4	24	0	5	96	6	96	6
5	4	14	18	8	162*	9	171	8
6	3	8	0	15	286	15	286	15
7	3	5	13	22	439*	24	457	22
8	3	23	0	6	114	6	114	6
9	3	24	0	5	95	6	96	5
10	3	16	11	7	144*	8	152	7
11	3	15	0	8	153	8	153	8

0

TOTALS 107 VEHICLES
5217 CAPACITY
2081 DOLLARS

mance summary. First the modal split summary will appear on the screen. The trips allocated to each mode are shown in terms of the number and percentage of the total demand for the analysis area. The summary also contains data regarding cost-revenue design parameters and trip characteristics. Detailed information for each route and parking lot in the design was obtained by selecting either the line summaries or lot summaries.

The first run of the Jeffries corridor analysis data produced a mode split summary that was inconsistent with existing ridership data. Existing demand was derived by dividing the August 1980 ridership totals for the routes in the design by the CBD demand figure in demand set 1. The total transit ridership estimated in the IGTDS model was off by 18 percent. The IGTDS model allocated 10.4 percent of the demand to transit; the actual demand was 8.5 percent. That figure could have been acceptable; however, the majority (10.1 percent) was allocated to walk-and-ride. According to the August 1980 ridership figures, the walk-and-ride mode received 5.6 percent of transit riders and park-and-ride received 2.9 percent of transit riders.

The inconsistency in the IGTDS mode split summary could be related back to the initialization values. There is a sensitive relation between the walk-and-ride and park-and-ride constants. The default value associated with drive time affects park-and-ride also. By comparing empirical data that describe ridership with the initial IGTDS ridership output, adjustments were made in the walk-and-ride and park-and-ride default values to achieve a more realistic balance between the two modes.

For this analysis, the basic network consisted of a 1-mile grid of highways and all demand allocated to the nodes that comprise the intersections of the highways. Such a demand allocation impedes accurate walk-and-ride predictions because it does not account for the long walks necessary for individuals who live in the interior of the cells to access transit vehicles as walk-and-ride patrons. This problem could be alleviated by inputting additional demand nodes and pedestrian links in the network, but such an effort could dramatically increase the time and effort necessary for network coding, and was thus not considered for this study.

The final results regarding the mode split analysis proved to be sound. The IGTDS modal split performance summary estimated transit ridership at 7.9 percent, which is approximately 0.6 percent less than the actual ridership figure. The walk-and-ride mode was 0.1 percent less than the actual ridership but the park-and-ride demand estimate was still low at 0.5 percent less than existing ridership. The IGTDS modal split estimations were considered to be adequate and acceptable for the Jeffries corridor analysis.

Sensitivity Analysis

Once an acceptable mode split was achieved for the 1980 Jeffries corridor study, a series of tests was conducted to determine the sensitivity of the IGTDS process to changes in certain variables. The following is a list of alternatives tested:

1. Fare increase,
2. Parking lot sizes,
3. Headway modifications,
4. Route configuration changes, and
5. 1978 data base.

Fare Increase

The first experiment involved the testing of the ridership model in terms of fare elasticity. SEMTA was planning a fare increase on July 1, 1981. A test was planned to determine what effect it might have on ridership. The base fare was to be increased to $0.75, which was a $0.15 increase from the current base fare of $0.60. The park-and-ride base fare also was increased by $0.15, from $0.80 to $0.95. Zone charges remained constant at a $0.20 increase per zone.

The new transit fares were input by using menu item 9, transit fares. All other Jeffries corridor transit design data remained the same. The IGTDS modal split summary estimated that a shift of 0.2 percent would occur between walk-and-ride and the drive mode. This meant that a total of 95 transit riders would transfer from the walk-and-ride mode to the drive mode. There was no percentage change in the park-and-ride mode. According to these results the fare increase was not substantial enough to have a significant effect on ridership.

Parking Lot Sizes

Park-and-ride lot sizes were increased as a test to determine their effect on ridership. The first test involved increasing the size of lot 4 at the Jeffries Freeway and Middlebelt from 100 spaces to 350. SEMTA anticipated that a larger lot would become available near this existing lot. We wanted to determine whether an increased lot size at this location would affect ridership for the park-and-ride mode. The IGTDS mode split summary estimated that park-and-ride would increase by 0.6 percent, meaning an increase of 260 patrons. The majority of this increase was due to a shift from the drive mode to park-and-ride. The walk-and-ride mode also lost some patrons to the park-and-ride mode.

The mode split was also run with park-and-ride lot sizes increased at some lots. All lots that were listed in the SEMTA park-and-ride lot inventory as having no limit were raised to 100 spaces from the original number designated. Also, lots that listed the estimated use as higher than the capacity per agreement were increased to the number of spaces actually required.

The results were generally the same as when the spaces in the single lot were increased. The park-and-ride total increased by an additional 0.8 percent to a total of 3.8 percent for that mode. Both the walk-and-ride and the drive modes lost patrons; the greater shift came from the drive mode. We assumed that the potential exists for increased park-and-ride ridership in the Jeffries corridor analysis area if expanded parking facilities are available.

Headway Modifications

Another experiment involved reducing the headways on the park-and-ride routes in the Jeffries corridor analysis area to determine what effect this would have on ridership. Headways were reduced to 5 min on four of the five park-and-ride routes. The headway for the number 815 Western Wayne was reduced to 15 min because its original headway was 24 min. Headways on the other park-and-ride routes were originally less than 15 min.

Headway reduction also has a positive effect on park-and-ride ridership estimates. The IGTDS modal split summary calculated a 0.4 increase in ridership for the park-and-ride mode. The shift in riders from the drive mode accounted for approximately 90 percent of the increase in the park-and-ride mode.

Another modal split was run by using an alternative that combined the effects of the reduced headways and the expanded park-and-ride adjustments. This produced an increase of 881 patrons or 2.0 percent in the ridership estimates for park-and-rides. Once again, the shift in riders from the drive mode accounted for 91 percent of this increase. According to IGTDS calculations, enough potential transit ridership demand existed to justify a service expansion program that would include headway reductions on existing routes and increased capacity at existing park-and-ride lots.

Route Configuration Changes

An experiment was conducted to determine what effect changing the configuration of a route would have on the modal split. One route, number 815 Western Wayne park-and-ride, was selected for the test because SEMTA staff planners were considering a change in the route at the time. Four different alternatives were input. All four route alignment alternatives for the 815 affected the modal split summary. Unfortunately, the effect was negative in terms of transit ridership. In this instance the cost-allocation model would have been useful. But, as stated earlier, certain problems with the data prevented its use here.

1978 Data Base

A new transit design was created to simulate the service in the Jeffries corridor analysis area that existed in September 1978. Only eight transit lines were operating in the Jeffries analysis corridor at that time, three routes fewer than in 1980. The data were input in the same fashion as for the 1980 transit design network. The initialization values and parameters used in the 1980 transit design remained constant. The results of the first-run modal split calculations were consistent with the actual ridership for the September 1978 time period. Actual ridership divided by the total demand in the IGTDS demand set resulted in a walk-and-ride demand of 5.5 percent and a park-and-ride demand of 0.7 percent. The IGTDS modal split summary estimated walk-and-ride at 5.4 percent and park-and-ride at 0.9 percent. These results were considered to be acceptable and appropriate for the 1978 Jeffries corridor analysis network.

COMPARISON OF IGTDS TO CONVENTIONAL ANALYSIS

One of the objectives of the Jeffries corridor demonstration project was to compare the conventional transit route planning method with IGTDS. This will be accomplished by first describing the conventional transit demand determination methodology used by SEMTA. This will be followed by a general comparison of IGTDS and the conventional system in terms of method, time, and application. For purposes of this discussion, the comparison between IGTDS and conventional transit planning techniques will be limited to the modal split portion of the analysis. Because available SEMTA financial information could not be reconciled with the data needs of the cost-analysis component of IGTDS during this project, no comparison will be made between conventional SEMTA cost-allocation techniques and those employed by IGTDS.

Conventional Analysis-Demand Determination

The service planning staff of SEMTA has developed a simple methodology for estimating ultimate ridership levels on CBD-oriented routes in metropolitan Detroit. This methodology uses the major employer data base to produce travel demand from each census tract in the region to the Detroit CBD. The major employer data base is also used for the IGTDS demand set. An ultimate ridership estimate can be made by allocating transit demand to the service areas of the proposed bus routes and then applying a transit mode split.

The methodology for predicting ridership on the manual analysis of the Jeffries corridor began by superimposing the transit routes on a census tract map of the analysis area. The second step was to determine the width of the assumed service area. From previous experience with park-and-rides, it appears that on assumption of a 2-mile wide service area, 1 mile on each side of the route, is appropriate for a park-and-ride that has no local routes within 2 miles of it. In those cases in which a new route is only 1 mile between parallel routes, a 1-mile service area was assumed. Generally, a 0.5-mile service area, 0.25 mile on either side of a route, is assumed for local routes.

On obtaining this information, the employment demands for each census tract within the service area of a transit route are located in the computer printout of residential location data by census tract. The applicable demand for each route is determined by taking a percentage of the total demand allocated to each census tract. This percentage is based on the portion of the census tract that is in the service area of the transit route. A mode split of 20 percent was applied to the demand totals for each route to obtain the total number of people that would possibly use bus service in that route's service area. The 20 percent mode split figures is a conservative estimate based on empirical evidence of mode split behavior for those corridors in the southeastern Michigan region well served by transit.

In comparing the potential demand to actual ridership, this demand estimation process produced acceptable results for the transit routes in the Jeffries corridor analysis. It predicted that existing SEMTA bus routes would carry 2289 people into the Detroit CBD. This compares favorably with actual ridership of 2193 in May 1981 from this corridor to the Detroit CBD.

IGTDS Versus Conventional Analysis

The IGTDS process and the conventional transit planning process were compared in terms of the nature of the method employed and the time and personnel needed to accomplish the analysis.

Obviously, with the conventional analysis all graphic displays and calculations must be done manually. This is naturally a time-consuming and, at times, a tedious process. Depending on the form in which the base network and demand data are available, the initial data input for IGTDS may also require additional time expenditures. However, once that data base is input, the rest of the process becomes relatively easy. Also, IGTDS is capable of calculating a mode split in a matter of seconds or minutes, depending on the number and type of jobs being processed simultaneously with IGTDS by a time-sharing computer installation. In the Jeffries corridor analysis, both the conventional methods and IGTDS produced acceptable results in terms of the mode split calculations related to existing service.

The most significant difference between the two transit route planning methods is the ability of IGTDS to predict traveler response to changes in service level. The sensitivity analysis performed on the Jeffries corridor area by using IGTDS would have taken months to accomplish if conventional analysis techniques were applied. Much of the analysis would have been based on past experience or educated estimations. The nature of the conventional transit planning methodology is not fully interactive. Each component is dealt with separately; however, IGTDS is capable of analyzing the effect of all the components and alternatives for the analysis problems as a whole. This seems to be the greatest asset of the IGTDS program.

In terms of personnel, development of the base network for both analysis types requires the efforts of several people. Also, with the IGTDS program, initial setup may require some training period. However, when both systems are set up, only one person is required to perform the analysis. The productivity of IGTDS is greater, however, because of its increased capacity for data manipulation.

CONCLUSIONS AND RECOMMENDATIONS

The major objectives of the Jeffries corridor demonstration project were accomplished successfully. The transportation planners at SEMTA greatly increased their knowledge of computer graphics technology and transit route planning in general. IGTDS was found to be a useful transit planning tool, especially in terms of analysis capabilities. Finally, IGTDS compares favorably with the conventional planning method and is capable of performing certain analyses that are beyond the realm of conventional techniques.

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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.

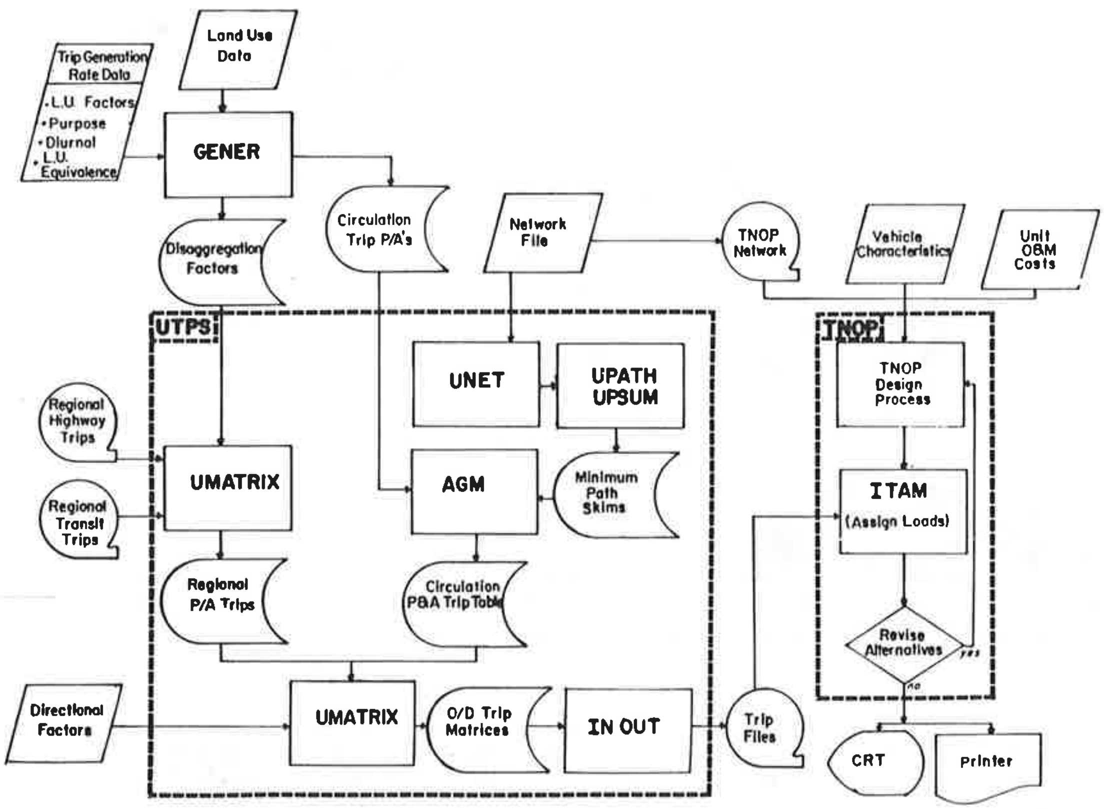


Figure 2. Baltimore CBD with DPM zones.

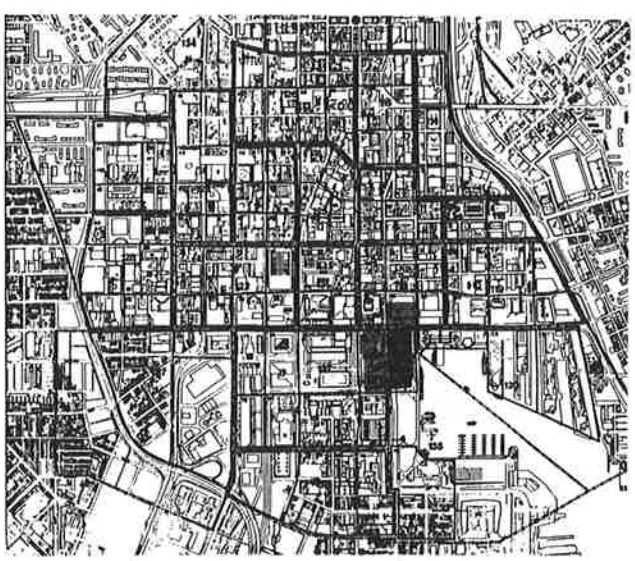
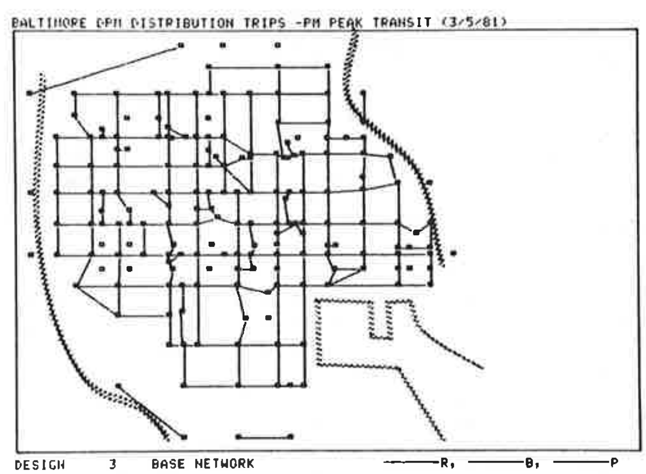


Figure 3. Baltimore DPM study area street network.

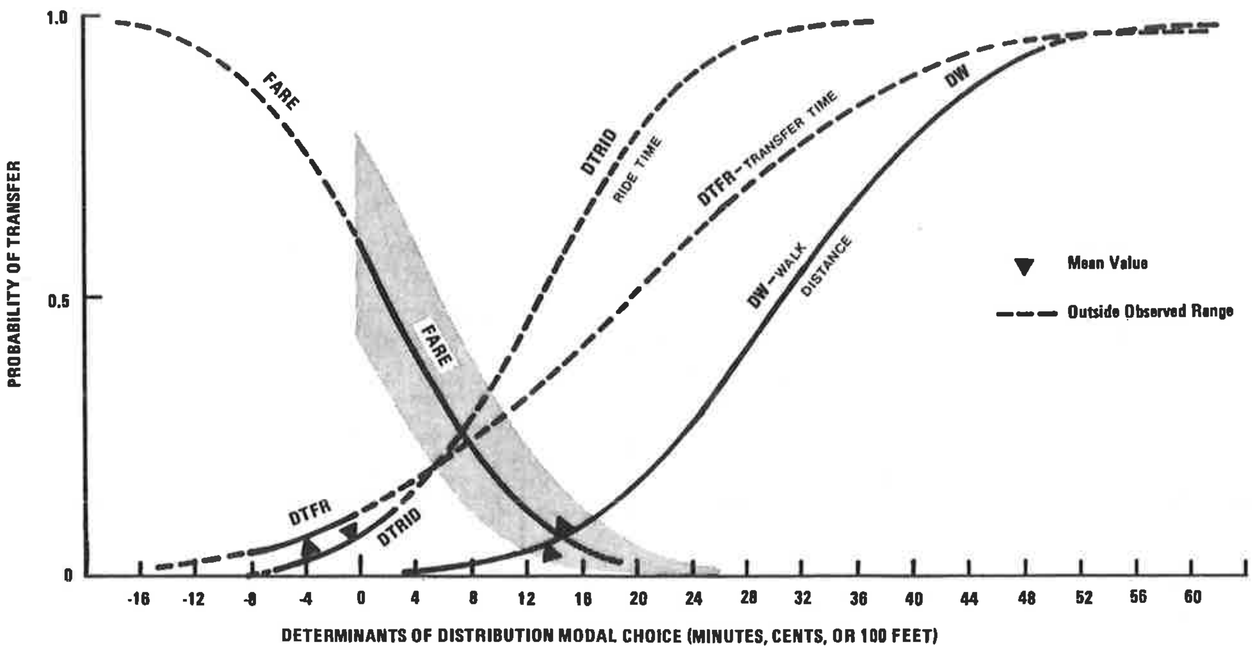


more sidewalk network as depicted on the CRT screen. Networks have also been developed for a proposed Buffalo Skywalk and the Jacksonville Transit Authority's bus network as part of recent alternatives analyses and AGT feasibility studies.

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

Figure 5. Evening peak transit trip origins and destinations.

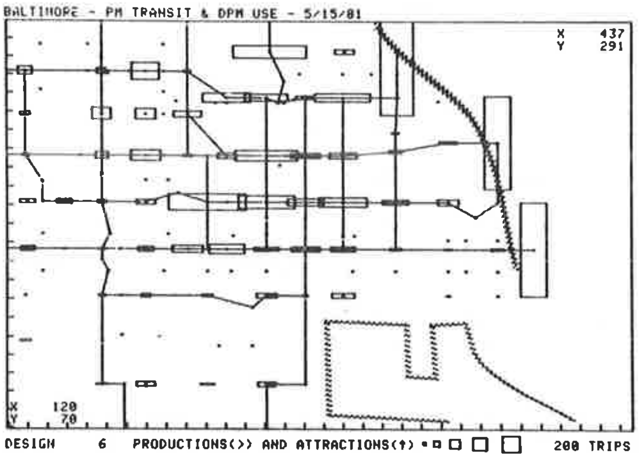


Figure 6. Transit trip desire lines.

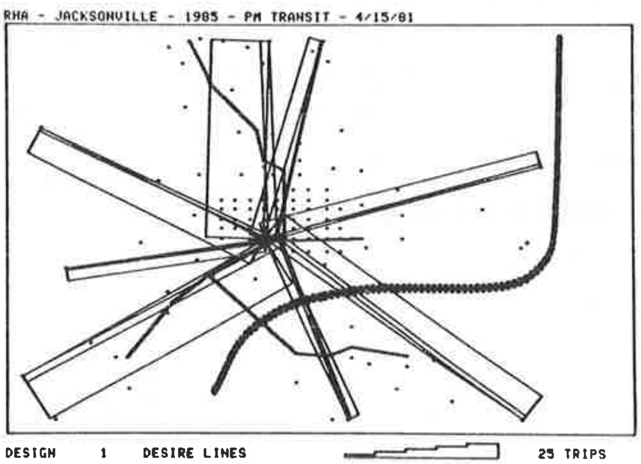
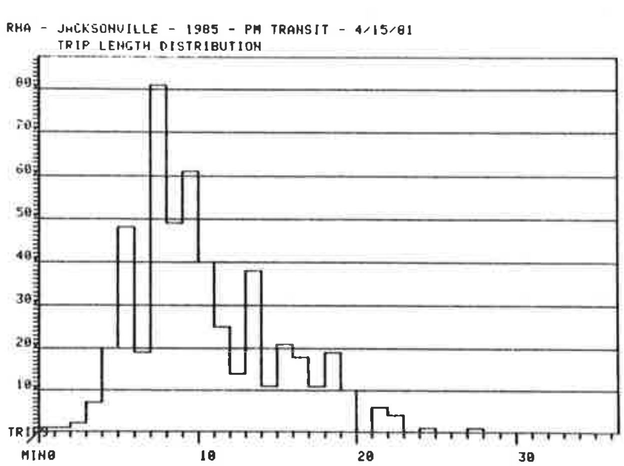


Figure 7. Trip length distribution.



from the center of Jacksonville to the new development areas north of the CBD and south of the St. John's River.

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.

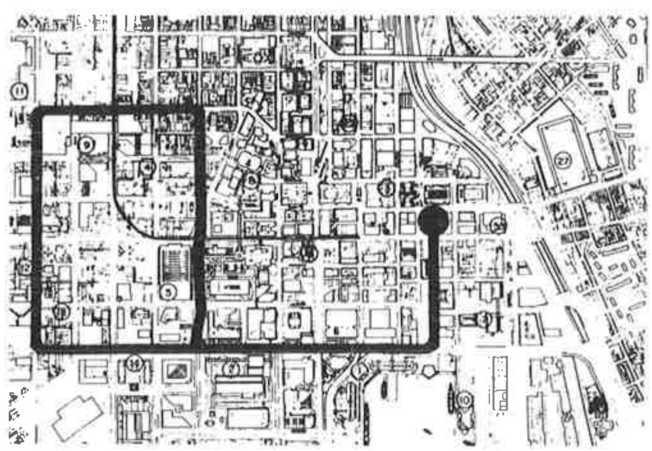


Figure 9. Baltimore DPM ridership.

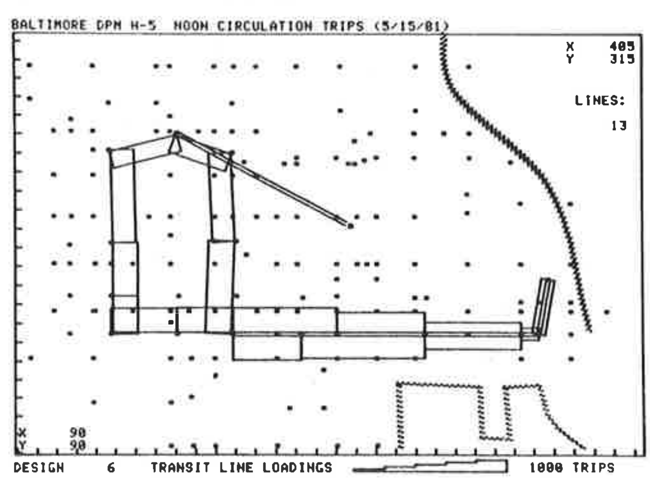


Figure 10. Jacksonville highway network volumes.

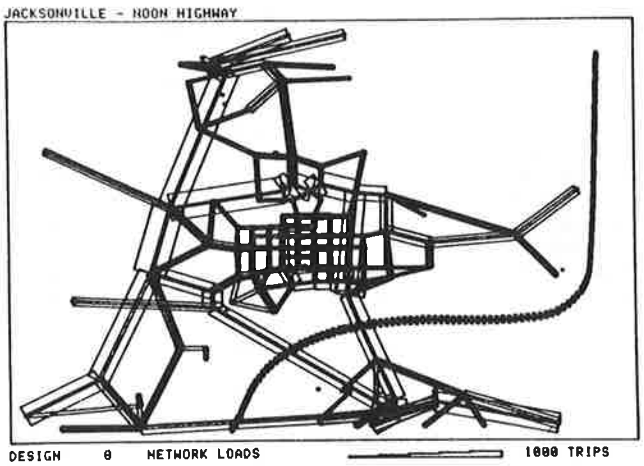


Figure 11. Pedestrian and bus network volumes.

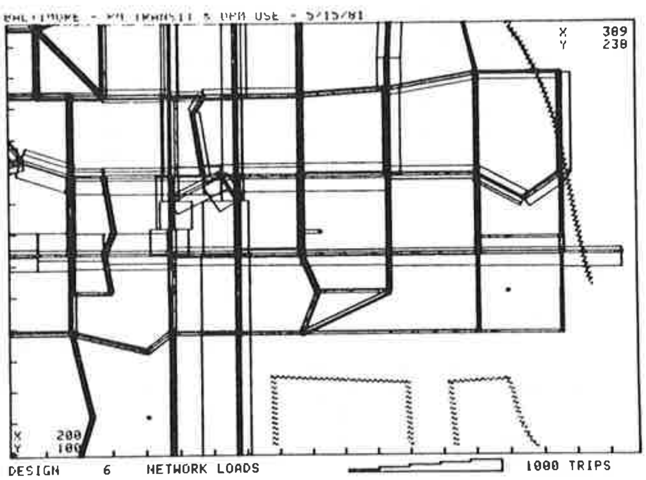


Figure 12. Patronage comparisons—designs 6 versus 7.

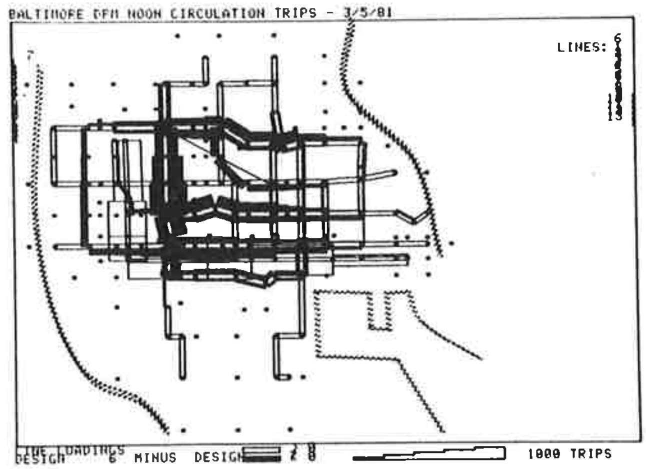
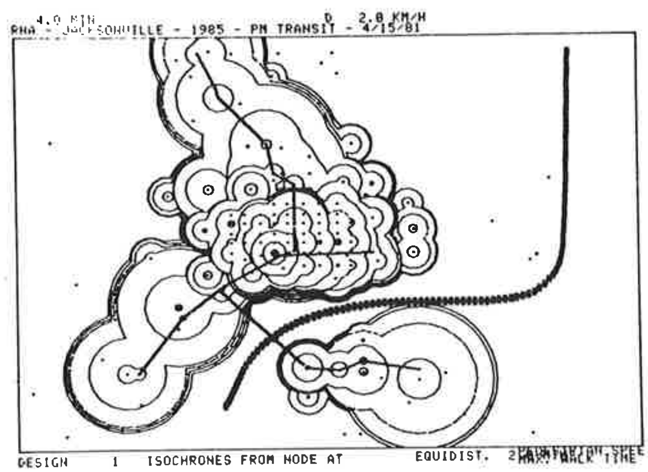


Figure 13. Travel times from Bay and Julia Streets, Jacksonville.



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.

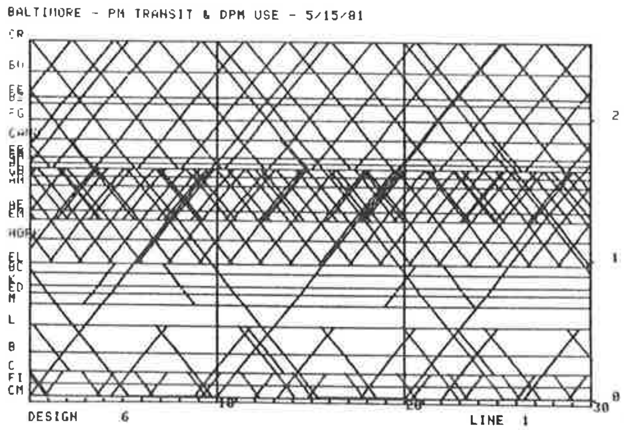
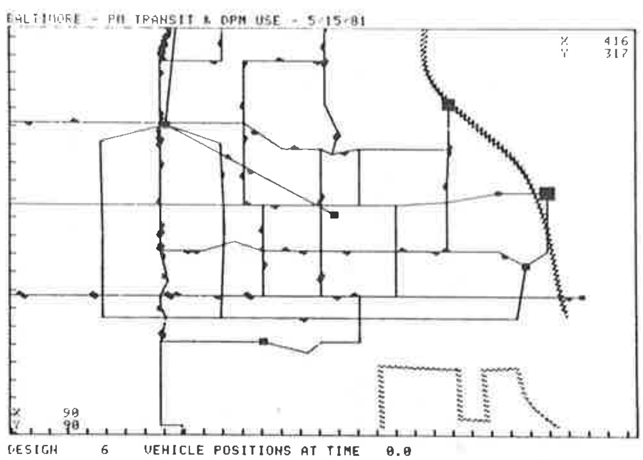


Figure 15. Transit vehicle positions at time 0.0.



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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Mapping Origin-Destination Patterns in Space and Time by Using Interactive Graphics

BOB EVATT, JR., JERRY SCHNEIDER, AND HARVEY GREENBERG

The process of mapping origin-destination patterns by using an interactive graphics program called FLOWMAP is described. FLOWMAP allows the interactive design of flow maps at a graphics terminal by using origin-destination data. The user has several options available that allow changes to be made in the maps quickly and easily to aid their comprehensibility. The program can display the temporal aspect of flows by mapping positive and negative change in flows over time. Several results from using FLOWMAP are displayed taken from various applications. The examples include shopping center travel patterns in Denver and cordon count data collected at the beltway in Washington, D.C. Some cost data for operating the program are presented along with specific hardware and software requirements.

Origin-destination (O-D) studies have been conducted regularly by transportation planners over the past few decades. Although analyses of the resulting data have provided useful insights on occasion, detailed geographic descriptions of these O-D patterns and how they have changed over time are rare. This is probably due, in most cases, to the difficulty one encounters when trying to map these data for one point in time and the differences in the pattern between two points in time. Yet the dynamics of change can often provide the trend information that can and should influence policy with regard to the allocation of costly transportation investments. The objective of this paper is to describe the design and use of an interactive graphic computer program that has been designed to produce a wide variety of maps of O-D data easily and inexpensively. This program, called FLOWMAP, enables the analyst to map O-D patterns at one or more points in time or to map differences in flow patterns between two points in time. A wide variety of map design options are provided so that these maps can be generated on a trial-and-error basis and modified until the desired result, a comprehensible map, is obtained. FLOWMAP provides the user with the ability to examine O-D data much more comprehensively than has been possible in the past and with ease and minimal cost. It also allows the production of report-quality maps or large wall-size displays for communicating these results to others.

Computer programs developed previously for this purpose have produced encouraging results (1-3). However, these programs have been limited to use in a batch-processing environment and, therefore, have not taken advantage of the computer's interactive capabilities. Interactive mapping allows the user to see the results of each trial map immediately, so that a series of modifications, made incrementally, can produce an optimal map design. This design process cannot be conducted effectively in a batch-processing mode.

This paper will describe the design and illustrate the use of FLOWMAP. First, the design of the FLOWMAP system will be described in functional and operational terms. Then example maps are presented that use FLOWMAP in various applications. One sequence of maps shows data from two points in time and the difference between them. Another set of maps shows the application of FLOWMAP to shopping center travel patterns and cordon count data. Finally, some information about costs, transferability, and other requirements is presented.

FLOWMAP PROGRAM OVERVIEW

FLOWMAP is a special-purpose thematic mapping program designed to produce flow maps from origin-destination data. From a menu the user can interactively move map elements, select display methods, and isolate specific subsets of the data set until an optimal map design is obtained. The finished map may then be drawn on paper by a plotter of some type.

FLOWMAP displays flows primarily as arrows, but proportional circle and piegraph maps can be drawn to illustrate internal flows. Six types of flow maps are possible:

1. Interzone flows are displayed as variable-width arrows with the width of the arrow proportional to the volume of flow (see Figure 1);
2. Net flows show the difference between the incoming and outgoing flows for each of several pairs of zones and are represented as variable-width arrows that point in the direction of the larger flow (see Figure 2);
3. Internal flows (flows that originate and terminate in the same zone) are displayed as graduated circles, with the area of the circle proportional to the flow volume (see Figure 3);
4. Origin piegraphs show a circle with area proportional to the total flow that originates in the zone, with a shaded sector proportional to the internal flow (see Figure 4);
5. Destination piegraphs are similar to origin piegraphs but show the total flow that terminates in the zone (see Figure 5); and
6. Piegraphs and arrows can be drawn on the same map (see Figure 6).

FLOWMAP may be run in interactive mode or in plotter mode. The plotter mode can be run from a terminal or submitted as a batch job. Interactive use requires a Tektronix 4014 interactive graphics terminal. Hard copy units are available for these devices, which inexpensively reproduce what appears on the screen. Higher quality paper copies can be drawn from plotter mode results by using a pen or electrostatic plotter. A typical use of the program might involve the design of a map interactively at a terminal, the saving of the set of instructions to produce that particular map, and then the running these in plotter mode to draw the final map on paper at the desired size (see Figure 7).

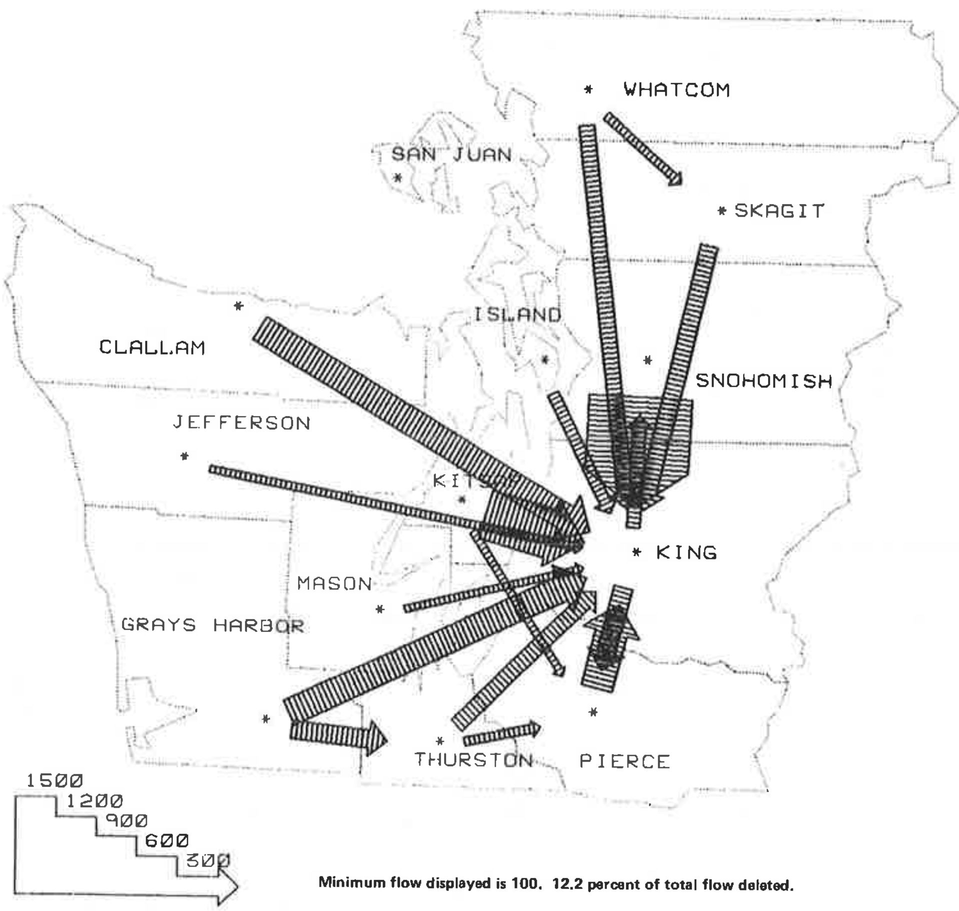
FLOWMAP requires input data from two files: a flow-data file and a geographic feature file.

The flow-data file is divided into three sections:

1. A map instruction section,
2. An O-D table, and
3. A point location section.

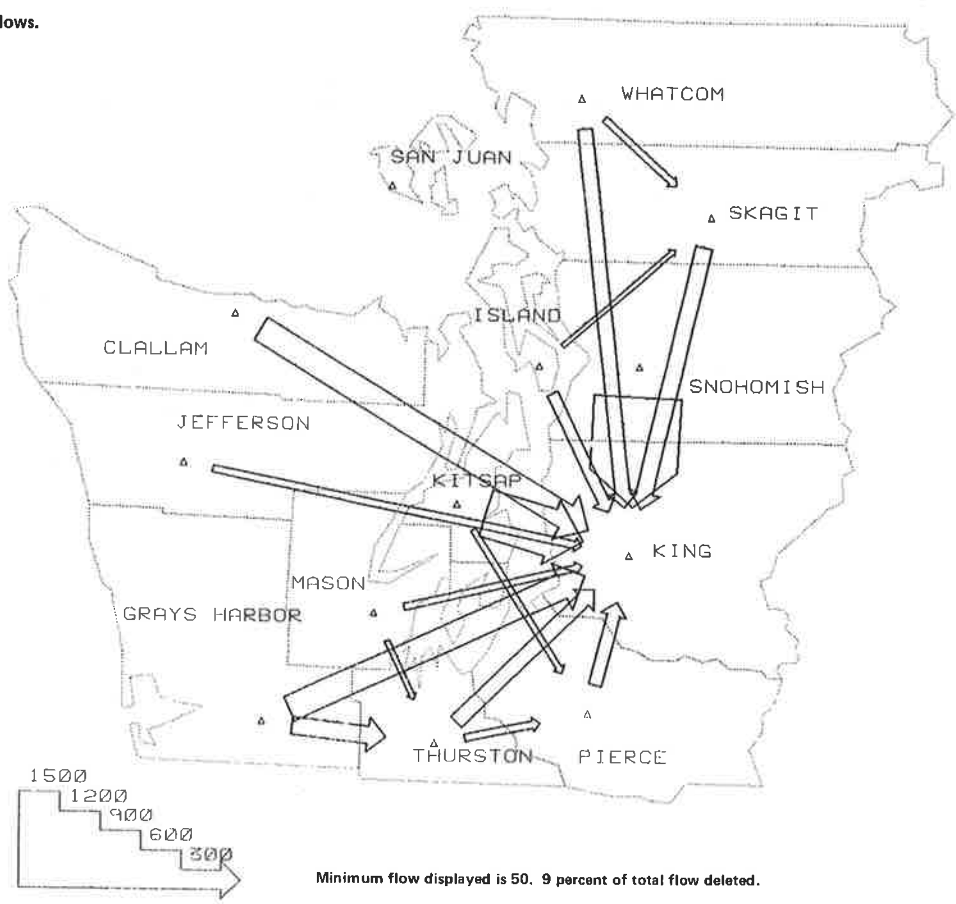
The instruction section includes the number of interacting data-collection points that are included in the O-D table. A data-collection point usually corresponds to a geographical zone. For example, an O-D table that shows flows between the 50 United States would have 50 zones and 50 interacting data

Figure 1. Interarea flows: cancer patient referral patterns, 1974-1978.



Minimum flow displayed is 100. 12.2 percent of total flow deleted.

Figure 2. Net flows.



Minimum flow displayed is 50. 9 percent of total flow deleted.

Figure 3. Internal flows.

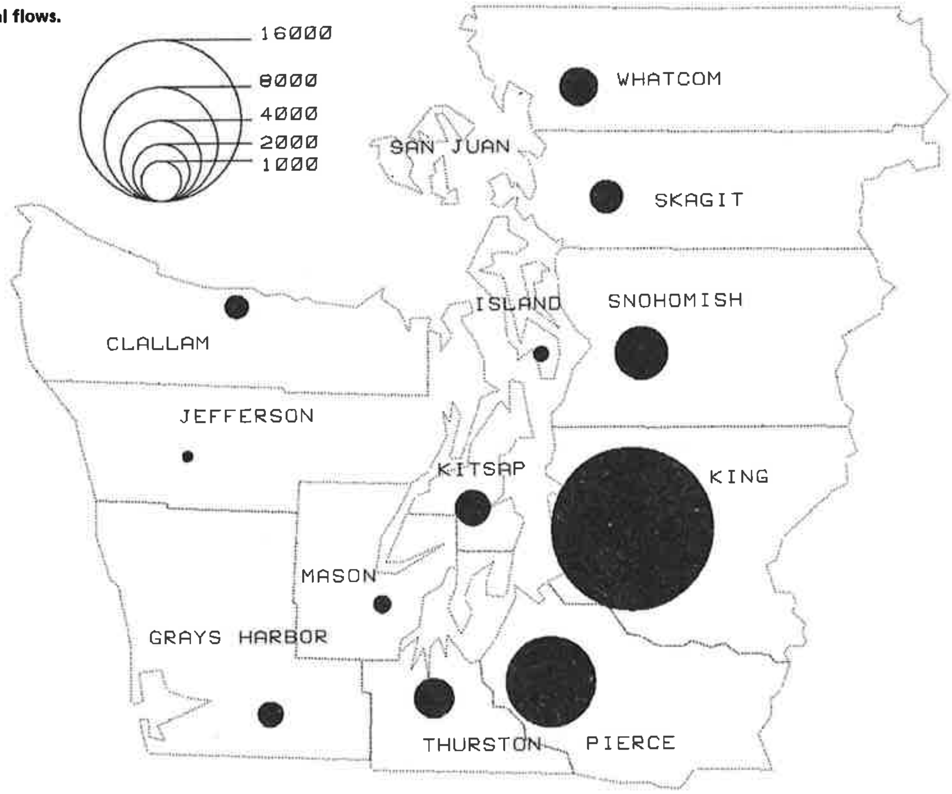
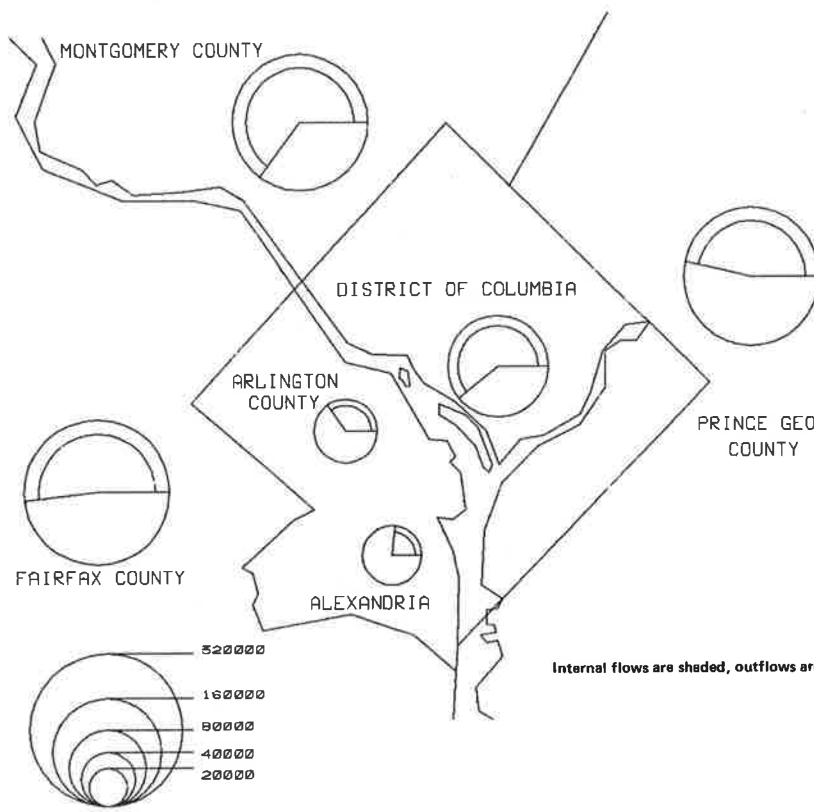
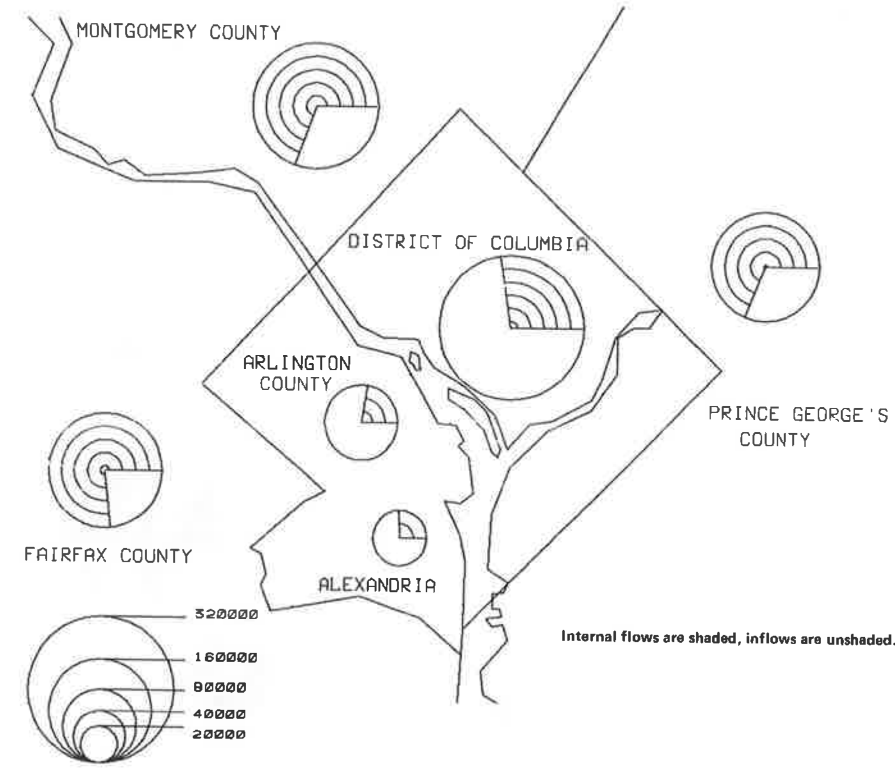


Figure 4. Origin piegraphs: home-to-work automobile driver trips.



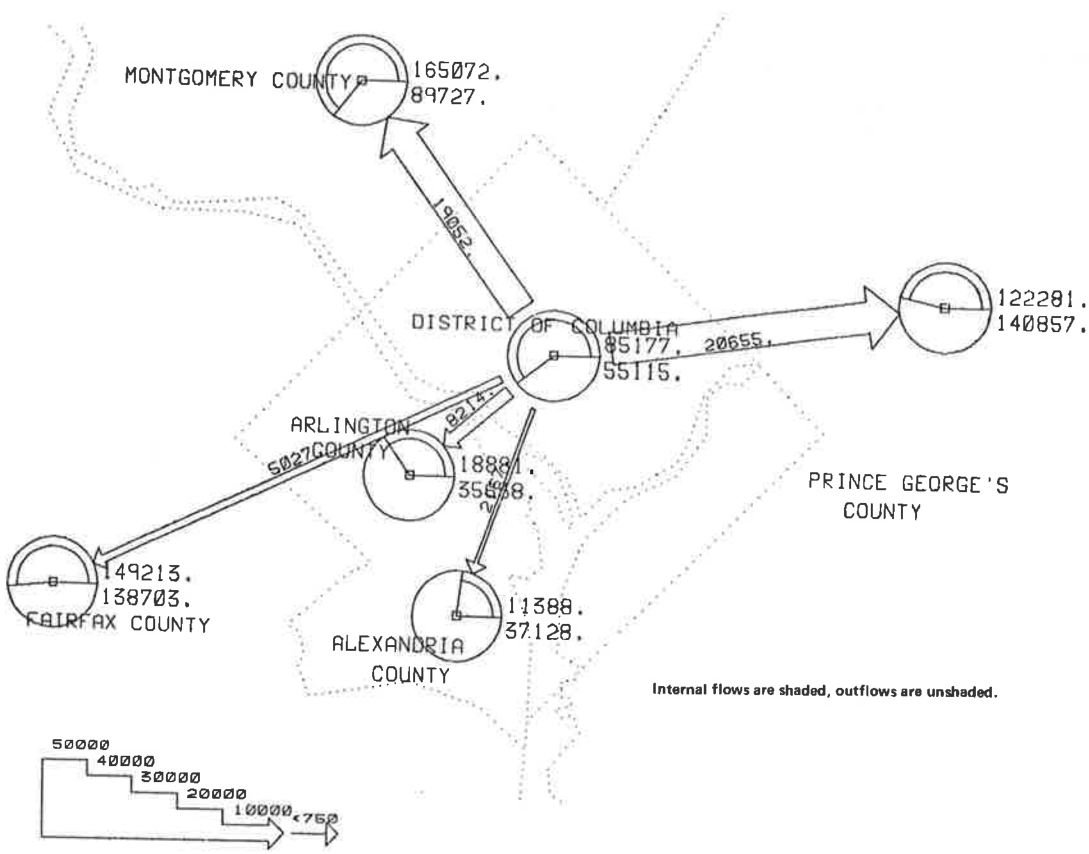
Internal flows are shaded, outflows are unshaded.

Figure 5. Destination piegraphs: home-to-work automobile driver trips.



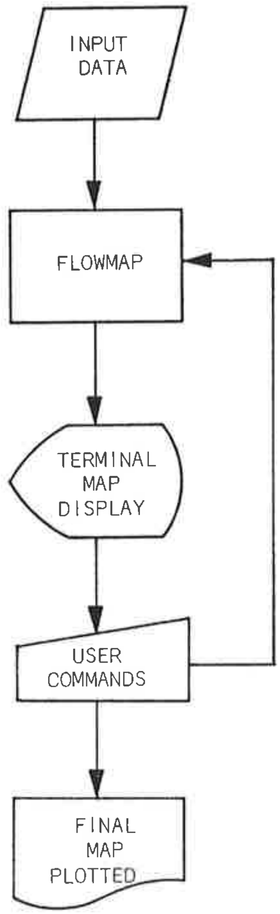
Internal flows are shaded, inflows are unshaded.

Figure 6. Piegraphs and arrows: home-to-work automobile driver trips.



Internal flows are shaded, outflows are unshaded.

Figure 7. Interactive design process.



Note: The map is modified iteratively at a terminal until the desired results are achieved.

collection points. The remainder of the instruction set includes a map title and optional parameters that allow the user to control various aspects of map design. With these parameters the user can designate the type of flows to be shown and choose among several map display options.

The O-D table is a square matrix in which the left tab represents the from zones and the top tab represents the to zones. Thus, the data value located in row 2 and column 3 is the volume of flow from zone 2 to zone 3. When the row and column numbers are equal, the value in that matrix cell represents the internal flow for a specific zone.

The point location section consists of a set of X-Y coordinates that identify a reference point for each interacting zone. These locations are used to define the starting and ending points for the flow arrows. They can be located anywhere inside a zone, such as the geographic center of the zone or at the location of the largest city within the zone. Also included in this section are the names of each zone and the X-Y coordinates for the map location of each name. Following this, an additional list of coordinates that are not data points may be added to be plotted as geographic reference points.

BASIC MAP TYPES AND DESIGN OPTIONS

Once the input data have been prepared, the user may elect to display interzone flows, net flows, internal flows, and piegraphs. Many-to-one and one-to-many flow maps may also be drawn (see Figures 8 and 9).

Many-to-many maps are the default type. All nonzero flows in the origin-destination matrix are displayed, although small flows can be eliminated. The user may select long arrows that extend from the origin to the destination or short arrows with annotated destinations. In some cases, the short-arrow option will improve map clarity. The user can also select curved arrows, so that inbound and outbound flows are not superimposed.

Many-to-one maps display all incoming flows to one destination and one-to-many maps display all outgoing flows from a single origin. The operator decides whether or not a zone is active as an origin or destination for each map drawn. For example, if all zones are active origins, and only one area is an active destination, a many-to-one map will be produced. It is possible to show several many-to-one or one-to-many displays on the same map.

Net flow maps display arrows that show the difference of flows between each pair of points. Internal flow maps produce no arrows but draw a circle with area proportional to the internal flow for each zone. Piegraph maps show circles proportional to total flows beginning or ending (as you choose) in each zone, with internal flows represented as a shaded slice of each circle.

When piegraphs are drawn with arrows, the following conditions apply. If all origins are active and not all destinations are active, destination piegraphs will be drawn; otherwise, origin piegraphs will be drawn. All zones will be regarded as active destinations. Piegraphs will be uniform, sized to the smaller of the radius values.

If the origin-destination matrix contains negative flows, they will not be displayed unless the shading option is invoked. If the shading option is on, positive flow arrows or circles will be shaded, and negative flow arrows or circles will be unshaded (see Figure 10).

The shading option and other map design options can be controlled by the user interactively by using the menu displayed on the graphics terminal. The menu appears on the right side of the terminal screen as a column of labeled boxes. The user positions the crosshairs over the desired option, then presses the spacebar or any character key to indicate the selection of the option. Requested changes are not incorporated in the map until the screen is erased and the map redrawn.

There are two menus: a main menu and a submenu. Current parameter values are shown on the menu as numerical values or as options enclosed in boxes. Some options involve picking a parameter directly from the menu (like "Arrowtype: long, short, curved"), and others prompt for numerical or graphic input. Following is a brief description of the menu options:

Main Menu Options

Main menu options include the following:

1. END/SAVE--Allows the user to save a modified data set or to exit the program;
2. REDRAW MAP--Instructs the computer to redraw the map and incorporate new design changes;
3. RESET WINDOW--Allows the user to zoom in on any part of the map; by using the crosshairs, the user first points to the lower left corner of the new window, then the upper right corner; when the map is redrawn the new window is in effect, so that only those portions of the map that lie within the new window are seen, and they are increased in scale to fill the entire plotting surface; when this option is picked again, the window is reset to the original window size.
4. MOVE--Allows the user to move map components around in order to clarify the display; area reference points, place names, or the scale key may be

Figure 8. Beltway cordon vehicle count (13-h total), 1978.

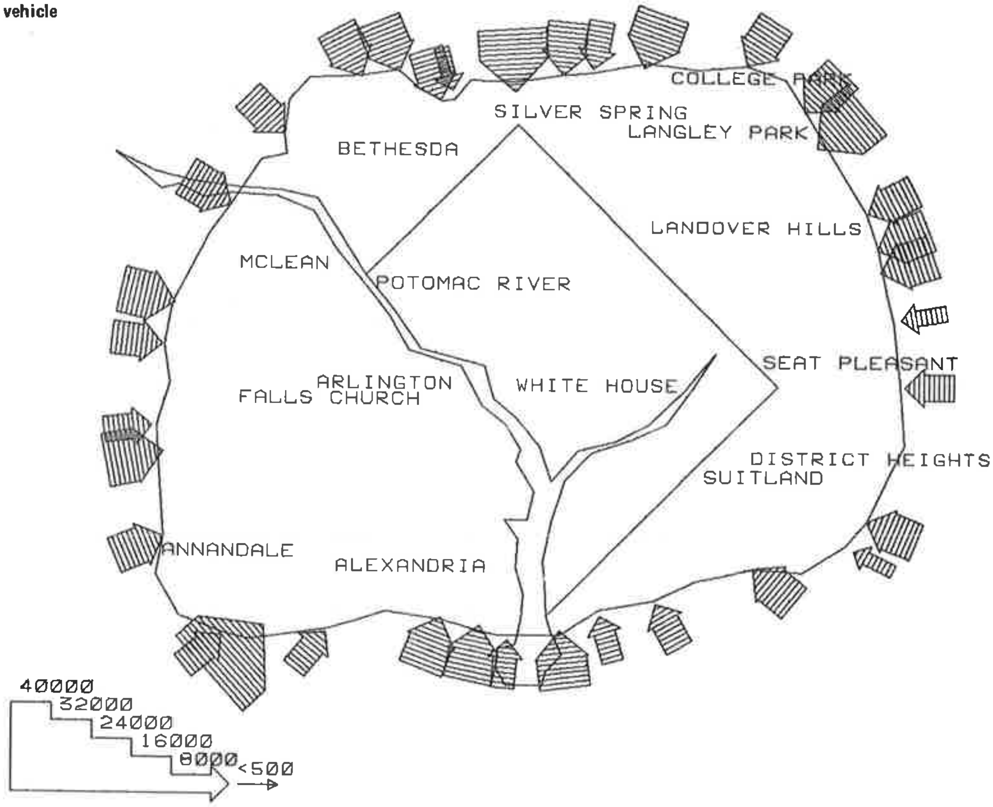


Figure 9. Denver area shopping patterns.

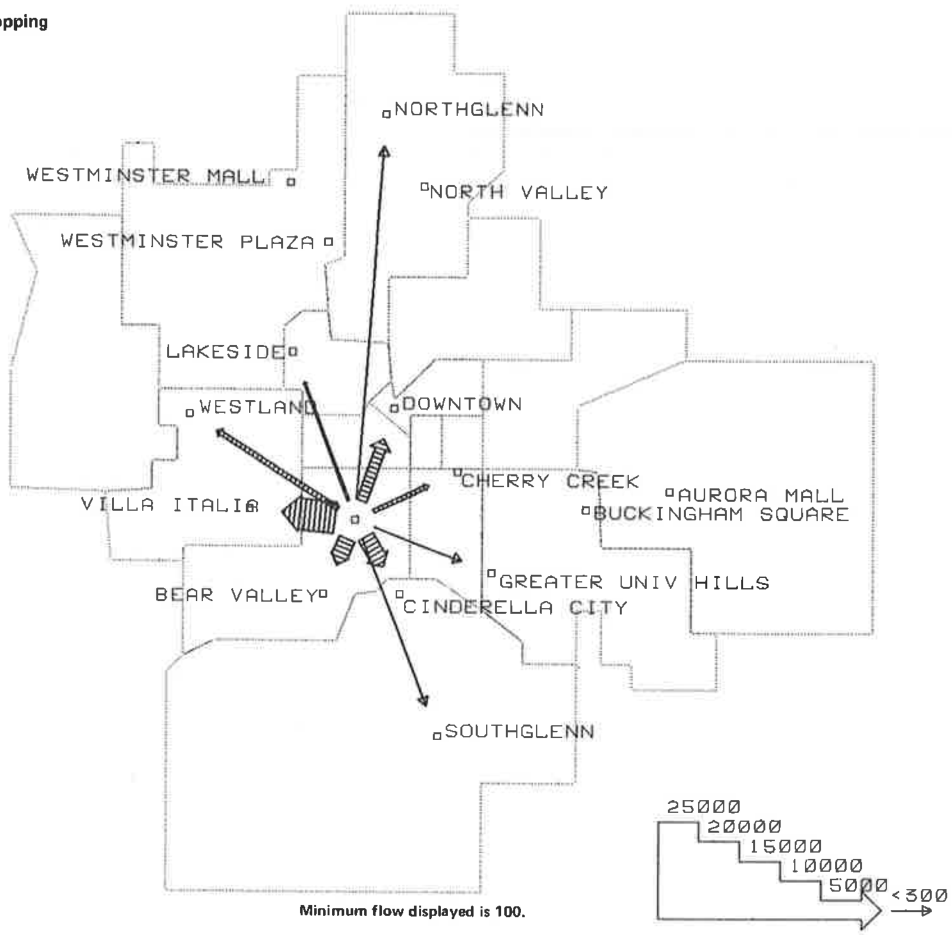


Figure 10. Change in cancer patient flow from Island and Skagit Company, 1974-1978.

Note: Shaded arrows indicate positive change. Unshaded arrows indicate negative change.

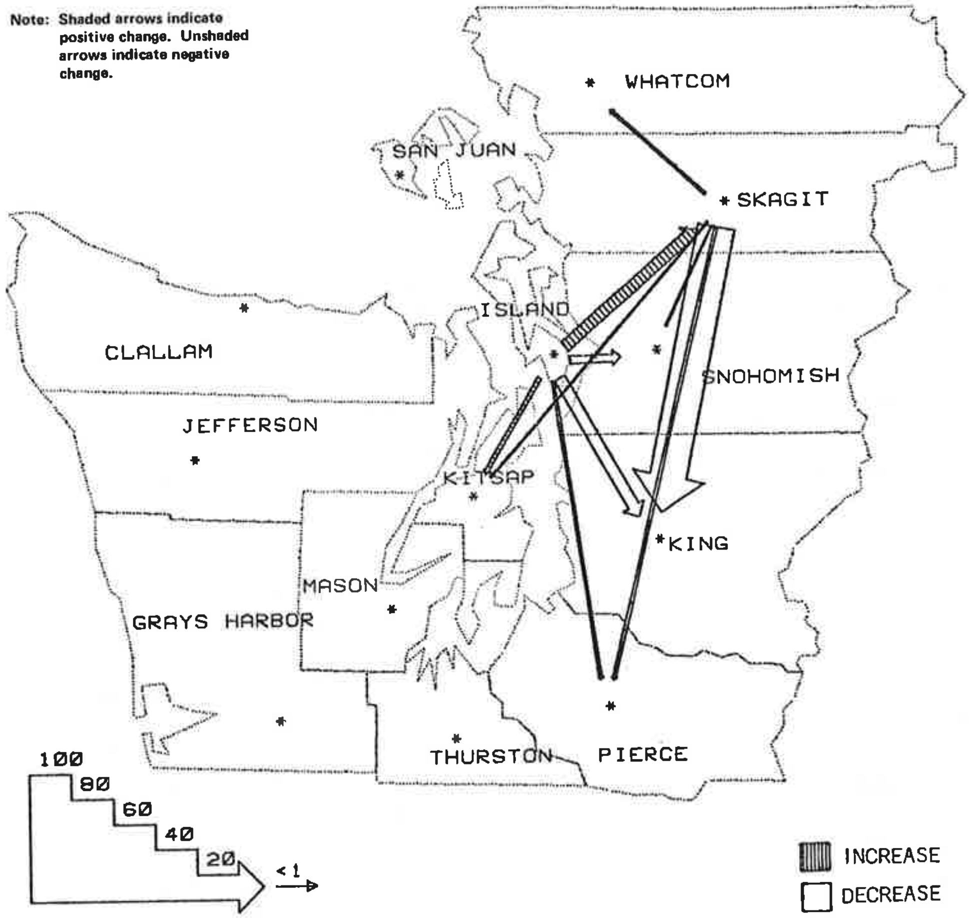
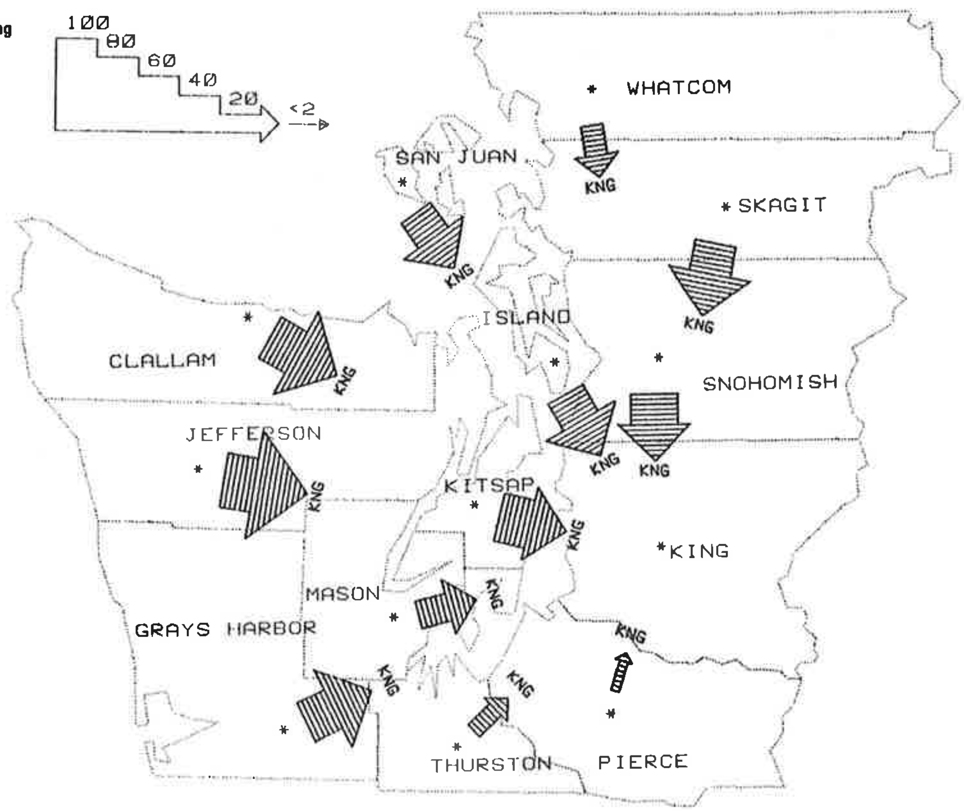


Figure 11. Cancer patient flow to King County in percent, 1974.



moved; the user first uses the crosshairs to indicate the point to be moved. Then the new position for that point is chosen; a line that terminates in a cross temporarily shows the new position.

5. SUBMENU--Causes the screen to be erased and the submenu to be drawn;

6. OUTBOUND RADIUS--Defines the distance between the area reference point and the beginning of the flow arrows;

7. INBOUND RADIUS--Defines the distance between the area reference point and the incoming arrowheads; in a many-to-one map, for example, one would specify a large value so that arrowheads would tend not to overlap;

8. MAX ARROW WIDTH--Tells the program how wide the largest flow should be; all smaller flow arrows are scaled to this value; for circle and piegraph maps, this value determines the radius of the largest circle; and

9. MIN FLOW SHOWN--Establishes a threshold data value below which flows will not be displayed; this enables the user to eliminate small flows that clutter the map.

Submenu Options

Submenu options include the following:

1. RETURN--Erases the submenu and redraws the main menu;

2. REDRAW MAP--Draws the map to the left of the submenu;

3. INTERACT--Allows the user to change the interaction specifications for the map; many-to-many, many-to-one, or one-to-many displays may be selected by typing the origin and destination zone numbers desired;

4. FLOWTYPE--Allows the user to change the type of flow display; the user simply positions the crosshairs in the small box that corresponds to his or her choice;

5. ARROWTYPE--The user positions the crosshairs in the box that corresponds to the type of arrow desired (long, short, or curved);

6. LINE TYPE--The user positions the crosshairs in the box that corresponds to the type of line in which the underlying map is to be drawn; solid, dashed, or dotted lines are possible;

7. SHADE--Changes the manner in which arrows or circles are shaded; one can choose light, heavy, or no shading; default value is no shading;

8. VALUES--Causes the flow values to be written to the map on the arrows or beside the circles or pies; one can select small text, large text, or none;

9. LINE TO NAME--Causes a line to be written from each visible point symbol to the corresponding name; this is useful in mapping regions that are cluttered with map symbols; and

10. SYMBOL--The user selects the desired type of symbol to mark the reference points. Ten symbol choices are available, including an invisible symbol.

Illustrative Examples

The following five maps (Figures 11-15) illustrate sample applications of the use of FLOWMAP to map geographic flows. In the first three, the data describe all cancer patients (7856 total) who were referred to a physician located in another county over the five-year period 1974-1978. The patient flows are between pairs of 13 counties in the western part of Washington State. Initially, reference points are located at population centers, which tend to be near Puget Sound in the central part of the map. The O-D matrix is 13x13 and contains 169 cells. Thirteen of these cells contain the internal flows; the other 156 contain intercounty flows (many of which are zero or very small).

Figure 12. Cancer patient flow to King County in percent, 1978.

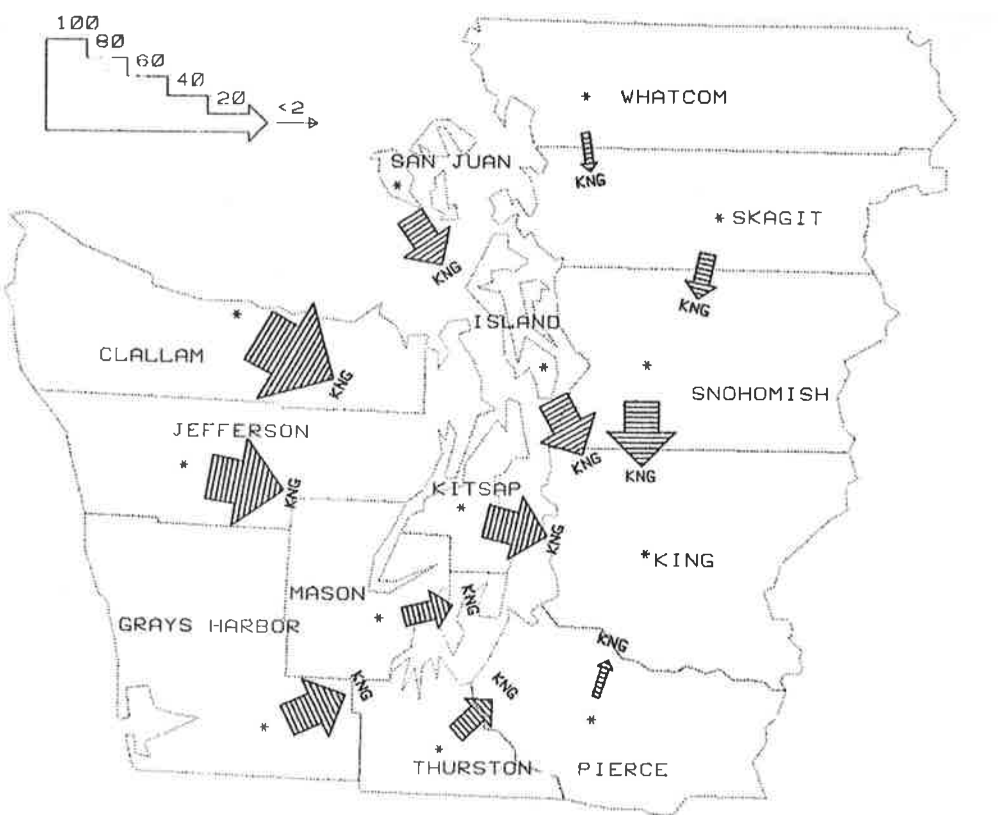
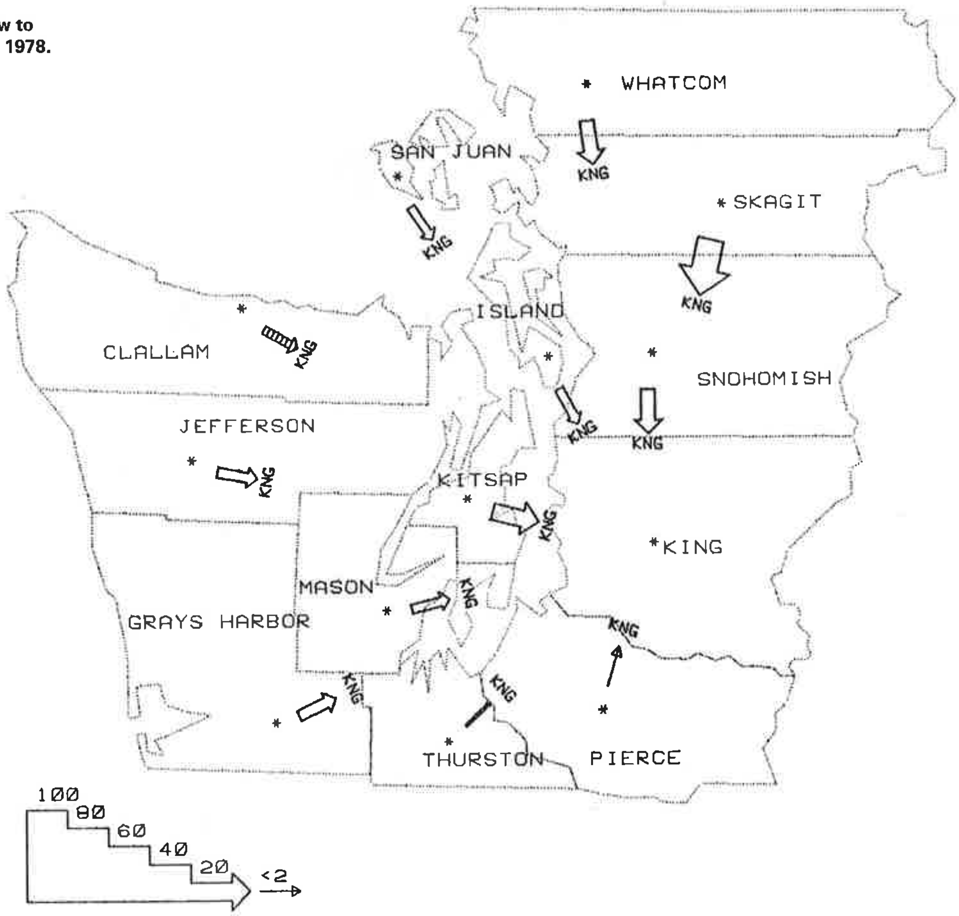


Figure 13. Change in patient flow to King County in percent, 1974 to 1978.



Figures 11-13 show the percentage share of all cancer patients who were referred to King County (the location of Seattle) from all other counties in 1974 and 1978 together with the difference in shares between these two points in time. Clearly, King County's share of the total has declined somewhat in all but two of the other 12 counties during this period. This indicates that King County's dominance as a referral center declined substantially during this period and raises some interesting questions regarding the future centralization-decentralization balance of cancer care in this region.

Two other examples of how FLOWMAP can be used are shown in Figures 14 and 15. Figure 14 illustrates aspects of work and college trips in Seattle. The circle sizes represent all commuters who live in each zone, and the shaded part of the circle differentiates intrazone from interzone travelers.

Figure 15 displays migration data collected for major regions in the United States for the period 1965-1970 (4). Three of the nine regions have been selected for mapping. The curved-arrow option has been used to avoid the overlapping-arrow effect that would otherwise occur.

PROGRAM COSTS AND TRANSFERABILITY

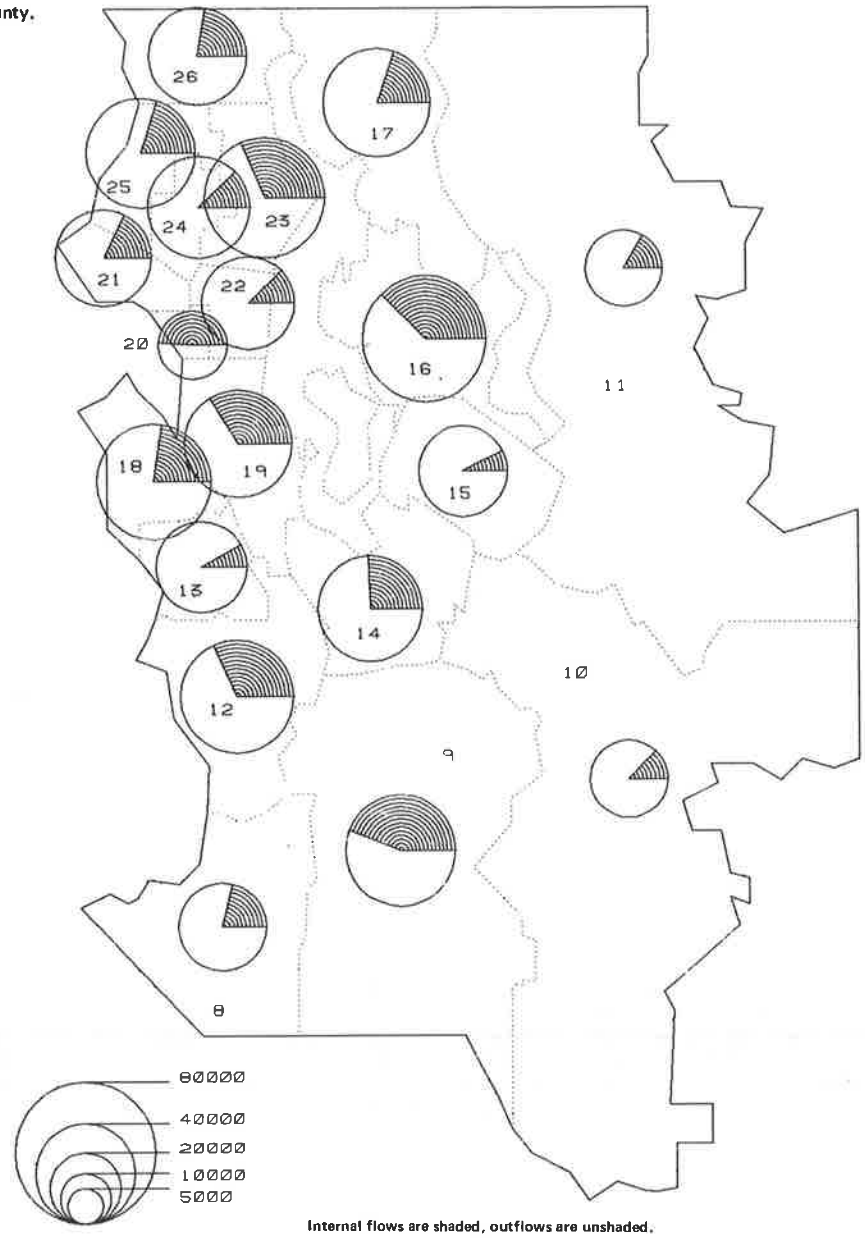
Since the program has not yet been tested on a large number of data sets, it is difficult to make statements about the costs of using it. However, the costs of the maps used in this paper provide some general indications. The maps that were produced interactively at a graphics terminal varied in costs from about $0.50 to $1.00/map. In general, the first map produced during an interactive session is the most expensive because the data are read in and initial parameters are set at this time. Subsequent maps are less expensive, although the cost goes up slightly when the shading and boundary options are invoked. The three-map sequence shown in Figures 1-3 cost just under $5.00 to produce interactively. This might be considered a typical cost for a normal map design session. The maps produced in batch mode were more expensive, largely due to plotting charges. Several of the maps were produced on a Gould electrostatic plotter, and they cost between $2.50 and $3.00/map. These costs will, of course, vary from installation to installation and with the size of the problem being dealt with.

FLOWMAP is written in ANSI FORTRAN 77, as implemented in CDC FORTRAN 5. FORTRAN 77 differs from earlier versions of FORTRAN in that it includes type character as a vehicle for manipulating alphanumeric data. This overcomes the machine dependency problems associated with internal storage of character strings. Consequently, FLOWMAP is more machine-independent than it would be were it written in some other FORTRAN. However, FLOWMAP will not run with compilers that do not meet ANSI FORTRAN 77 standards. The current version of FLOWMAP is operational on a CDC CYBER 170/750 under the NOS operating system. The GCS graphics software package is a library requirement.

SUMMARY AND CONCLUSIONS

FLOWMAP has been found to be a useful tool for displaying flow data for two main reasons. First, it decreases total production time through the use of interactive design. The user's time and design

Figure 14. Flow of work and college trips in King County.



Internal flows are shaded, outflows are unshaded.

abilities are used more productively in the design process. Minor problems such as overlapping text become trivial to correct use of interactive procedures. This allows additional time to be spent on more substantive map design problems.

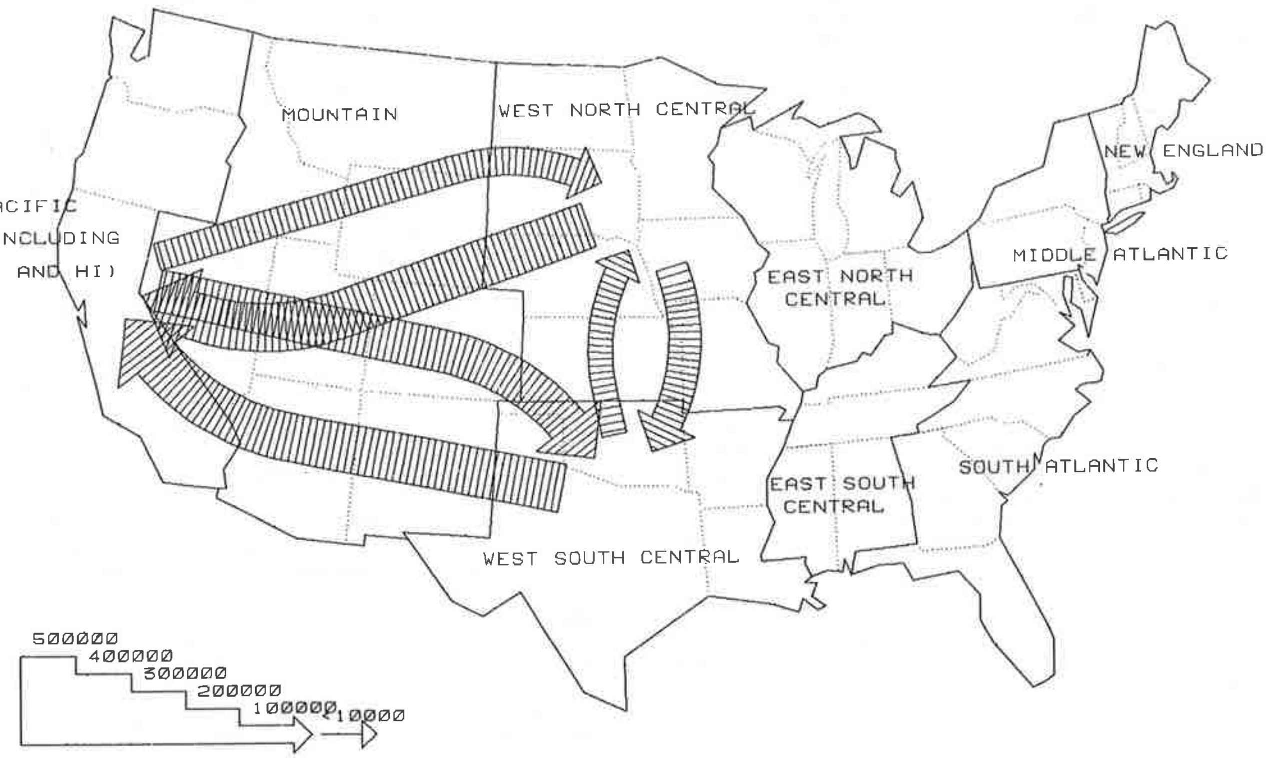
A more important advantage of FLOWMAP is that it allows the user to explore a data set thoroughly before creating final maps tailored to particular concerns. By alternately requesting many-to-one, one-to-many, and many-to-many maps, the user can quickly determine the best way to show the significant portions of the flow matrix. This type of flexibility is not available by using traditional cartographic techniques. It should facilitate the discovery of potentially important relationships in the data that might otherwise go unnoticed. Data errors can be readily detected by mapping the data as well.

In addition, once the original data are compiled, it is relatively simple to map different types of flow data for the same study area. In this way, flow data can be mapped with respect to pertinent control variables. For example, the cancer patient data can be examined by age, sex, treatment type, or several other variables.

Extensions to FLOWMAP that should be explored include the use of color and simulated motion. Color computer graphics have become popular in choropleth mapping, and color is frequently used in manually drawn flow maps. Similar techniques could be applied to the production of automated flow maps.

Concurrently, simulated motion could be used to enhance the visual effectiveness of flow displays. Raster scan color graphics equipment allows color changes on the screen to be program controlled. This capability could be used to create a movie marquee effect, whereby alternating colors would seem to move along a flow arrow. The speed of color change could be adjusted according to volume of flow. This type of pseudoanimation would be fairly inexpensive to use and could add a dynamic dimension to flow displays.

Figure 15. U.S. migration, 1965-1970.



ACKNOWLEDGMENT

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Graphical and Mathematical Methods in the Analysis of Urban Gasoline Consumption

ROBERT M. RAY

Some preliminary results are presented of a study that focuses on urban form efficiency. Results are based on a new method for analyzing dimensions of urban form. This method employs linear programming as a technique for measuring the spatial congruence of urban population and activity distributions. By using daytime employment distributions derived from data of the travel-to-work supplement of the annual housing survey (1975-1977) and 1970 census population data, the spatial congruence of population and employment is computed for 23 standard metropolitan statistical areas (SMSAs). A statistically significant positive correlation is found between these measures and per capita gasoline consumption across these SMSAs. The method employed requires no assumptions regarding travel behavior within SMSAs. Thus, like graphical models, it offers a purely descriptive means of analyzing urban form. The method also permits measurement of some of the spatial consequences of social distance relations among urban populations. Thus, it may provide an effective means of combining both functional and social distance factors within a common framework for descriptive analysis of urban spatial structure.

This paper reports some preliminary results of a study under way at the Research Triangle Institute for the U.S. Department of Transportation (DOT) that looks at alternative methods for comparing the spatial structure of U.S. cities. Both quantitative and graphical methods are being used in a productive manner. A primary objective of this research is to explore the relation between urban form and gasoline consumption. We hope that, by identifying characteristics of spatial structure that correlate strongly with rates of gasoline consumption, we will better understand this important aspect of urban form. This should prepare us to encourage more efficient courses of urban development through plans and policies.

PROBLEM

Urban spatial structure (urban form, spatial organization, order) is an extremely complex concept that does not lend itself easily to quantitative treatment. Where it has been entered into statistical analyses, it has often been poorly represented by available variables and measures.

Proxy boundaries of urban space, such as standard metropolitan statistical area (SMSA), urbanized area, place, central business district (CBD), and major retail trade area are borrowed directly from the U.S. Bureau of the Census. The criteria used by the Bureau for these definitions may be largely irrelevant to the purposes of the individual researcher. However, even the concept of density, as it is employed in most studies, depends in a fundamental way on these definitions. For U.S. cities, centrifugal forces of accessibility, telecommunications, and municipal fragmentation have greatly reduced the usefulness of these concepts.

Given the decentralization and general defocusing of activity distributions in U.S. cities, various measures of spatial dispersion might seem appropriate for describing urban spatial structure. A good comprehensive presentation of the variety of measures available has been given by Neft (1). Unfortunately, the majority of these measures (like the concept of variance itself) assumes unimodal distributions. Since multimodality, multinucleation, or at least acute lumpiness is a frequent property of urban landscapes, the value of most of these concepts is also limited. They transmit ambiguous messages.

Other difficulties concern the measurement of areal association (spatial congruence, dissimilarity, proximity) between urban population and activity distributions. Here, a serious problem is that most measures depend in a fundamental way on the geographic scale of subareas (tract groups, tracts, blocks) selected for spatial sampling. Duncan and others (2) provide a good review of problems here. Analyses conducted at the tract level yield different results when conducted at the block level. Furthermore, most of these methods do not permit us to measure spatial associations between items reported by different area units. This condition has impacted critically much urban research where often important variables are collected by independent agencies by using different data-reporting systems.

PROMISE OF GRAPHICAL AND SPATIAL ANALYSIS METHODS

All of the above difficulties suggest that an important role will exist for computer graphics and computer cartography in the study of urban space for some time to come. Since so many interesting aspects of spatial structure such as complexity, dispersion, and lumpiness are more easily discussed with visual displays, and since such spatial properties have shown themselves to be numerically (as well as verbally) difficult, complete maps are often the only means sufficient for characterization of urban space. Computer graphics provide a practical method for producing such displays in the quantities and time frames needed.

Computer cartography permits visual analysis of spatial variation across cities; however, it does nothing per se toward increasing our ability to treat such variation quantitatively. For this we still require numerical methods. Nevertheless, graphics has a role to play in the development of such methods.

Mathematically, the description of urban spatial structure is akin to the problem of feature extraction in visual pattern recognition research. To gain confidence that a specific numerical index consistently measures some characteristic of spatial structure (say, for example, distribution multimodality), we need to compute the index for a large number of sample cases and compare numerical outputs with visual displays of data inputs. We hope that the index yields automatically a rank ordering of all samples that agrees closely with the rank ordering obtained by visually comparing all samples with respect to the spatial feature. Again, computer cartography provides a means for displaying such samples in comparable format and in the quantities needed.

In our present research, we are examining the usefulness of several new measures of spatial pattern properties that seem particularly well equipped for analysis of urban space (3). In particular, we are attempting to demonstrate that, with an appropriate redefinition of system variables, some of the same mathematical models used for transportation network analysis may be used profitably for more general analysis of spatial relations between distributions.

Specifically, the models derived appear to yield unambiguous measures of the extent of spatial congruence between population and activity distributions. Because gasoline use is usually associated with the movement of people between activities, per capita rates of gasoline consumption will be positively correlated with the distances that separate activity distributions.

One of the most important spatial relations that defines the form of U.S. cities and determines greatly their gasoline consumption is the distance between place of residence and place of work. This one relation is probably more important than we would initially think because work places for many are often the shopping, eating, and entertainment places for many others. Thus, we suspect that much of the essential character of U.S. cities is contained in the information conveyed directly by population and employment distributions. Cities that have revitalized inner-city neighborhoods are, in general, cities with stable concentrations of employment in downtown areas. On the other hand, lively daytime downtowns become quite dead at night if at 5:00 p.m. everyone returns home to the distant suburbs.

METHOD SELECTED FOR USE

Let X (nxl) and Z (nxl) be discrete probability distributions of some two urban variables over some area sampling frame. For example, X might be the distribution of total population by place of residence across census tracts and Z might be the tract-level distribution of total employment by place of work. In this case, x_i is the probability that a randomly selected person lives in tract i, and z_j is the probability that any worker works in tract j.

Let C (nxn) be a matrix whose elements ($c_{i,j}$) are some function of the distance between tracts i and j. Then, a measure of the overall distance that separates the two spatial distributions X and Z may be formulated as follows:

$$D = \min \sum_{i=1}^{n} \sum_{j=1}^{n} q_{i,j} c_{i,j} \quad (1)$$

subject to

$$\sum_{j=1}^{n} q_{i,j} = x_i \quad i=1,\ldots,n \tag{2}$$

$$\sum_{i=1}^{n} q_{i,j} = z_j \quad j=1,\ldots,n \tag{3}$$

$$q_{i,j} \geq 0 \quad i,j=1,\ldots,n \tag{4}$$

Equations 1-4 will be recognized by many as a special case of linear programming known as the transportation problem (4,5). If X and Z are given in terms of absolute supply and demand quantities instead of probabilities, and C is defined in terms of network travel costs (distances, times), then the problem is to determine a set of flows from supply sites to demand sites that minimizes aggregate travel costs. The transportation model of linear programming finds wide application in urban planning for both descriptive and normative models of traffic flow between activities.

Our interest in this model, however, stems not from its ability to describe or prescribe efficient traffic patterns but rather from its usefulness as a method for measuring proximity relationships generally among spatial distributions. If X and Z are probability vectors for any two spatial distributions and C is a matrix of Euclidean distances between area units, then D may be interpreted directly as a measure of the spatial congruence that exists between the two distributions.

Note that such a measure has an interpretation of distance in the abstract that is completely independent of any material flow between the two distributions. Thus, in our example above that measures the distance between total population and total employment, it makes little difference that many people never go to work. The measure has a mathematical meaning that is valid apart from any assumption of traffic between the two distributions. Namely, the measure reports simply the physical congruence of the two distributions. It does this in a manner completely neutral to any real or simulated patterns of home-to-work commuting. Similarly, such a measure may be used to quantify the degree of residential distance between racial, ethnic, income, and employment groups in a city in cases where it is meaningless to think of traffic flows between distributions.

If in Equations 1-4 we define C as a matrix of squared Euclidean distances between area frame units, we arrive at an index of interdistribution distance with still more interesting mathematical properties. We call this measure pattern distance. This least-squares index can be shown to be decomposable into a set of additive terms that express the squared distance between the centroids of the two distributions X and Z, the spatial variance of X, the spatial variance of Z, and a fourth term that represents the composite covariance of spatial coordinates matched optimally between the two distributions by the matrix Q. Thus, pattern distance measures the extent to which two spatial distributions share the same location, the same dispersion, and the same shape. The square root of this measure can be translated directly into units of physical distance (e.g., miles or kilometers).

Pattern distance may be viewed as an extension of an index proposed earlier by Bachi (6). By measuring the distance between spatial distributions of population before and after migration, Bachi developed an index that has identical decomposition properties that he called quadratic averages of squared distances. However, Bachi did not specify tight limits for the range of his measure. Here, linear programming allows us to determine for any two distributions the minimal feasible value of Bachi's distance.

Both measures have the desirable property that they depend only in a minor way on the number and size of subareas of the area sampling frame. In fact, both may be computed between pairs of distributions sampled with respect to different frames, provided that both frames can be described by using a common coordinate system. Of course, neither measure requires any assumption concerning the unimodality of distributions.

Our present research concerns the relation between urban form and gasoline consumption across U.S. cities. We would like to show that urban spatial structure can be meaningfully characterized in terms of pattern distance relations between population and employment distributions and that differences in spatial structures so characterized can be related statistically to variations in gasoline consumption. In posing the problem this way, it is our hypothesis that the spatial patterning of phenomena within cities directly conveys much information about spatial efficiency. This pattern analysis method permits us the convenience of macroscopic study of spatial systems despite incomplete microscopic specification. Thus, it functions much like graphical methods and allows comparative analysis to proceed in the absence of complete data and operational behavioral models.

DATA

To carry out our study we needed data that describe population and employment distributions in comparable format across some sample of U.S. cities. We also needed data that indicated comparable levels of gasoline consumption for these same cities.

Decennial census data, of course, are our best source of data on population distributions. Since 1980 census data were not available to our project, we are using 1970 data. Our access to these data has been greatly aided by the special area profile tapes created by the Bureau in conjunction with the urban atlas project. These summary files provide a convenient source of tract-level 1970 census data for a large number of cities.

Data on employment distributions across cities are not as easily found. Problems in this area, however, should diminish greatly in the future as a result of the travel-to-work items included on the 1980 census questionnaire and new methods adopted by the Bureau for place-of-work address coding. (In 1970, similar travel-to-work information was sampled but, due to questionnaire instrumentation and post-coding methods, only low rates of place-of-work address coding resulted.)

The only convenient source of comparable employment distributions across cities that we have been able to find is the travel-to-work supplement of the annual housing surveys (AHS) of 1975 and 1976. The tract-to-tract files available from these surveys provide a set of comparable home-to-work commuting data for 41 SMSAs. On these files, home-to-work traffic volumes are cross-tabulated by census tract of employment and tract of residence. By aggregating trips across tracts of origin for each tract of destination we can obtain an estimate of the total daytime employment in each tract.

Unfortunately, the AHS tract-to-tract files allow us to break down these tract-level employment totals along only two dimensions: (a) mode of travel to work and (b) time of departure from home. We know nothing about occupations or industry types for the employment of each tract. We know only how many people came to work there, how they got to work, and what time they left home. Despite these limitations, this information appears useful for our purposes.

Fortunately, the Bureau used 1970 census geographic definitions for all of the AHS waves. This means that the 41 AHS SMSA data files can be matched directly with 1970 census files. SMSA and tract codes are identical across the two data sources. In choosing to work with 1970 population and 1975-1976 employment distributions we simply make the assumption that population and employment patterns in the AHS SMSAs did not shift radically during the early 1970s.

To compute pattern distances between population and employment distributions we need geographic coordinates for the centroids of all census tracts in all SMSAs. It is possible to obtain such coordinates from the tract boundary files created by the Bureau, again in conjunction with the urban atlas project. We used the Bureau's EASYCORD program to compute the areas and centroids for all tracts in the 35 SMSAs common to both the AHS and the tract boundary files.

Data that describe levels of gasoline consumption across cities are available in a restricted form from the census of retail trade, which is conducted by the Bureau every five years. These data are reported in machine-readable format at both county and SMSA levels. Of course, SMSA definitions change frequently as additional counties are added to each, and so the SMSA retail trade data are not comparable over time. Since, however, SMSAs outside of New England are proper collections of counties and county equivalents, it is possible for most of the U.S. to aggregate county-level retail trade data to the level of 1970 SMSAs. We have done this for the data of the 1972 and 1977 retail trade censuses. The 1967 data have already been aggregated and reported in machine-readable format by 1970 SMSAs by the Bureau in the 1972 County and City Data Book (CCDB) files. Due to data reporting formats and SMSA definition changes in the 1970s, only these 1967 retail trade data of the 1972 CCDB are available to describe 1970 New England SMSAs. The 1972 CCDB files also provide a convenient machine-readable source of other SMSA-level 1970 census variables, such as total population, density, percentage urban, median income, and transit ridership, which we also want to include in our analysis.

For research purposes, one problem with all of the machine-readable retail trade files is that they report only total dollar sales of gasoline service stations. In printed reports, additional data are given for total gallons of gasoline by selected counties and for some censuses by selected SMSAs. Other printed materials permit factoring of service station sales by states into component trade items. These figures suggest that gasoline sales make up about 70 percent of all station sales across all states.

At this point we have not resolved to our complete satisfaction all data problems in this area. To date, we have contented ourselves with the use of the dollar sales data as a proxy for gasoline consumption. To improve marginally the accuracy of this variable, we have divided it by a weighted, state-level estimate of the per gallon price of gasoline in each SMSA. We hope in future months to be able to key other data from the retail trade census printed reports and to further improve the accuracy of this proxy.

RESULTS

Table 1 presents some preliminary results of our study. Pattern distances computed between total tract-level population and employment distributions are reported for 23 AHS SMSAs. The square root of pattern distance has been listed, because this measure translates directly into units of miles and therefore more strongly correlates with actual travel distances. Table 1 also gives for all SMSAs the proxy for 1972 gasoline consumption (i.e., total gasoline service station sales in 1972 divided by average 1972 retail prices and 1970 population) along with several other 1970 census variables. SMSAs are ranked in order of increasing pattern distances between population and employment distributions.

Figures 1 and 2, which sketch tract-level distributions of daytime employment for the Milwaukee and Houston SMSAs, illustrate the principal dimension of the data of Table 1. Relative to Houston, Milwaukee is much more spatially compact, and thus distances

Table 1. Root pattern distance between population and employment distributions and other data items for selected SMSA.

SMSA	Population in 1970 (000s)	Density (persons/mile^2)	Percentage Workers Commuting by Transit	Gasoline Use [total station sales in 1972/(price x 1970 population)]	Root Pattern Distance Between Population and Employment (miles)
Milwaukee, WI	1403	964	12.0	406	2.10
Allentown, PA-NJ	543	501	3.2	417	2.12
Columbus, OH	916	613	8.1	445	2.18
Miami, FL	1267	621	9.1	449	2.26
Omaha, NE-IA	540	353	7.2	463	2.27
Buffalo, NY	1349	848	10.4	320	2.33
Cleveland, OH	2064	1359	13.3	412	2.46
Denver, CO	1227	336	4.4	443	2.56
Louisville, KY-IN	826	911	6.7	442	2.68
St. Louis, MO-IL	2363	574	8.1	460	2.81
Oklahoma City, OK	640	300	1.6	435	2.84
New Orleans, LA	1045	530	20.4	387	2.93
Atlanta, GA	1390	805	9.4	576	2.93
Grand Rapids, MI	539	380	2.2	526	2.98
San Diego, CA	1357	319	4.3	431	3.12
Raleigh, NC	228	267	3.8	455	3.26
Portland, OR-WA	1009	276	6.0	449	3.32
Kansas City, MO-KS	1253	454	5.5	531	3.37
Indianapolis, IN	1109	361	5.8	556	3.54
Sacramento, CA	800	234	2.3	500	3.59
Houston, TX	1984	316	5.4	479	3.74
Cincinnati, OH-KY-IN	1384	644	8.3	456	3.94
Seattle-Everett, WA	1421	337	7.1	477	4.01

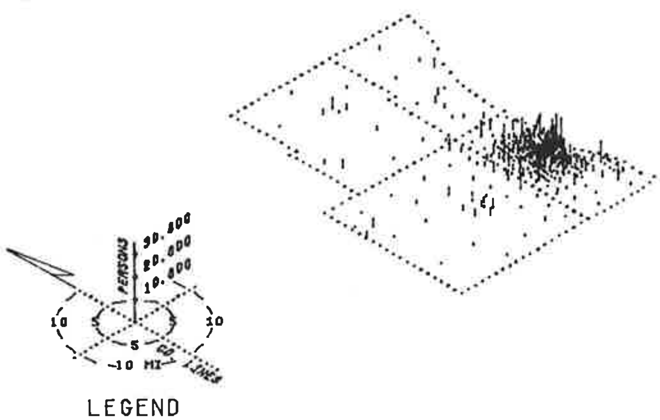
between population and employment distributions are smaller and per capita gasoline consumption is less. Note also the difference in transit use between the two cities.

Table 2 presents the correlations that exist among the variables of Table 1. The pattern of correlations suggests that some collinearity exists among the variables of pattern distance, gasoline consumption, density, and transit use. The data indicate that SMSAs that have low per capita gasoline consumption tend to be SMSAs that have large populations, high densities, larger percentages of workers who commute by transit, and smaller distances between population and employment distributions. None of this is particularly surprising.

What is surprising is that, of all variables, the measure of pattern distance has the strongest correlation (r = 0.49) with the proxy for gasoline consumption. Furthermore, a multiple regression of gasoline consumption on all of the other variables of Table 1 indicates that the pattern distance variable remains the most significant predictor of gasoline consumption even after the variables population size, density, and transit use are entered into the regression. Thus, pattern distances between population and employment distributions appear quite useful for analysis of urban form-efficiency relationships.

Figures 3-6 assist our understanding of the value of the pattern distance measure. From the data of Table 1, we might expect that gasoline consumption would be higher in Columbus than in Cincinnati. The density of Cincinnati is slightly greater than that of Columbus. Transit use in Cincinnati is slightly greater than transit use in Columbus. However, the pattern distance computed between population and employment for Cincinnati is almost twice that determined for Columbus. To an extent, this difference between the spatial structures of the two cities is visible in Figures 3-6. Can this be the explanation for the slightly higher rate of gasoline consumption in Cincinnati?

Figure 1. Milwaukee daytime employment by tracts, 1976.



SUMMARY DISCUSSION

Of course, the relation between gasoline consumption and urban structure across U.S. SMSAs is much more complex than the few data above could describe. In more comprehensive analyses, we are also examining the significance of other predictors of SMSA gasoline use such as through traffic, tourism, climate, local automobile fleet efficiencies, and economic conditions. At this point, our analysis is incomplete. However, we can report that a preliminary reading of all data available indicates that the pattern distance measure will survive the challenges of alternative explanations.

More detailed descriptions of employment distributions across SMSAs would be nice. For example, a breakdown of employment by at least broad occupational or industrial classes would be useful. Such data could be used as a surrogate for land use. We could begin to explore the relative efficiencies of alternative land use structures and mixtures. There is some hope that data such as these will be available from the 1980 census as a result of the place-of-work address coding now under way at the Bureau for the transportation planning community.

Since the currently available AHS employment data are cross-tabulated by mode of travel and the 1970 census data provide numerous tract-level population distributions, we are computing pattern distances between employment by two modes of travel (driving alone and public transportation) and residential distributions for two broad classes of workers, (white-collar and blue-collar workers). This may allow us to say something about the relative effects on SMSA gasoline consumption of the residential distribution of these two occupational groups with respect to general employment opportunities and tran-

Figure 2. Houston daytime employment by tracts, 1976.

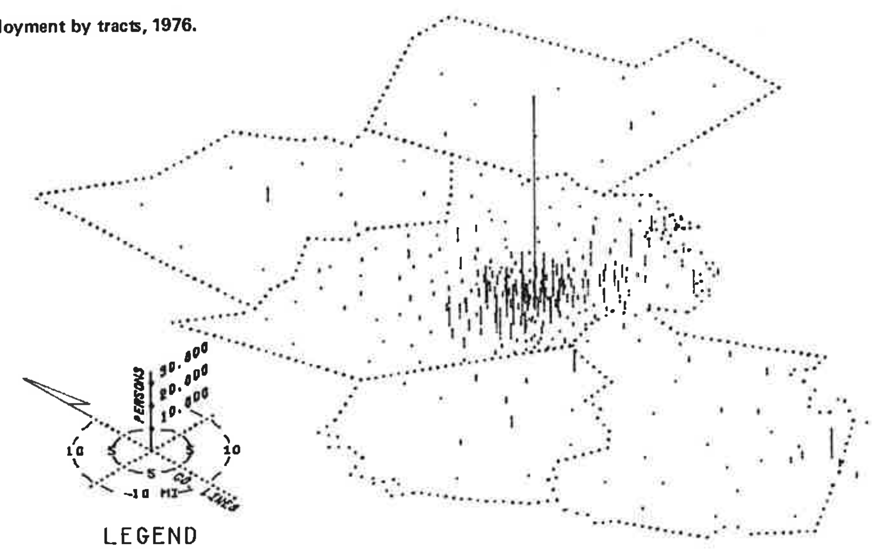


Table 2. Correlations between SMSA variables of Table 1.

Variable	Population	Density (persons/ $mile^2$)	Commuting by Transit	Gasoline Use	Pattern Distance
Population	1.00	0.43[a]	0.40[b]	-0.06	0.12
Density		1.00	0.60[c]	-0.33	0.48[a]
Transit use			1.00	-0.40[b]	-0.25
Gasoline use				1.00	0.49[a]
Pattern distance					1.00

Note: All variables are defined in Table 1.
[a] Statistically significant at 0.05 level.
[b] Statistically significant at 0.1 level.
[c] Statistically significant at 0.005 level.

Figure 3. Columbus daytime employment by tracts, 1976.

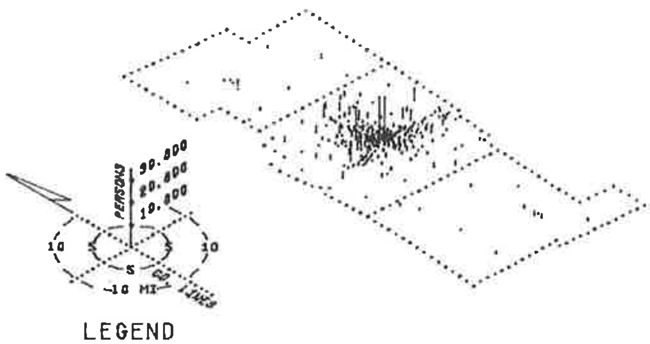
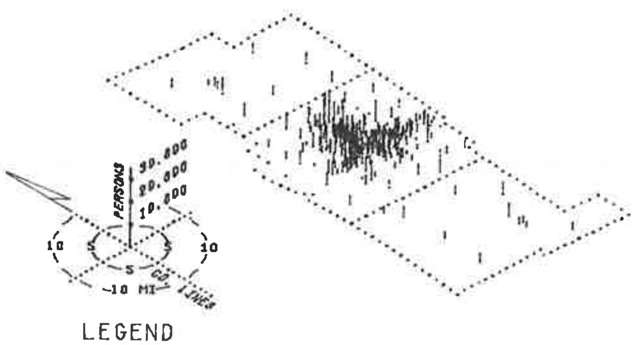


Figure 4. Columbus nighttime population by tracts, 1970.



sit services. By examining the distance between the residences of these two occupation groups, we may find that the social clustering of occupation groups in space (i.e., the pattern distance between white collars and blue collars) proves just as significant a predictor of gasoline consumption across cities as the distance between homes and work places. In a similar manner, we are investigating the extent to which racial residential segregation influences gasoline consumption across SMSAs.

In any case, analyses suggest that the pattern distance measure will prove advantageous to our present study of the relation between urban spatial structure and gasoline efficiency. For reasons mentioned earlier, we suspect that the concept can be shown to be useful in other areas of urban research as well. The method appears to work much in the manner of graphics, allowing us to sift through large quantities of spatial data to determine those spatial relations that make a difference.

Techniques of spatial analysis have the advantage over graphics that they tie directly to methods of

Figure 5. Cincinnati daytime employment by tracts, 1976.

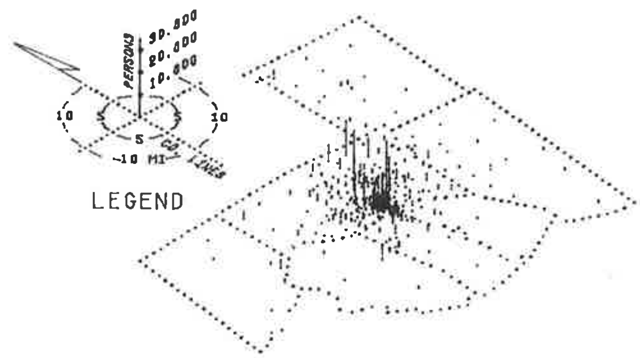
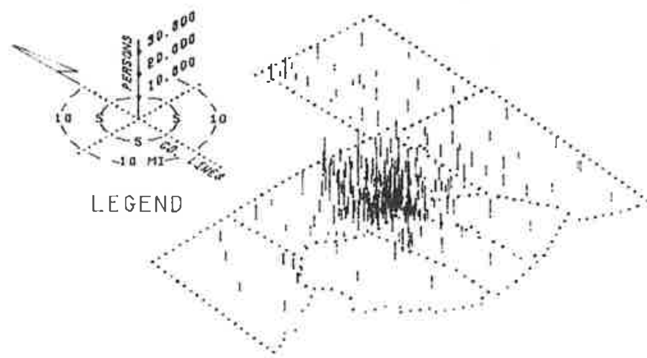


Figure 6. Cincinnati nighttime population by tracts, 1970.



statistical hypothesis testing. Occasionally, they have the disadvantage of being somewhat more difficult to compute. The data base requirements of the two methods are for the most part identical and modest. Since the most severe problem of urban research is often the insufficiency of information with respect to the questions that we must try to answer, it seems appropriate to devote resources to the development of such purely descriptive methods that offer the potential of insight despite the incompleteness of our data.

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