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

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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).

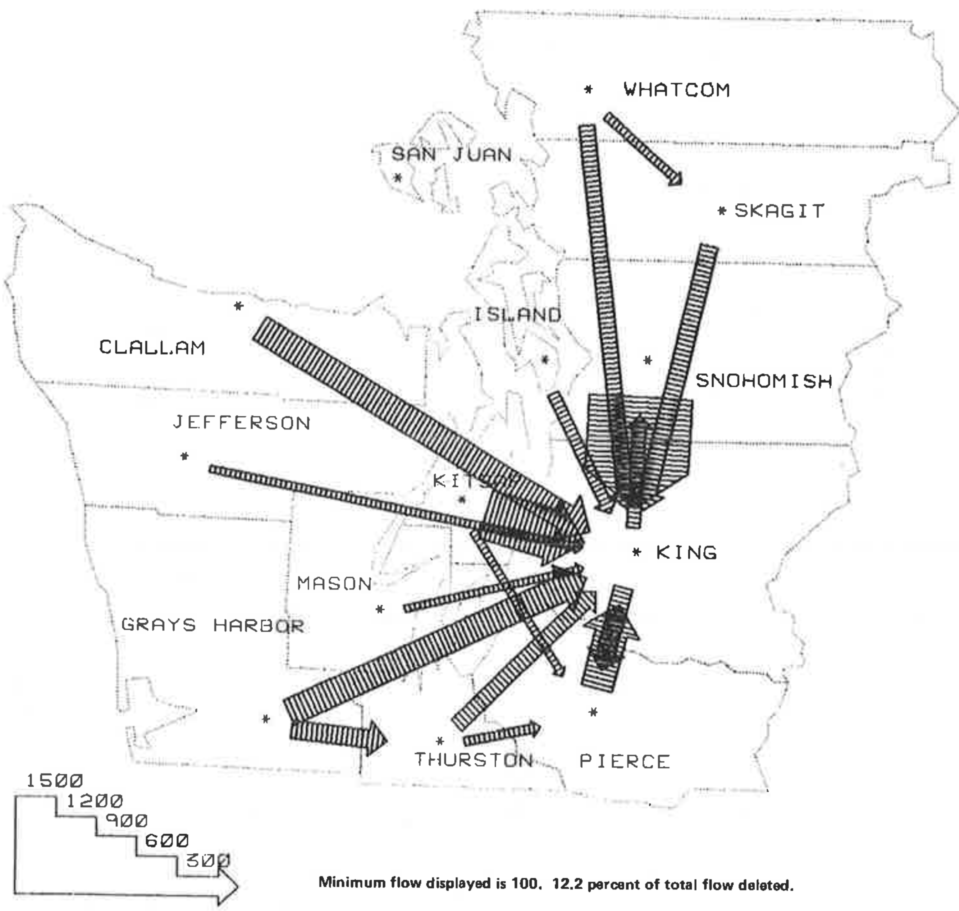
FLOWMAP requires input data from two files: a flow-data file and a geographic feature file.

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.

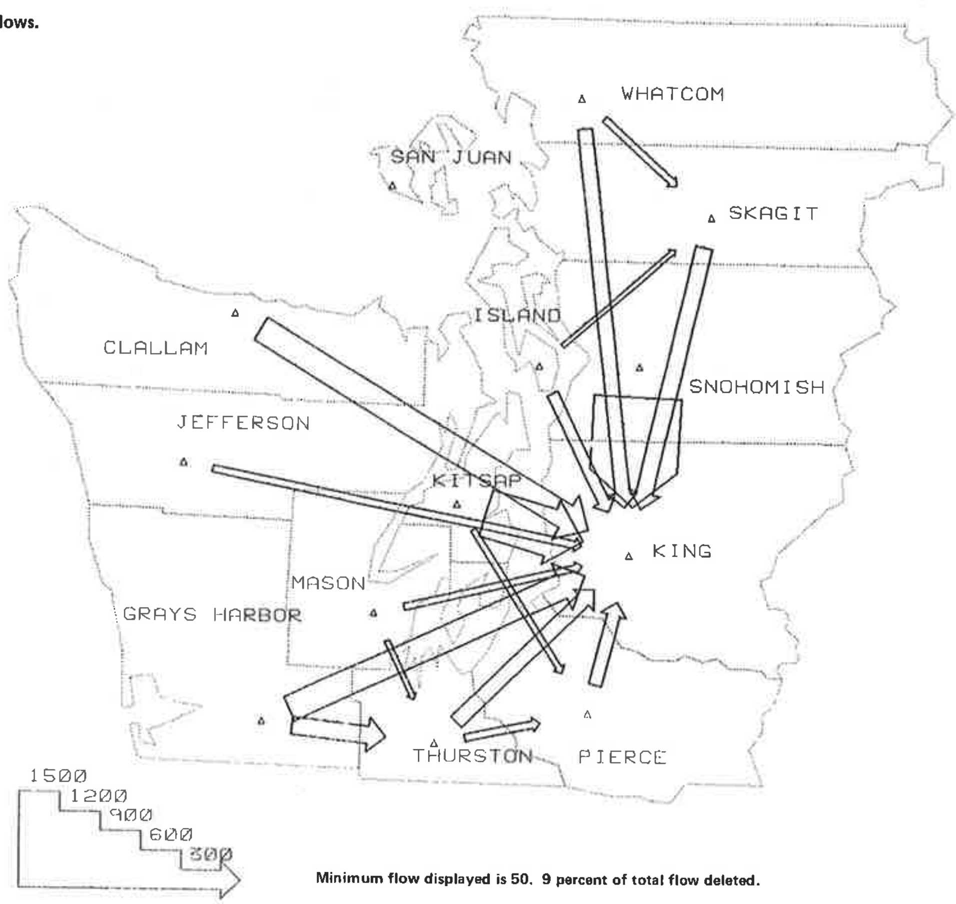
The instruction section includes the number of interacting data-collection points that are included in the O-D table. A data-collection point usually corresponds to a geographical zone. For example, an O-D table that shows flows between the 50 United States would have 50 zones and 50 interacting data

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.

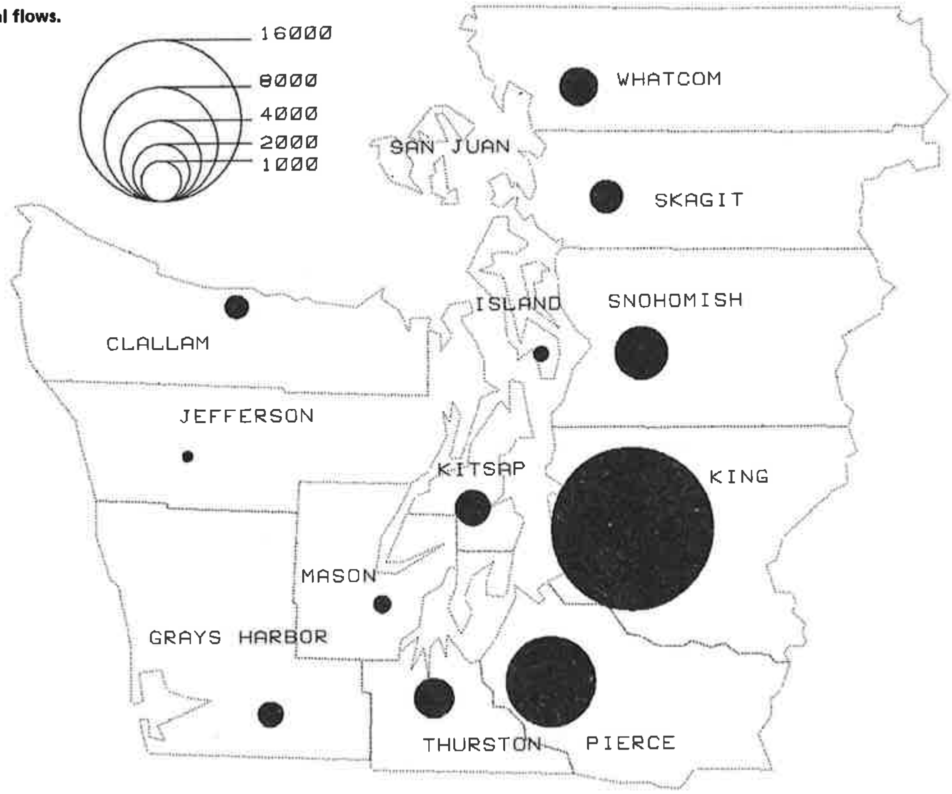
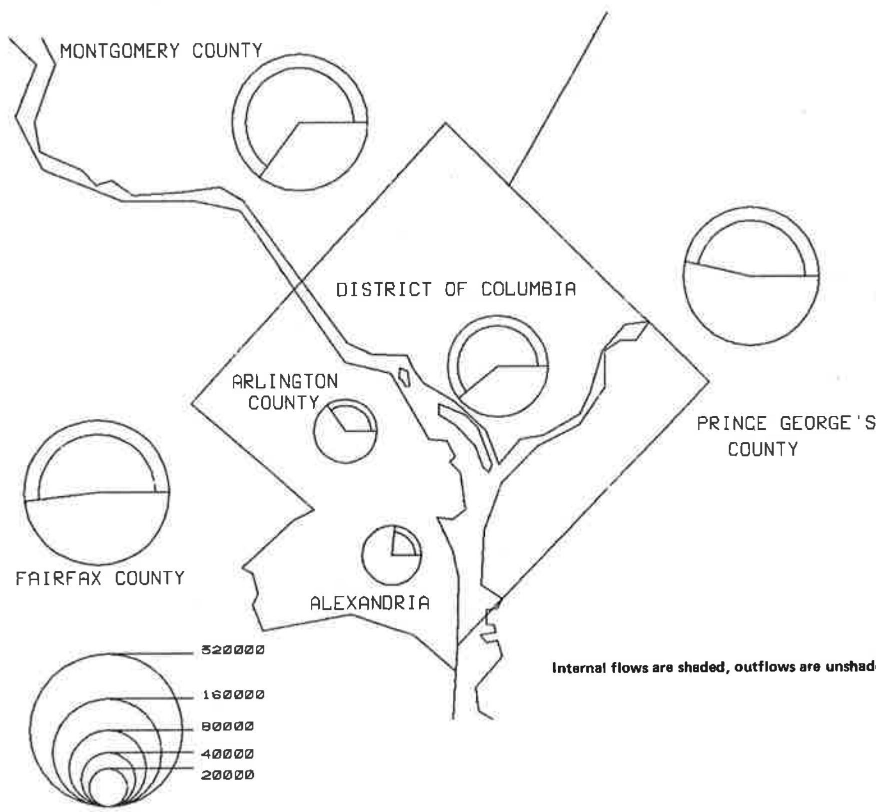


Figure 4. Origin piegraphs: home-to-work automobile driver trips.



Internal flows are shaded, outflows are unshaded.

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

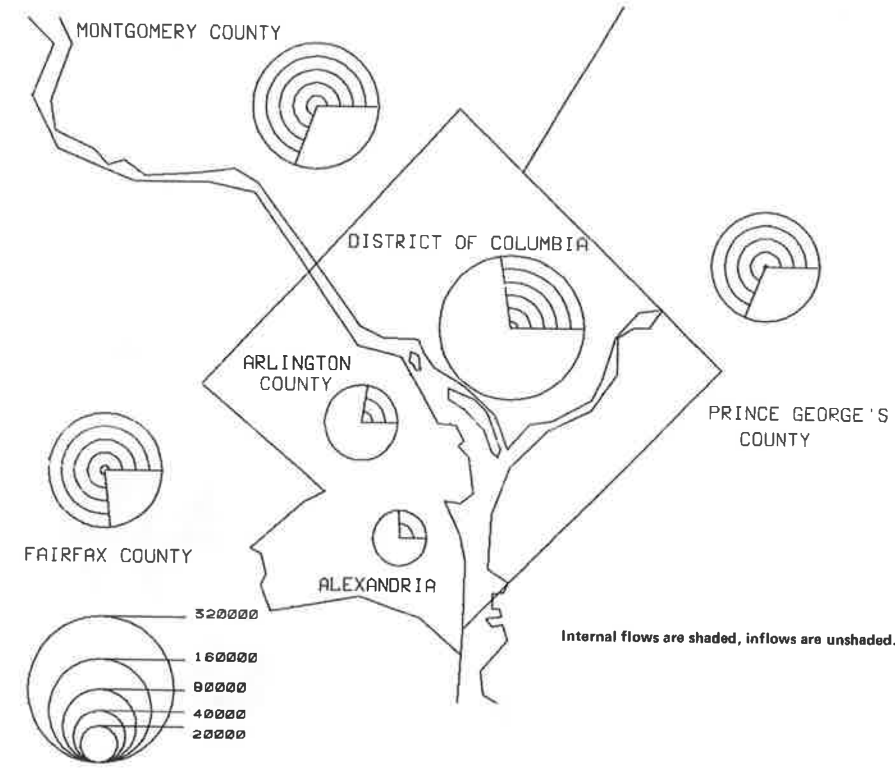


Figure 6. Piegraphs and arrows: home-to-work automobile driver trips.

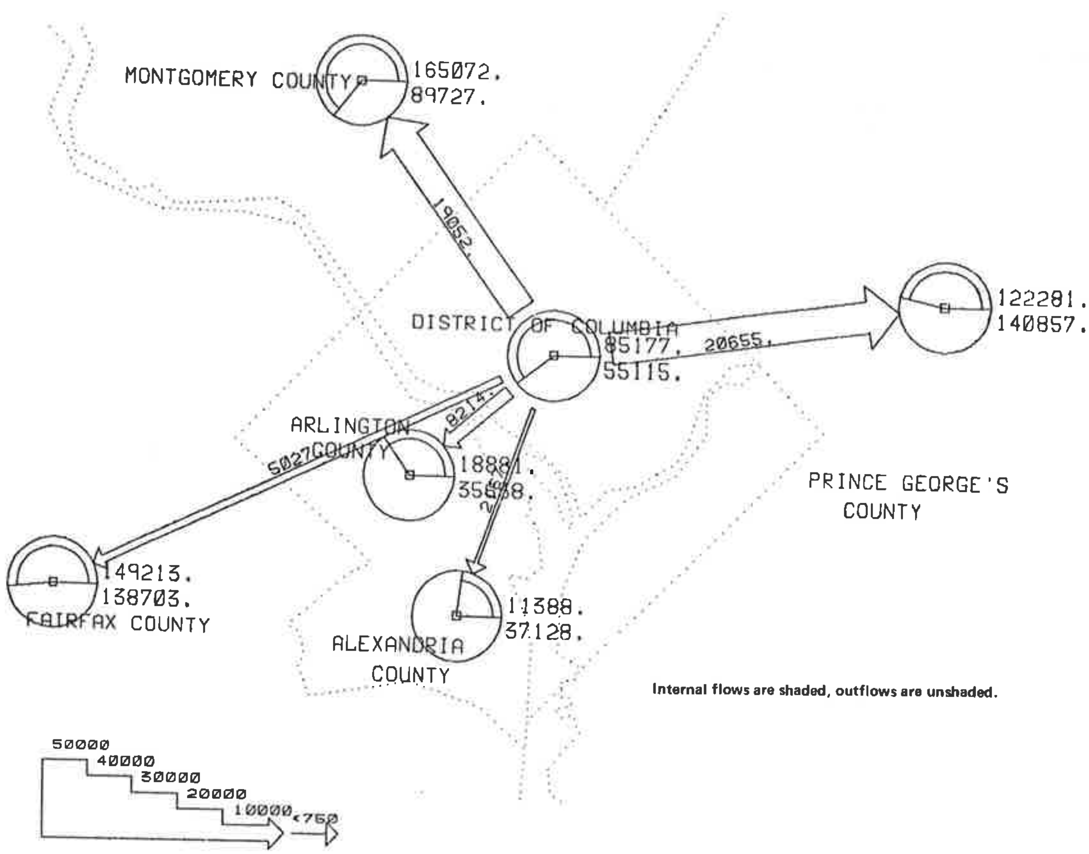
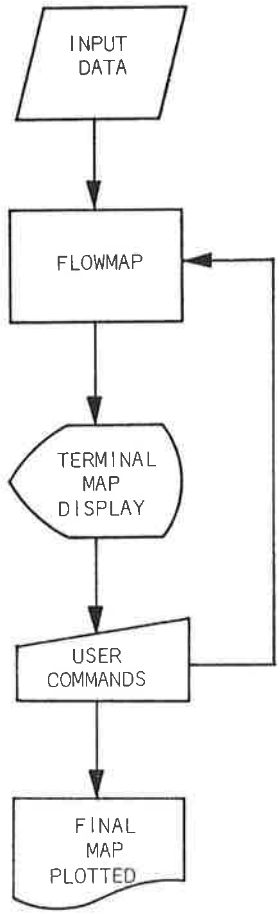


Figure 7. Interactive design process.



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.

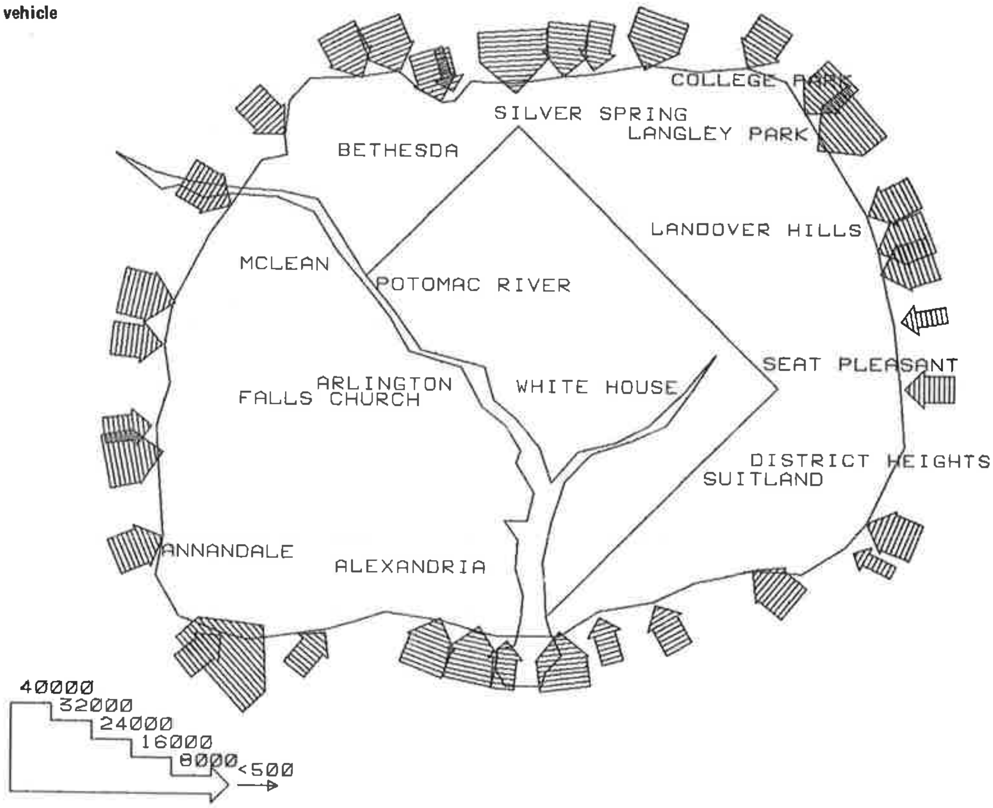
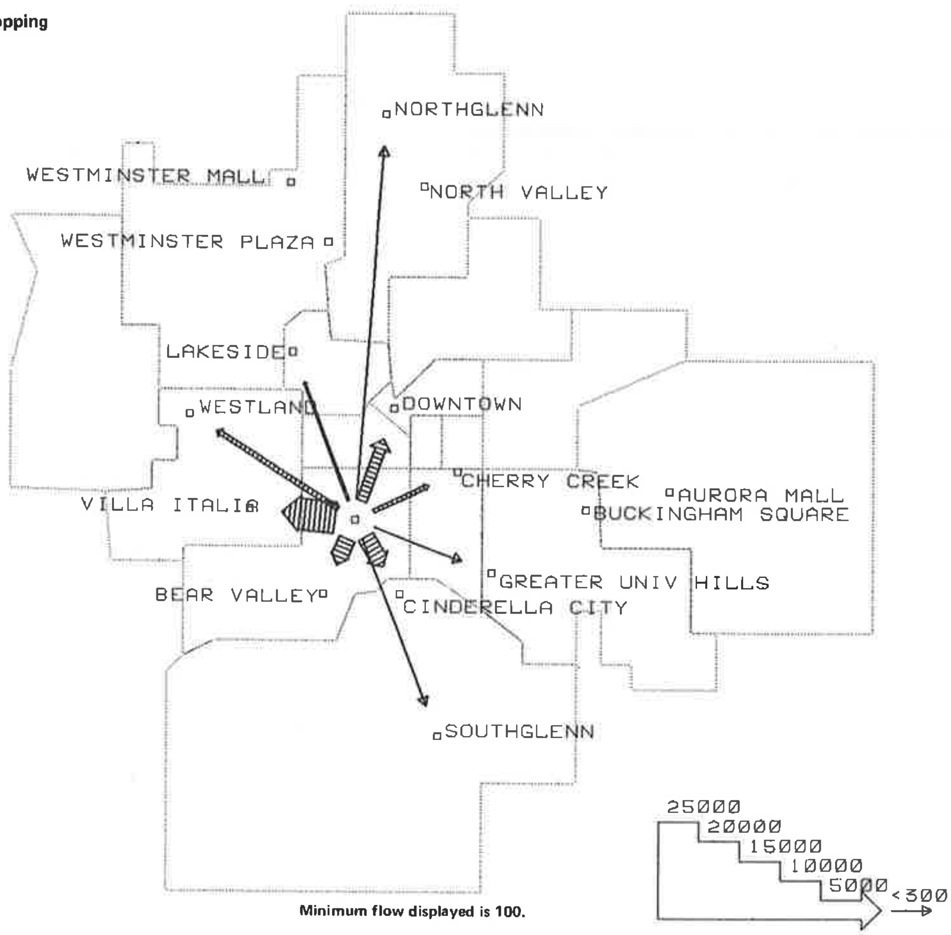


Figure 9. Denver area shopping patterns.



Minimum flow displayed is 100.

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.

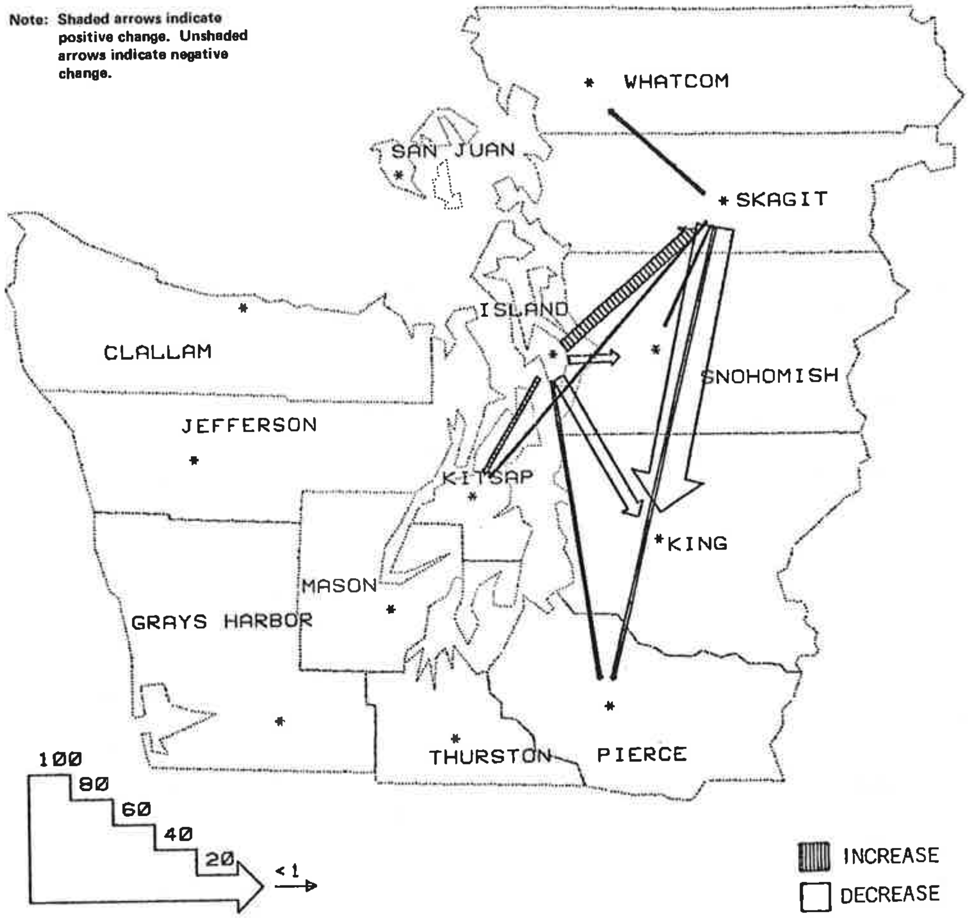
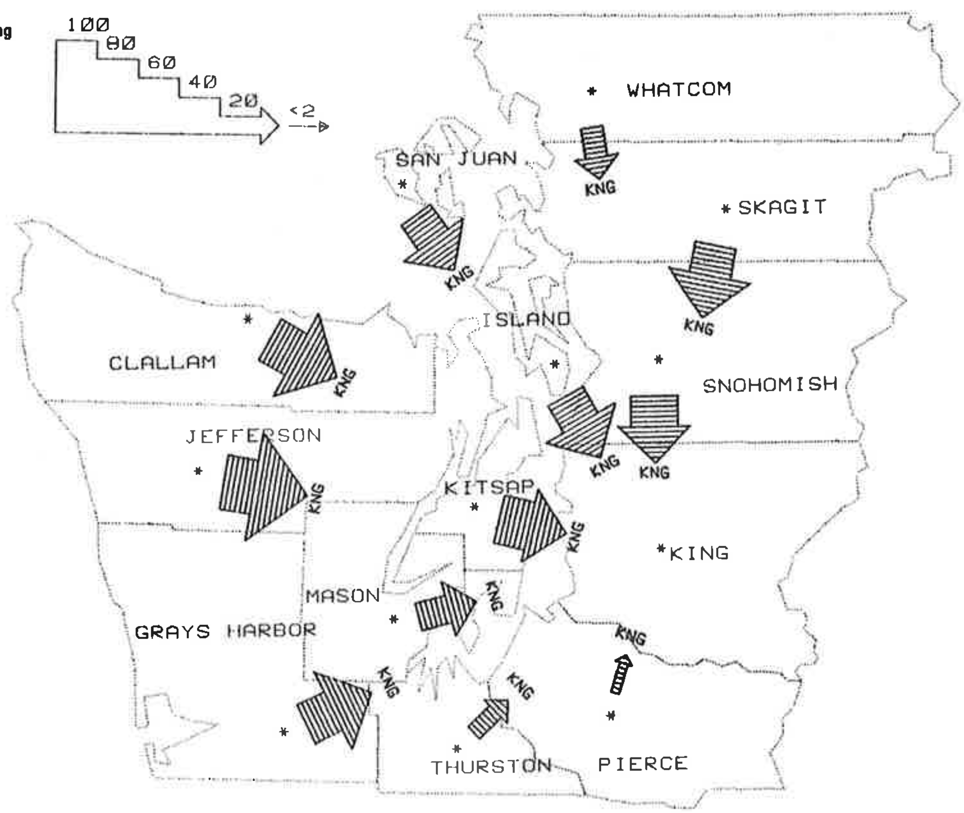


Figure 11. Cancer patient flow to King County in percent, 1974.



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.

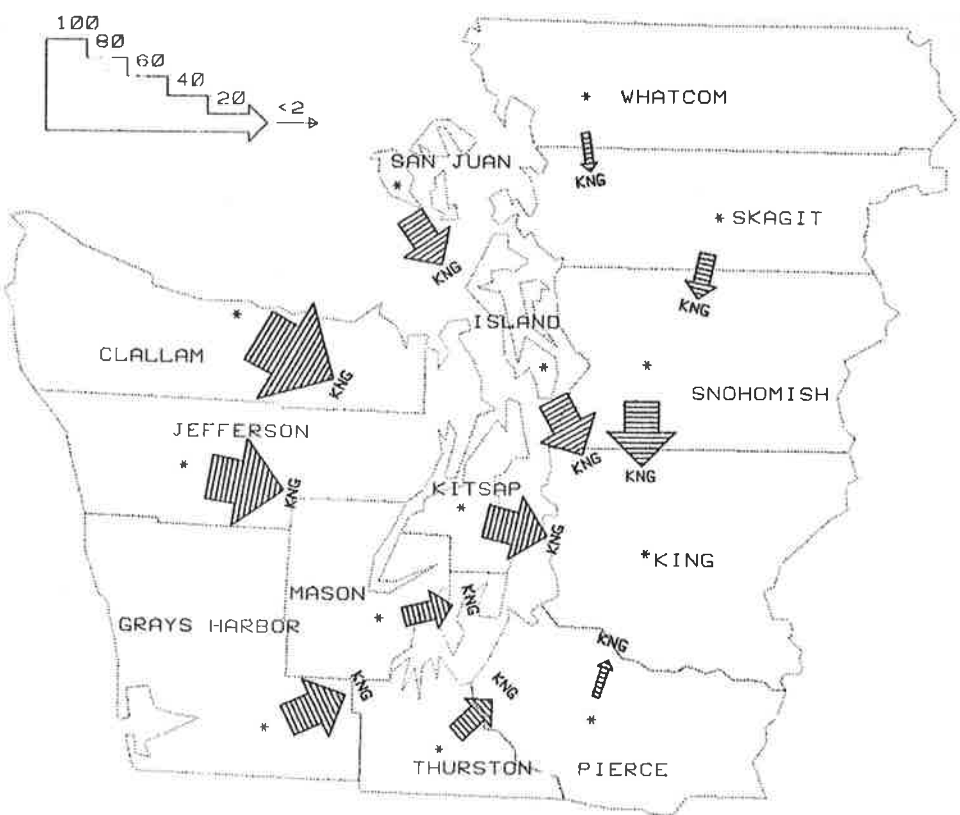
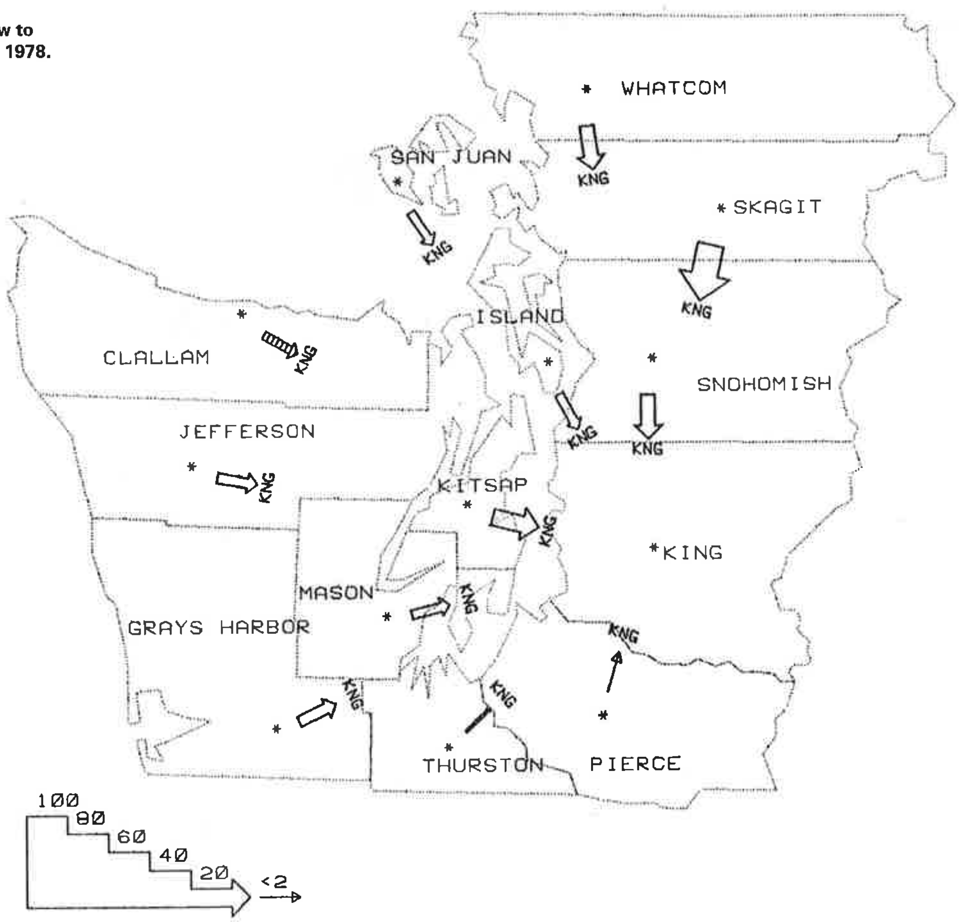


Figure 13. Change in patient flow to King County in percent, 1974 to 1978.



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

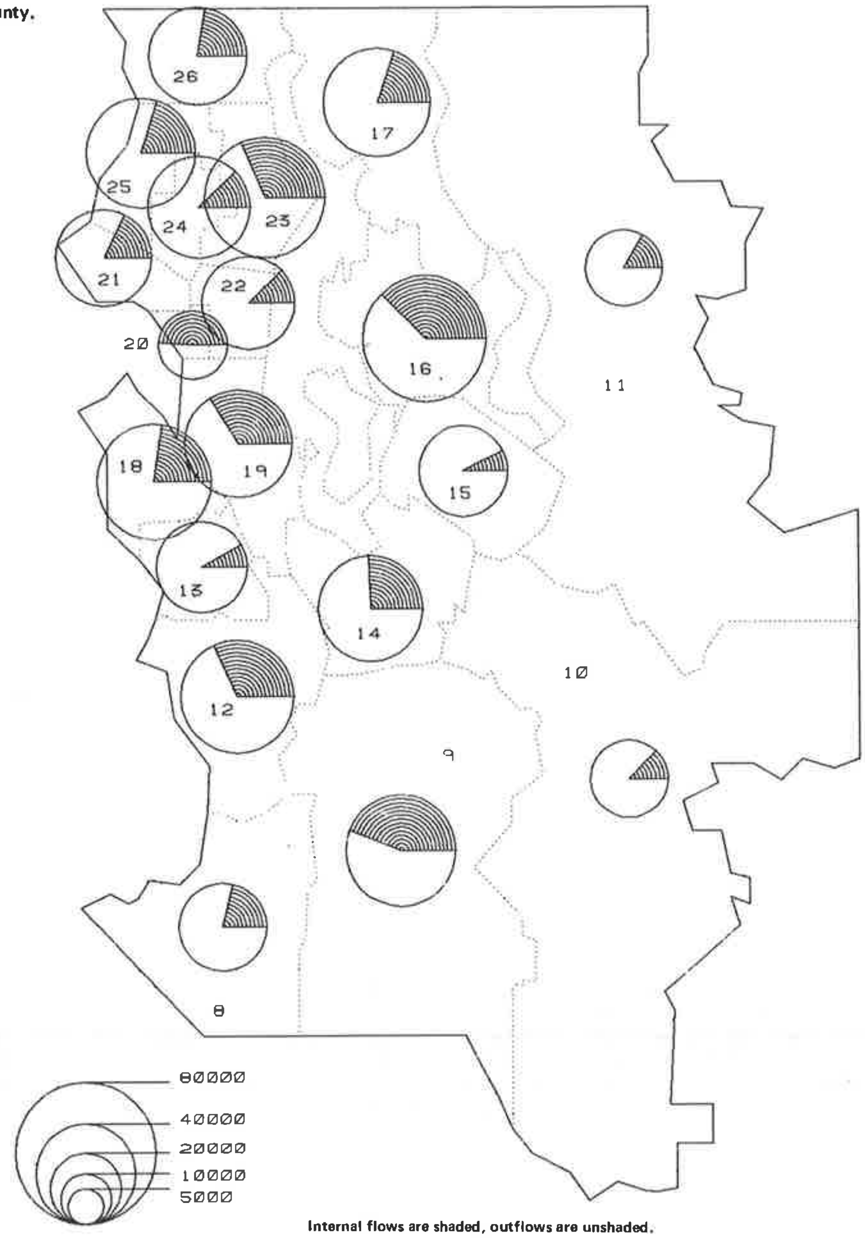
Since the program has not yet been tested on a large number of data sets, it is difficult to make statements about the costs of using it. However, the costs of the maps used in this paper provide some general indications. The maps that were produced interactively at a graphics terminal varied in costs 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.

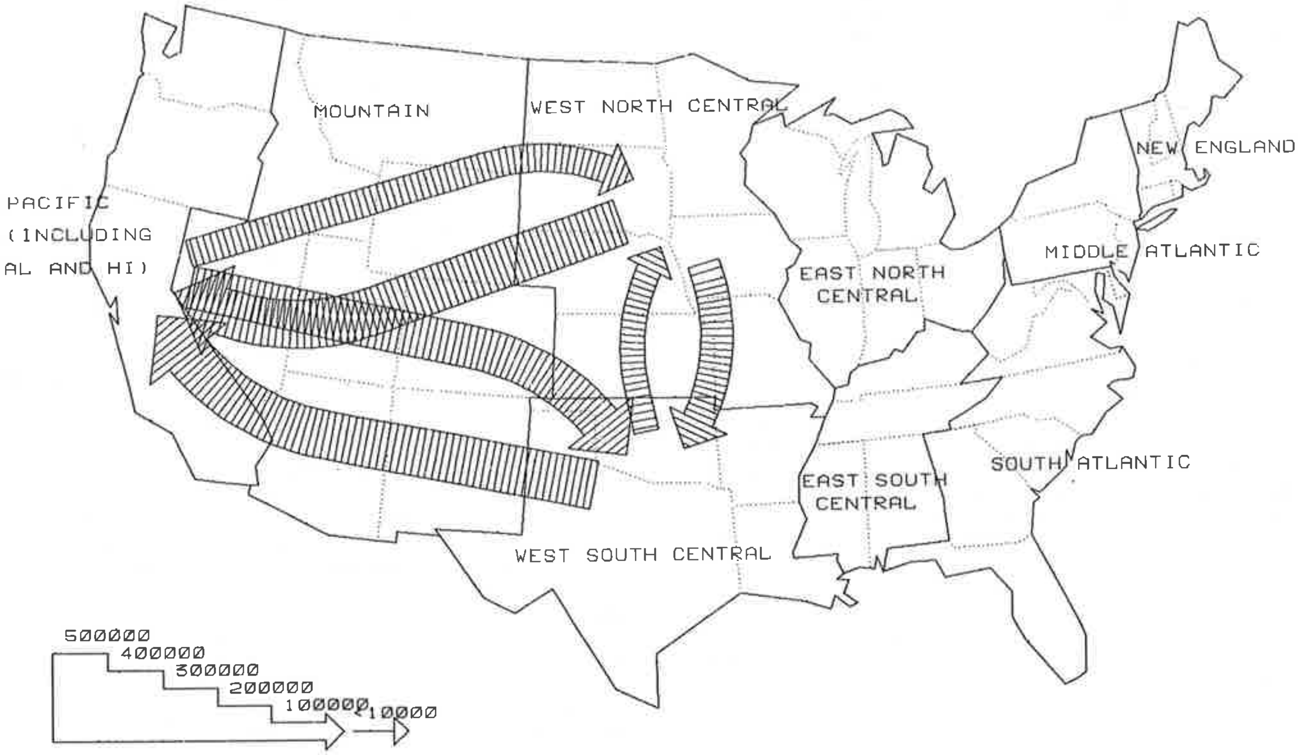
A more important advantage of FLOWMAP is that it allows the user to explore a data set thoroughly before creating final maps tailored to particular concerns. By alternately requesting many-to-one, one-to-many, and many-to-many maps, the user can quickly determine the best way to show the significant 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.



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REFERENCES

1. W. Tobler. A Geographic Flow Mapping Program. Department of Geography, Univ. of California, Santa Barbara, 1979.
2. R.I. Wittick. A Computer System for Mapping and Analyzing Transportation Networks. Southeastern Geographer, Vol. 16, No. 1, May 1976, pp. 74-81.
3. N. Kadmon. Komplot: Do-It-Yourself Computer Cartography. The Cartographic Journal, Vol. 8, No. 2, 1971, pp. 139-144.
4. D.A. Plane. Estimation of Place-to-Place Migration Flows from Net Migration Totals: A Minimum Information Approach. International Regional Science Review, Vol. 6, No. 1, 1981, pp. 33-51.

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