The GEOTRANS Geographic Decision Support System

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Disclaimer

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1. INTRODUCTION

A Geographical Information System (GIS) is a software environment that supports management, display, and analysis of high-quality maps and associated data. A GIS fundamentally extends the functionality of a database management system by supporting spatial data as well as attribute data. Many transportation organizations have made commitments to GIS technology, because spatial information is of basic importance in the management and operation of transportation infrastructure (e.g., roads, railways, and bridges) and in analyses of many related issues such as safety, congestion, material transport, etc.

However, GIS functionality can be extended to include more advanced decision support features such as mathematical models, artificial intelligence inferencing techniques, statistical methodologies, spatial analysis and other decision-making aids. We use the term Geographical Decision Support System, or GDSS, to describe a GIS that is extended in this way. The advanced capabilities offered by a GDSS can provide decision makers with the means of quickly carrying out sophisticated analyses that help address difficult issues in rural transportation. The GEOTRANS (GEographical Optimizer for TRANSportation) is an implementation of a GDSS for rural transportation. Algorithms and specialized data structures were developed to accomplish accurate and efficient solution of a suite of network flow optimization models for use in GEOTRANS. These include shortest path, assignment, transshipment, capacitated transshipment and facility location models. The design of GEOTRANS is expandable, to easily accommodate a larger repertoire of modeling tools as they become available. The models can be used to directly support transportation decision making in a map-based environment in rural states.

GEOTRANS can be used in wide variety of rural transportation applications. Several examples are given below.

- ! Customized maps and reports (onscreen and printed)
- ! Facility location analysis
  - > Based on arbitrary networks, such as highways, railroad or combinations

- > Objectives include reducing transport cost and minimizing distance to facilities, and involve both fixed and variable costs
- ! Shortest route analysis (based on distance or time)
- ! Point-to-point transportation analysis
- ! Regional demographic data displays
- ! Truck and bus routing and scheduling
- ! Census data analysis
- ! Location and siting analysis for:
  - > Manufacturing facilities
  - > Public service facilities
  - > Emergency service facilities
  - > Waste disposal facilities

GEOTRANS was developed under the sponsorship of the Mountain-Plains Consortium of Transportation Institutes, with the North Dakota State University Upper Great Plains Transportation Institute being the lead institute. Although relatively new, GEOTRANS has already been useful in carrying out a number of applied analyses of routing and facility location problems in North Dakota.

Section 2 describes the major issues involved in extending GIS functionality into the network modeling domain. Section 3 is a presentation of the GIS capabilities on GEOTRANS. In Section 4, we explain the integration of network models into GEOTRANS, and include a number of examples. A Conclusion and Further Work Section summarizes the capabilities and potential of GEOTRANS, and describes some areas to consider for future work. Finally, details concerning getting started with GEOTRANS on a PC platform are provided in an Appendix.

2. TRANSPORTATION MODELING AND GIS

Geographical information systems are able to do an excellent job of managing and displaying data that pertains to geographic regions. Through the use of layering and database management techniques, thematic maps can be produced that clearly show the entities of interest. In particular, GIS techniques can produce maps that show vector data of importance in rural transportation, such as the highways, streets, and rail lines of a region. However, they are mostly limited to display purposes, and are typically only able to make minimal usage of these roads for modelling transportation problems. Computer programs that solve network models of interest in transportation have typically been written to run within stand-alone systems, independently of a GIS.

Such programs abstractly represent the network upon which they optimize, without reference to or correlation with the underlying geographic environment. Moving data between an external network solver and a GIS under such conditions is a time consuming task. This is due to varying data structures and representations, and the need to communicate through flat files. In this loosely coupled type of interaction, output files produced by one system (e.g. a GIS) are used as input to another program (e.g. a network model). The results of the processing are then communicated back, again via a file. The design and implementation of GEOTRANS is much more integrated and tightly coupled. GEOTRANS seamlessly melds features from each of the above types of software in one coherent, highly visual setting. This allows relatively untrained users to have easy access to powerful network algorithms. Professionals who routinely work with transportation models can also benefit from the GIS features and associated data base.

GEOTRANS currently supports several network models: Dijkstra's algorithm modified to include capacity constraints for shortest path; a 2-optimal travelling salesman problem solver for route construction; a 1-optimal heuristic for p- median, p-center and requirements facility location problems with fixed costs; and a primal simplex capacitated transshipment problem solver for network flow.

GEOTRANS functions with a graphic user interface (GUI) that uses menus and dialogue boxes with a mouse as the primary input device. Information and modeling results are conveyed and contrasted through extensive use of color, layering, and algebraic specification of relationships among variables. The system can be highly customized by the user. Scientifically established principles of human-computer interaction were employed to ensure that the GUI is intuitive and user friendly.

A wide range of editing functions are built into the software. The tools provide for the modification of existing maps or the construction of new maps entirely on the computer screen. Several maps have been digitized for the system, including North Dakota state and county highway maps and state railroad maps. The primary data development effort thus far has primarily been restricted to North Dakota, but some data gathering has been done for other states in the Mountain-Plains region. Tools are under development for facilitating data development from government sources such as TIGER line files.

GEOTRANS employs specialized algorithms and data structures to accomplish accurate and efficient solution of a suite of network flow optimization models of importance in rural transportation. The design of GEOTRANS is expandable and evolutionary, to easily accommodate a larger repertoire of modeling tools as they become available. An ever-increasing suite of models will make the ability of GEOTRANS to directly support transportation decision making in a map-based environment in rural states even better in the future. GEOTRANS has already been applied to a number of analyses of routing and facility location problems in North Dakota.

The system runs on DOS microcomputers with a 386 class or better processor. The code is written in the C language using Borland version 3.1, and the TEGL Windows Toolkit is used to provide the GUI functions. An Appendix to this paper provides additional implementation and system details.

3. GIS CAPABILITIES IN GEOTRANS

Basic graphical support in a GIS can be raster-based, vector- based, or a combination of the two. In raster graphics, each geographical area of interest is divided into cells, with one or more attributes associated with each cell. An aggregation of such cells is called a raster. Rasters can be displayed very quickly, because the data model is simple and the cells can be quickly mapped to displayable units (pixels) on the screen. There is inherently a fixed level of detail, high data overhead, and no direct access to vector information. Raster graphics is extensively used in image processing and in the production of relatively static maps that show topographic, geological and soils information. A vector GIS is based on points, lines and polygons that can be individually referenced by location and attributes. Although the data model is more complex than in a raster system, a vector model minimizes data redundancy and offers cartographic precision. A vector model is well suited for a rural transportation GIS, because it offers direct access to explicit locations of entities such as bridges, intersections and road links. Direct access to road link vectors also provide a natural correspondence with the information needed for the types of network analyses commonly carried out in rural transportation. For these reasons, GEOTRANS is based on a vector model.

Functionally, GEOTRANS includes capabilities one would expect from a GIS: independently selectable map layers of roads, railroads, cities, and regional borders; a data base with a flexible query language; a full set of map and data editing tools; and arbitrary zoom-in. These features are augmented by several transportation models: shortest path, facility location, route construction, and network flow.

A highly intuitive graphical user interface (GUI) binds all these elements together. The GUI is built on a hierarchy of menus and dialogue boxes with a mouse as the primary input device. During the GEOTRANS design phase, special attention was paid to the organization of the menus. Much time was also spent on selecting colors for the various screen components, as well as, providing mechanisms to allow the user to customize them.

Thematic maps based on a map's data fields are easy to produce. An algebraic query language is provided for this purpose. The data fields can be combined using arithmetic and logical operators. The results of these operations can be flexibly grouped, then displayed with color coding on the map. These calculations can then be passed to the various mathematical models to serve as input.

The program was written to facilitate easy expansion. The code is not dependent on the data, so different maps can have varying numbers and definitions of the data fields. Additional models can be incorporated, either to expand the capabilities of the system or for testing purposes.

Getting Started with GEOTRANS

GEOTRANS is invoked by typing "gdss" at the command prompt. The system will respond with the prompt "SVGA?", to which a yes or no answer is given.

The main menu bar will appear on the screen. The main menu contains six choices, each of which can be selected with the mouse, or by pressing the first letter of the choice while holding down the Alt key. A drop down menu of further choices is then presented. These items can be selected by pointing at them with the mouse and then pressing the left mouse button. Alternatively, if one of the characters in the choice is underlined, pressing the corresponding key selects that item. If none of the selections is desired, pointing the mouse anywhere outside of the menu and pressing the left mouse button will return to the parent menu.

The leftmost choice on the main menu bar is "File". The associated options provide several file-oriented functions as well as the option to exit the program. Next is "Edit", which provides several options for editing maps. Following this is "Query", which is invoked to find information on map objects or to run the mathematical models. "Display" governs which and how map objects will be displayed and scaled on the screen. Several display and modelling choices are grouped under "Options". Finally, comes "Control" with remaining selections which tend to be used less frequently than the others.

Many of the choices from the drop down menus are not available until a map file is loaded. To load a file, choose the "File" option on the main menu and choose the "Open" selection. A dialogue box that lists available map files will appear. Selection of a file is done with the left button on the mouse, followed by choosing the "OK" button in the dialogue box. Figure 1 shows the appearance of the screen for selecting a file, and Figure 2 shows the resultant display after retrieval of the file from disk. As an alternative, file selection can be done by clicking on the file name with the left mouse button. Once a map is loaded, all the menu options are be available for working with the map.

When the map is drawn on the screen, the objects displayed appear in various colors and line styles. To reveal their meanings, click on the map name button in the upper right corner of the screen with the left mouse button. The map legend is then displayed. The legend illustrates and identifies the various road and city types, and a map mileage scale is also drawn. The color codes for demographic information are also shown. The legend may be moved around the screen by pointing at the legend and pressing the right mouse button, then moving the mouse while continuing to hold down the button. Releasing the button when the legend is in the desired position places the legend in the new location. The legend may be removed entirely by clicking on the map name button in the legend with the left

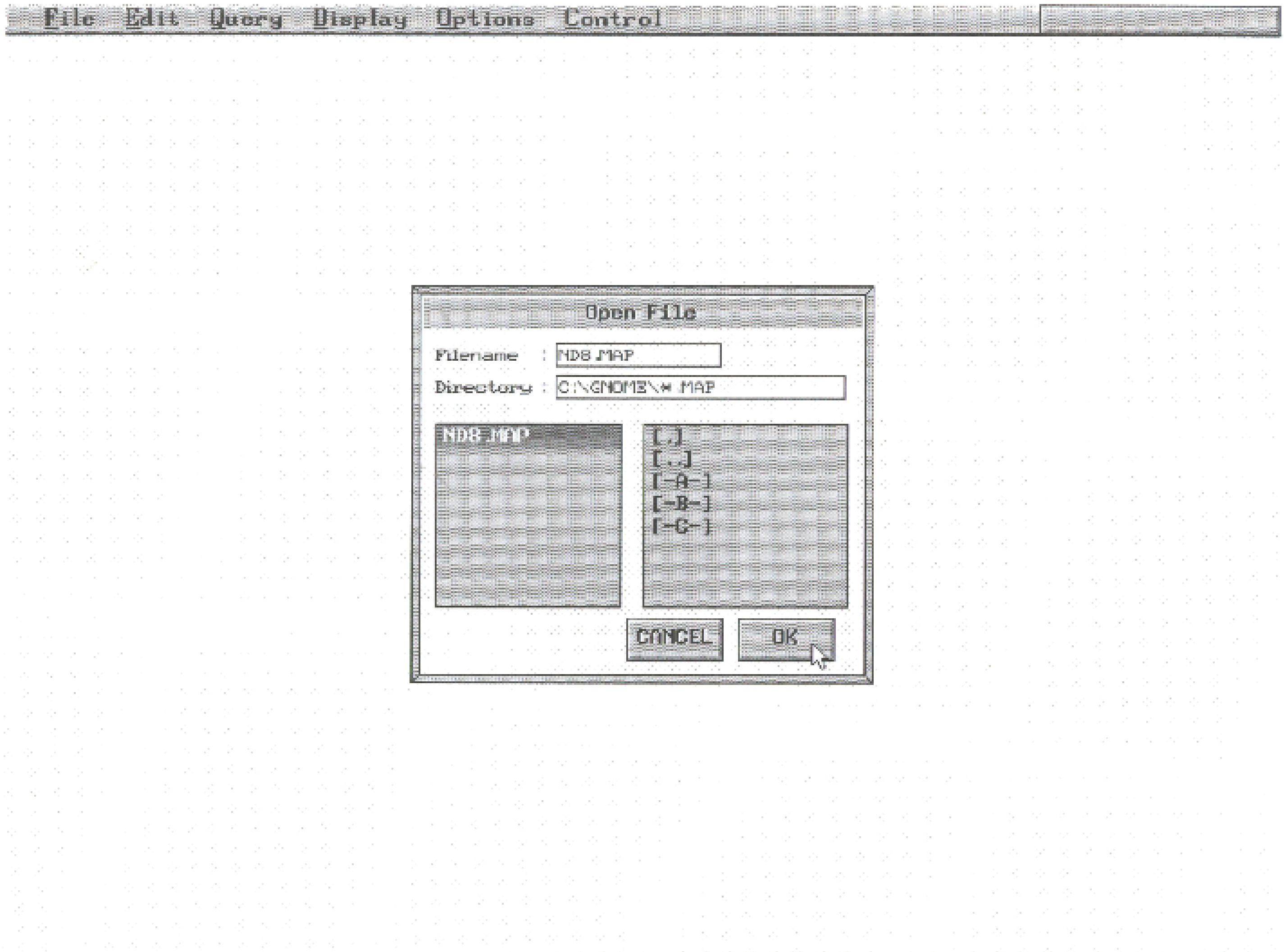

Figure 1. An illustration of the file selection dialog box.

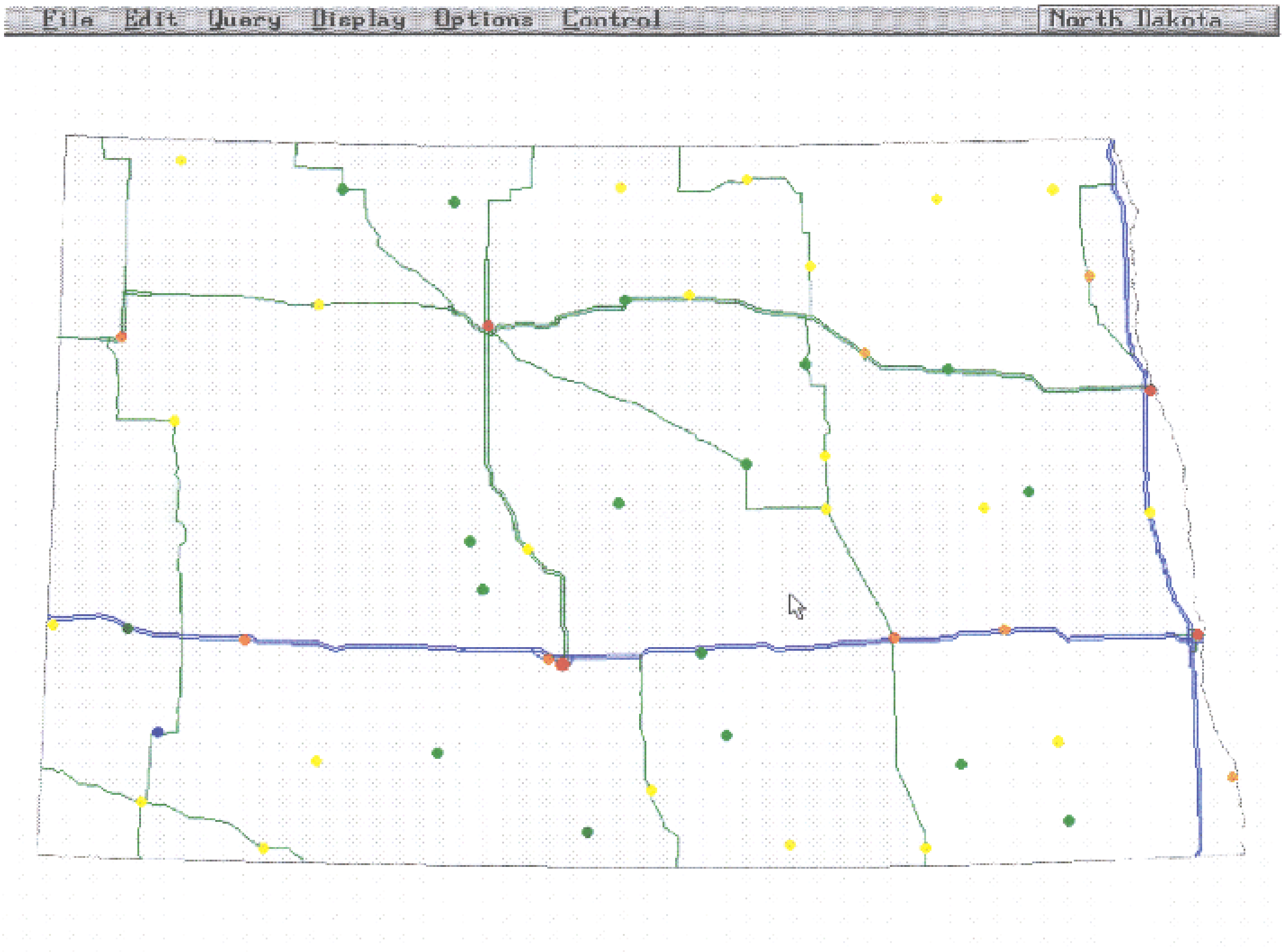

Figure 2. An illustration of the initial map display.

mouse button. The main menu is not available while the legend is displayed. To select which map objects should be displayed, the "Display" is used, followed by the "Layers" option. This triggers the display of a dialogue box that lists the various map objects with check boxes to indicate which particular items are currently displayed.

The left mouse button may be used on any of these boxes to toggle the display status of any of the corresponding item. Clicking on the "OK" box invokes the redisplaying of the map will be redrawn according to the specifications. Figure 3 shows an example screen for which rail lines, Capitals, County seats, other cities, and the state boundary have been selected. Figure 4 shows the following screen that displays the selected entities. Combining features in this way can reveal patterns not otherwise obvious. For example, in Figure 4 it is easy to see that many towns and cities in North Dakota are spaced at regular intervals along rail lines. Also note that where rail lines have been abandoned, the locations of the towns reveal where the lines were at one time.

The "Zoom in" feature can be used to magnify a map region. After clicking on "Zoom in", the mouse is used to draw a rubber banding rectangle around the area of interest. The bounding box is created by pointing at one corner of a rectangle surrounding the area and pressing the left mouse button. The button should be held down while dragging the mouse until the area is encompassed. Releasing the button produces the magnified area. The "Zoom Out" option restores the map to its original scale.

To retrieve information about a particular map object, the "Query" option followed by "Identify" is used. The menu that is produced lists the various map objects. After selecting the menu choice and pointing at and clicking on an object on the map, the object is highlighted. Clicking the left mouse button once again pops up a window displaying information retrieved from the database concerning the selected object. The window can be moved on the screen with the same technique used for moving the legend. The information box can be removed by clicking on the "OK" button with the left mouse button.

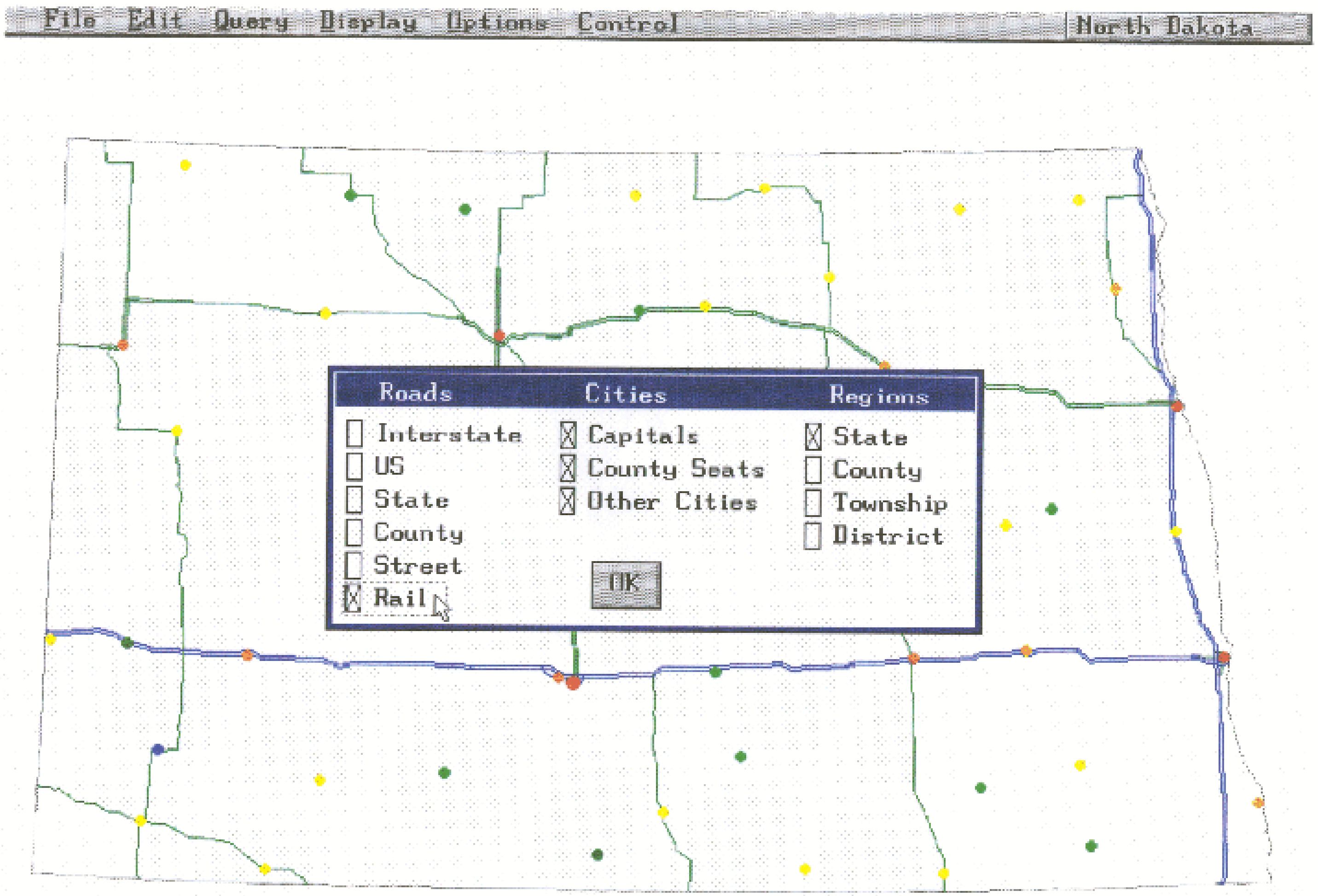

Figure 3. An illustration of the layer selection dialog box. Railroads and all cities are selected.

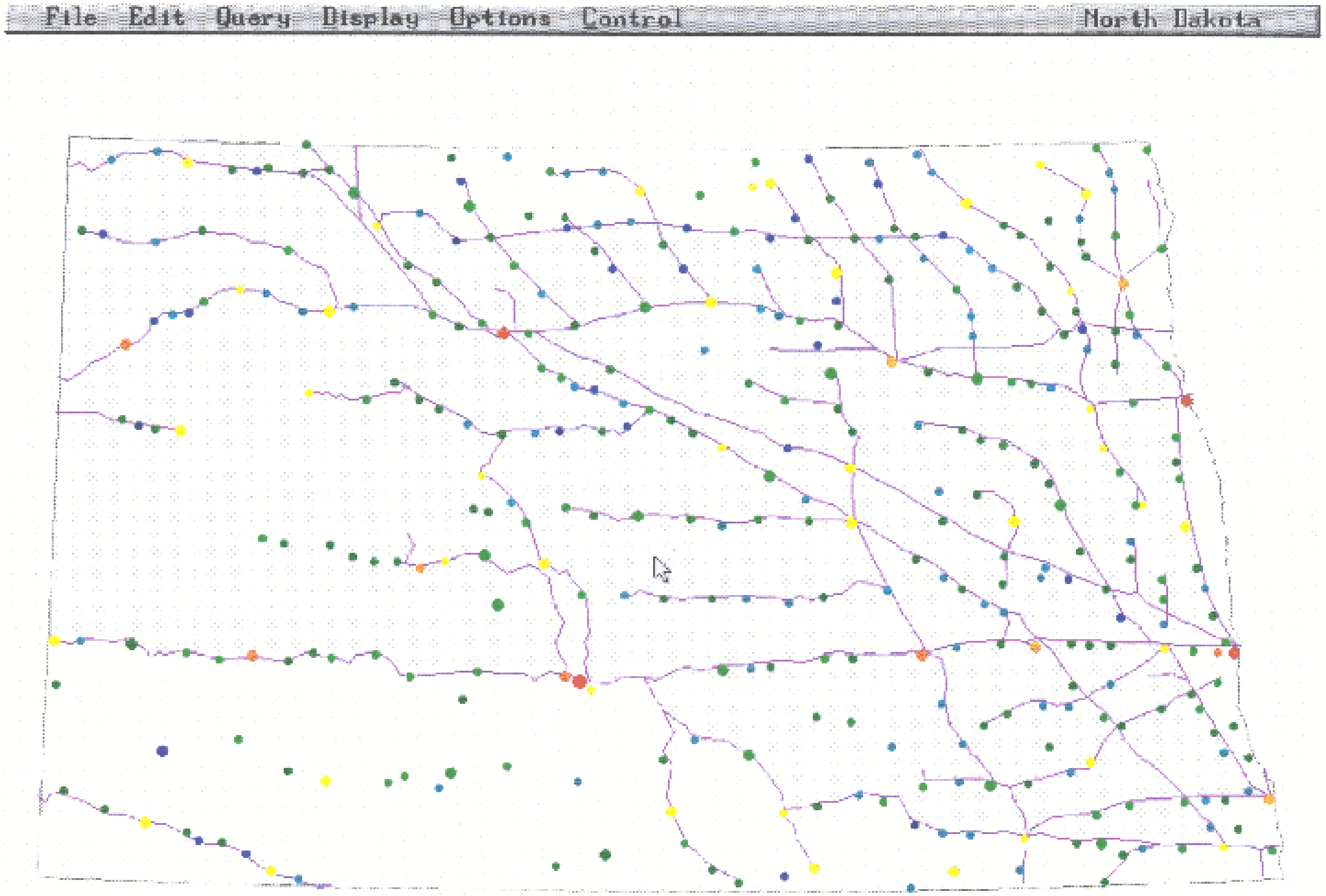

Figure 4. The resulting map display following the layer selection in figure 3.

To choose a road, it is necessary to choose both end points of the road segment. First, one point is selected as described above. This point is highlighted and all other road points which are connected to it are also indicated. Picking one the these points completes selection of the road segment. The segment is highlighted to easily confirm the selection.

To find any given object on the map by using the object name, the "Find" option from the "Query" menu is used. First the an object type on the menu is chosen, which produces an input box. The object name is entered in either upper or lower case. All objects of the selected type are then indicated on the screen.

The choice "Region Cities" also appears under the "Find" menu. This provides a mechanism to display the cities that are located within a region. A left button mouse click on a region shows all cities within the area. It may be desirable to first display the map with all city layers turned off. This can be done by turning auto redraw off ("Control|Auto Redraw") then turning on the desired city layers.

Cities and regions can be color coded thematically by their demographic information. This is done by invoking the "Demographics" option in the "Display" menu. Another menu is then drawn which lists the available fields. The currently used choice is checked. Clicking the left mouse button on a field will trigger the displaying a map that is colored according to this choice. Figure 5 provides an example, complete with legend. The choice "Off" turns off demographic color coding.

The choice "Enter expression" allows you to enter a custom specified mathematical or logical expression using the demographic fields as variables. A dialogue box is drawn for this purpose. The fields are all listed with a corresponding letter. Lower case letters refer to the corresponding demographic field for the map object. Upper case letters refer to the average of this field over all cities or regions of the same type. An expression can then be formed using these letters, mathematical operators (+, -, *, /), relational operators (<, =, >) and logical operators (& <AND>, | <OR>). Parentheses can be used to group terms. Conventional rules of

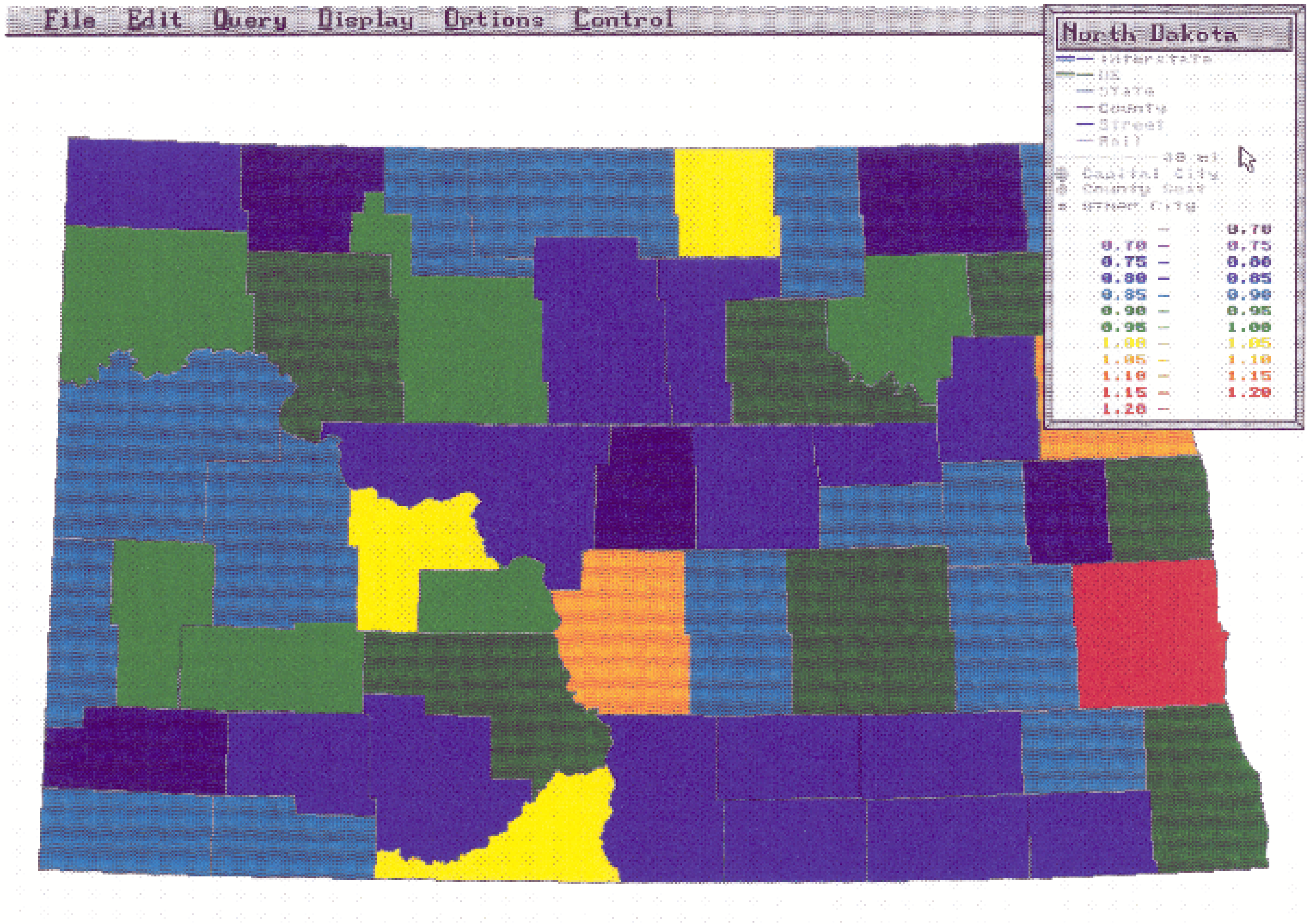

Figure 5. An illustration of a thematic map and legend. The counties are color coded by the ratio of 1990 population to 1980 population.

precedence are followed (*, /, +, -, <, =, >, &, |). Figure 6 shows an example expression for displaying North Dakota counties according to population change from 1980 to 1990. A logical condition in the expression selects counties that had a population decrease greater than 10%. In addition to entering the expression, there are choices for grouping and scaling the results of the expression. Minimum and maximum values for the scaling can be specified. By clicking on "Scale" with the left mouse button, the system will supply the values. Linear or logarithmic grouping based on the scaling values can be used. Checking "Use" will produce the map color coded in accordance with the expression. This is functionally the same as checking "Use Expression" in the Demographics menu. The dialogue box is terminated by clicking on the "OK" button.

Regions are colored based on their demographics by making the "Fill Areas" choice under the "Options" menu. The resultant color coded or "thematic" map is them produced. Figure 7 shows the map for the population change calculation.

The use of arbitrary algebraic expressions to manage data and the capability of producing the corresponding thematic map is a very flexible and powerful capability. This functionality is a significant distinguishing feature of GEOTRANS.

The "Options" menu contains several other choices. "Color" allows you to the color choices for highways, borders and highlighting to be custom chosen by the user. To use this capability, a left click on a color is used, followed by a left click on a map object. The color used for "Markers" may not be used for any other purpose. The color WHITE should be avoided if the "Query|Find|Region cities" or "Edit|Area". is also going to be used, because the results will be invisible against the background. Another capability is to use "Labels" to toggle the display status for city or area labels.

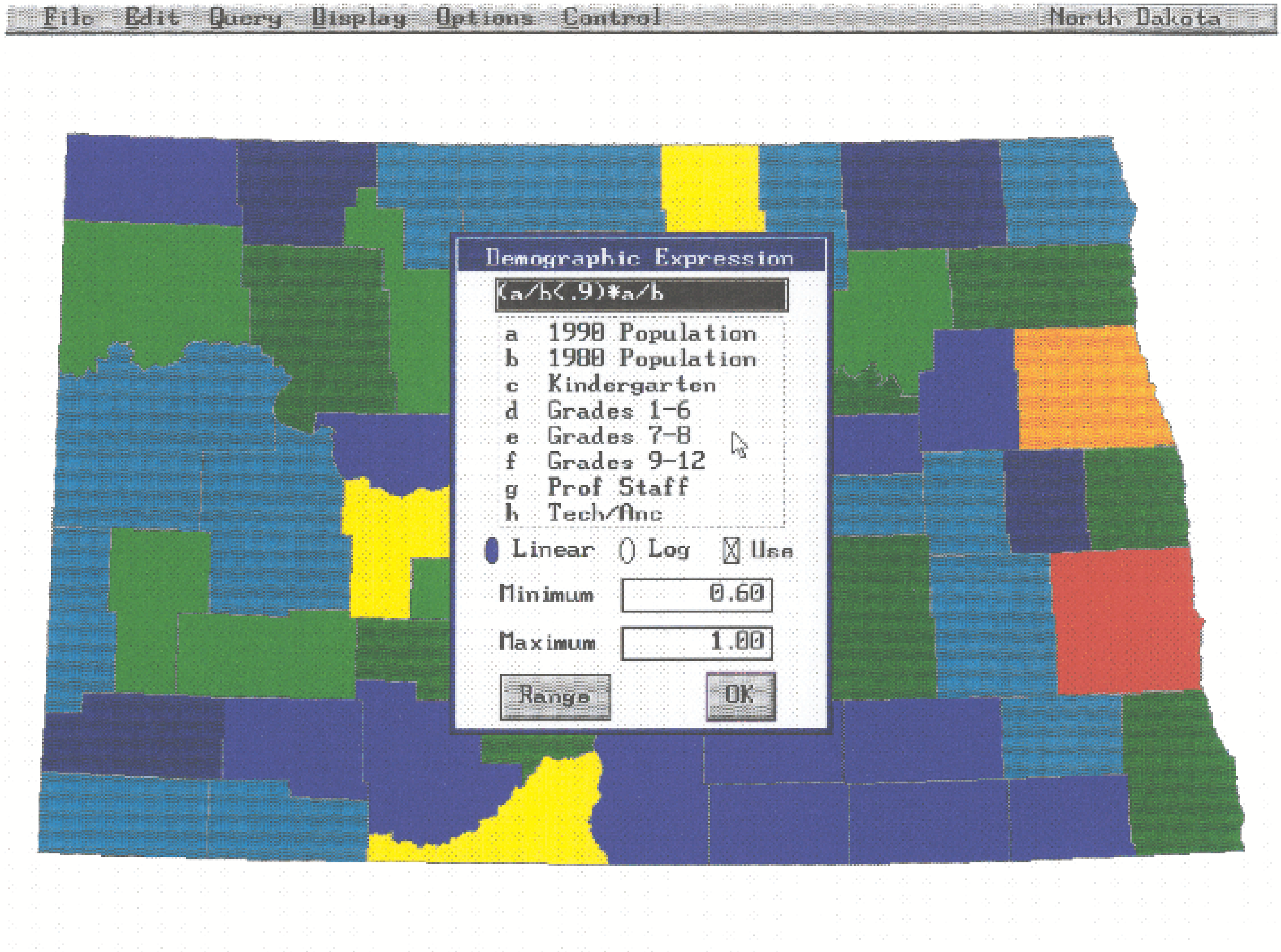

Figure 6. An illustration of the demographic expression dialog box. This expression will select counties that had a population decrease greater than 10%.

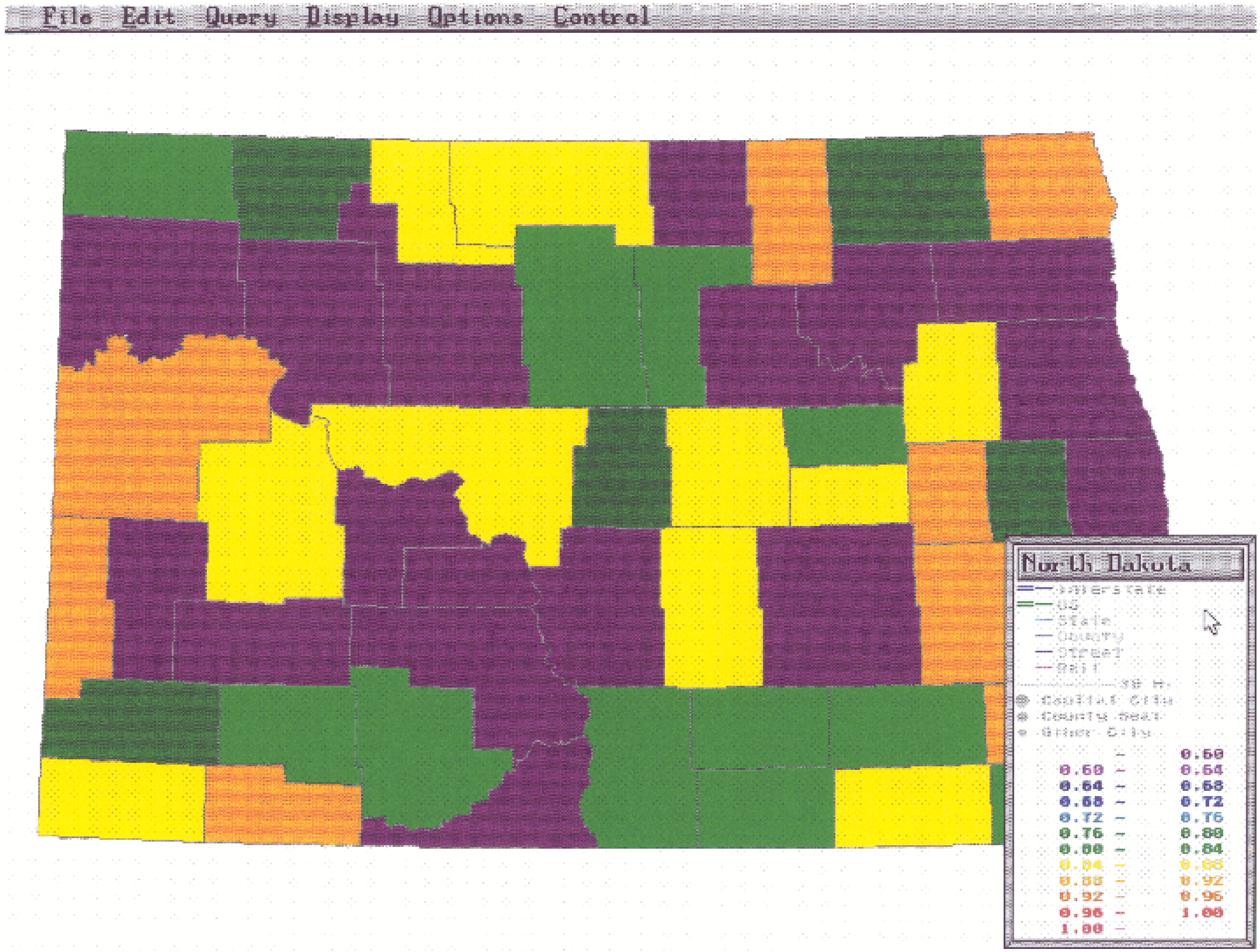

Figure 7. The resulting thematic map and legend after applying the expression from figure 6. Counties shown in deep violet did not meet the test condition.

4. TRANSPORTATION NETWORK OPTIMIZATION IN GEOTRANS

GEOTRANS supports several network models. All of these models are found under the "Query" menu.

The first network model option is "entitled Shortest Path". Within this model choice there are several options. "One to One" finds the shortest path between two point locations. The user is prompted to first enter a weight parameter. The road network segments have a weight field which can be used to model tonnage limitations, such as might be imposed for truck travel. If the weight parameter is used, the shortest path is constrained to use only those roads that are rated for the offered load. Pressing enter without a weight parameter specifies that the calculation should ignore to consider road capacity constraints. Clicking the left mouse button on one road point followed by another then click it on another point triggers the shortest path calculation for connecting the two points on the road network. The path is highlighted on the map. A window will pop up with a report of the length of the shortest path, reported in units of time or distance. Figure 8 illustrates the shortest path calculation for Fort Yates and Linton in North Dakota. Notice how the absence of a bridge over the Missouri River makes the shortest road network path through Bismarck/Mandan, a great deal further than the straight line distance. The network editing capabilities of GEOTRANS could be used to simulate future alternatives. For example, adding a simulated bridge over the Missouri River with a few point and click operations followed by shortest path analysis would reveal the routing advantages of a the project and be useful in benefit/cost analysis.

All of the reporting windows in GEOTRANS can be moved to unobtrusive locations or deleted in a fashion similar to the way described for the Query and Identify windows.

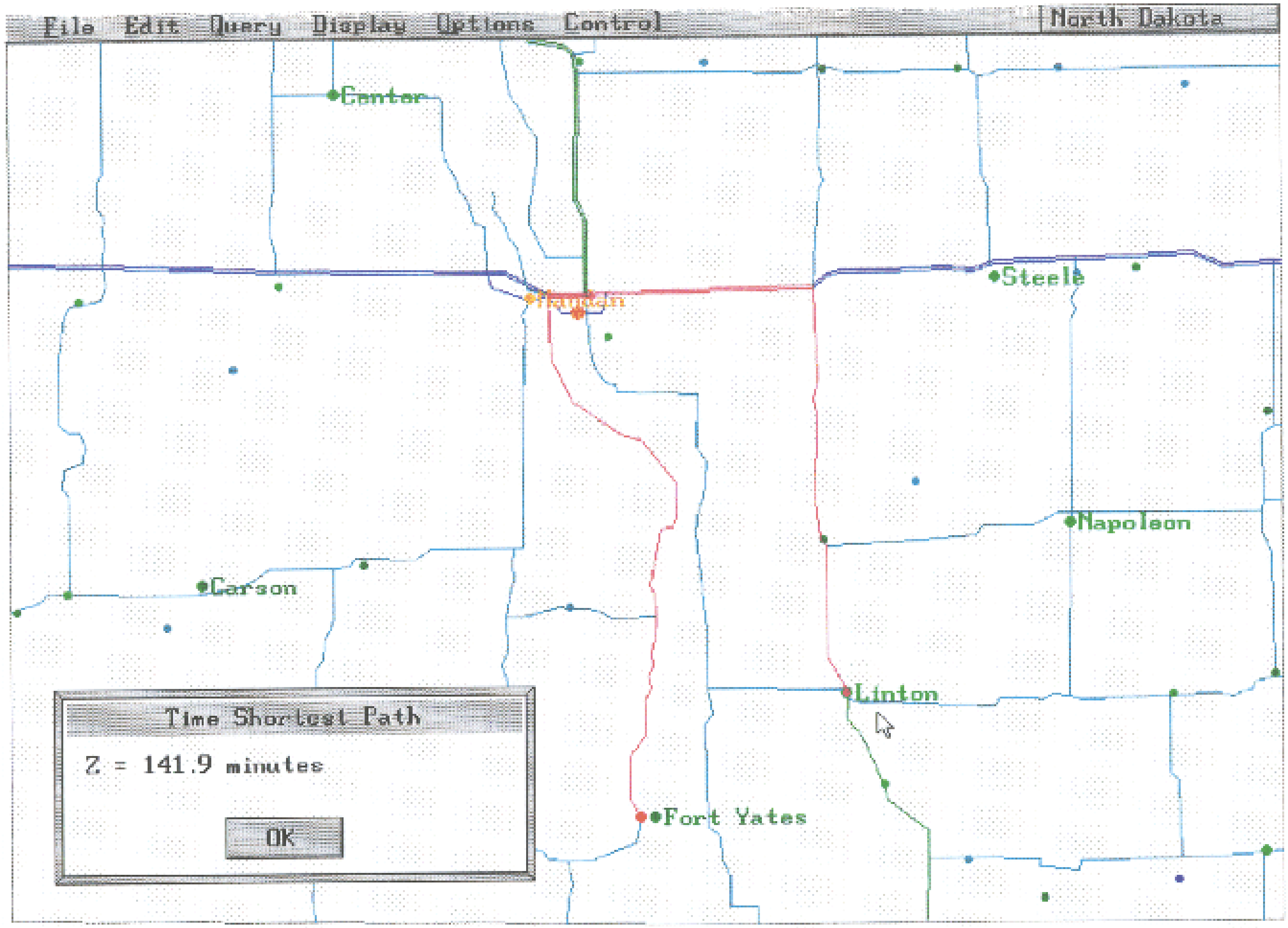

Figure 8. An illustration of a zoomed display showing the shortest path from Fort Yates to Linton. The route, shown in red, is based on travel time.

The "Route" option provides the means of calculating the shortest path connecting a sequence of points. A left click on the starting point followed by another point triggers the display of the shortest path between the two points. Clicking on additional points extends the shortest path to include the specified point locations. A click the right mouse button completes the sequence. The total length for the selected route is displayed in a window.

"One to Many" is very similar to "One to One". The difference is that any number of points can be selected. A right click on the mouse button completes the operation. The shortest path connecting the first point selected to each of the other selected points will be displayed.

"One to All" is similar to "One to Many" except only a single point is picked. The shortest path is calculated from this point to each of the displayed cities. "One to All Population" is similar, except that the cost for each path is multiplied by each city's population to produce a weighted result.

The cost for a path can be based on either distance or time. The selection is made under by the "Arc Cost" choice under the "Options" menu. Time is calculated using the speed limit for a road type. This can be adjusted by the "Speed" control item in the "Control" menu. Highways are used for the paths by default. Routing on another network, such as the rail network, is accomplished by using the "Routes" command under "Options".

During the shortest path calculation, the distance from the first point selected (the source) to each city is calculated. Using this information, it is possible to display all cities within a certain radius from the source by using the "Distance" option under "Control". This feature has been useful, for example, in calculating and displaying the degree of isolation of school districts that considering merger.

The "Routing" option under "Query" is used to generate the collection of shortest paths that interconnect a set of specified points on the map. The solution consists of a "tree" structure, having no loops or cycles. The term skim tree is sometimes used for such a solution. This set of points can either be those that are currently displayed or user selected. To choose a specific set, the left mouse button is clicked on all desired road points. A right mouse button click terminates the process. In addition to the shortest route linking these points, a window showing the total cost is also displayed. Figure 9 illustrates a skim tree calculation from a specific site (Carrington, North Dakota), with paths interconnecting all county seats with population greater than 10,000 in the state. Skim tree calculations are also useful in calculating layouts of communication networks in such a way that total network mileage is minimized.

GEOTRANS supports two facility location models, called the "P Median" and the "P Center" models. In the P Median solution, P facilities facilities are placed so as to minimize the total cost of travel from each node to their nearest of the P facilities. The P Center solution is similar, except the facilities are located to minimize the maximum distance. After choosing the desired model, several questions must be answered:

(1) "How many facilities". The user must provide the number of facilities or sites to maximum acceptable cost for the solution, 999 can be entered.

(2) "Required max cost". This question is asked only if "999" is entered for "How many facilities" question of part 1.

(3) "Use displayed points?" This question has a yes or no answer. If the answer is yes, the cities currently displayed, complete with their demographics, are input to the proble m. This provide s a closely couple d link betwee n the data manag ement capabil

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(4) "Use fixed costs?". If there is fixed cost to establish a site, it may be included in the calculation of the solution, in addition to the variable transportation cost. This question is asked only if the "Use displayed points?" is answered with "no".

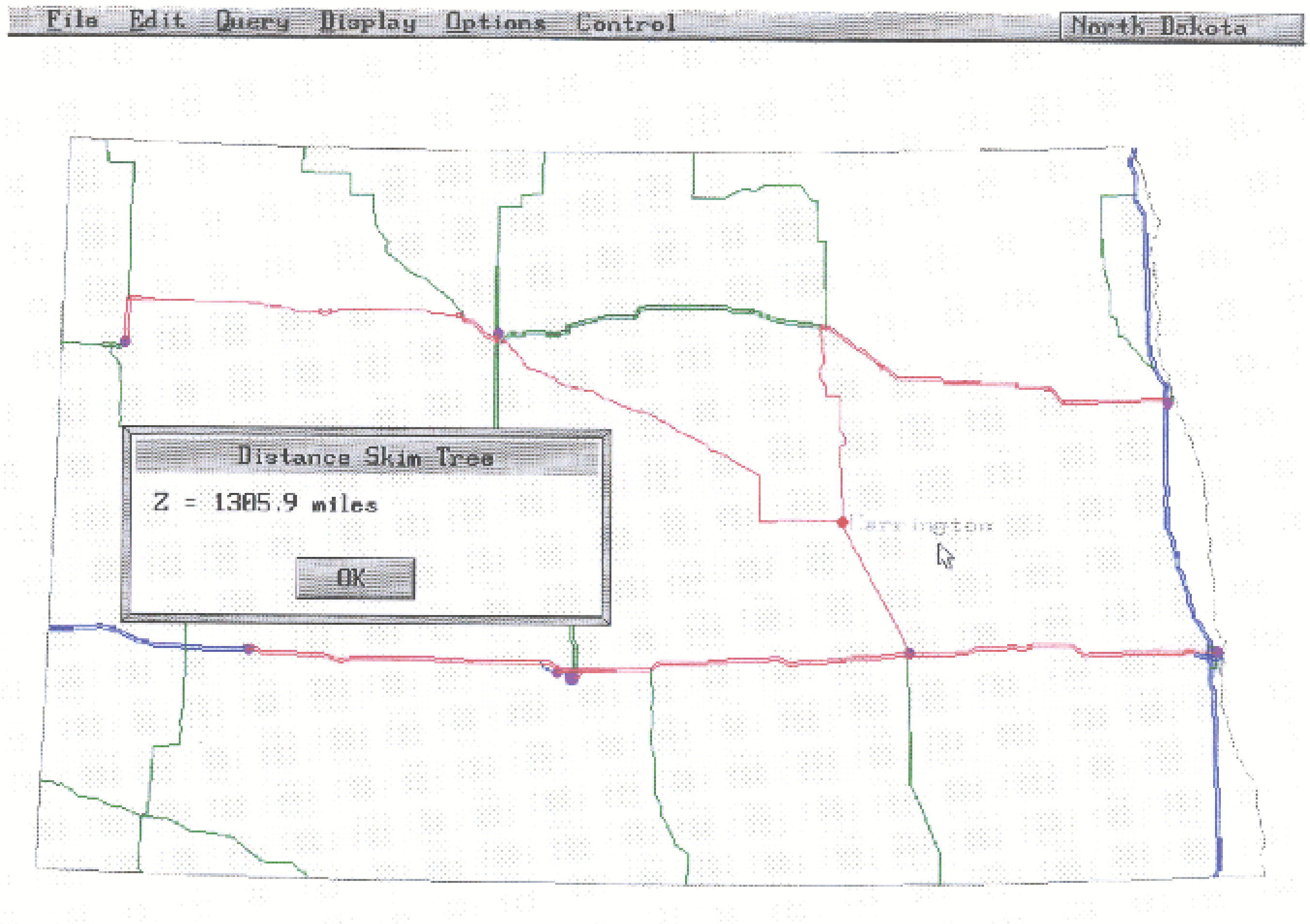

Figure 9. A skim tree from Carrington to all county seats that have a population greater than 10000. The route, shown in red, is constrained to the Interstate and U.S. highway network.

(5) "Cents per mile". If the "Use fixed costs?" question is answered "yes", then the calculation uses this as the variable cost in the model. If the "Use displayed points?" question is answered "no", then the user must click on each of the candidate sites with the left mouse button directly. For each of these selected candidate sites, it is required to "Enter demand" for the site. If the "Use fixed costs?" question is answered "yes", it is also necessary to enter "Site fixed cost". To terminate the process of adding candidate sites, the right mouse button is pressed. The model will then solve the problem. Facilities to be established will be highlighted and paths will be displayed to any other sites they should serve. A window will be drawn to give numerical details of the solution. In Figure 10, an example solution to 1 14-median problem over the entire state of North Dakota is shown. In the Figure, all of the colored dots are cities were initially eligible to be one of the final l4 facilities. The larger red dots are the optimal sites, calculated by the algorithm. The smaller dots are sites that were not selected, and the shortest path to the nearest median site is highlighted in red.

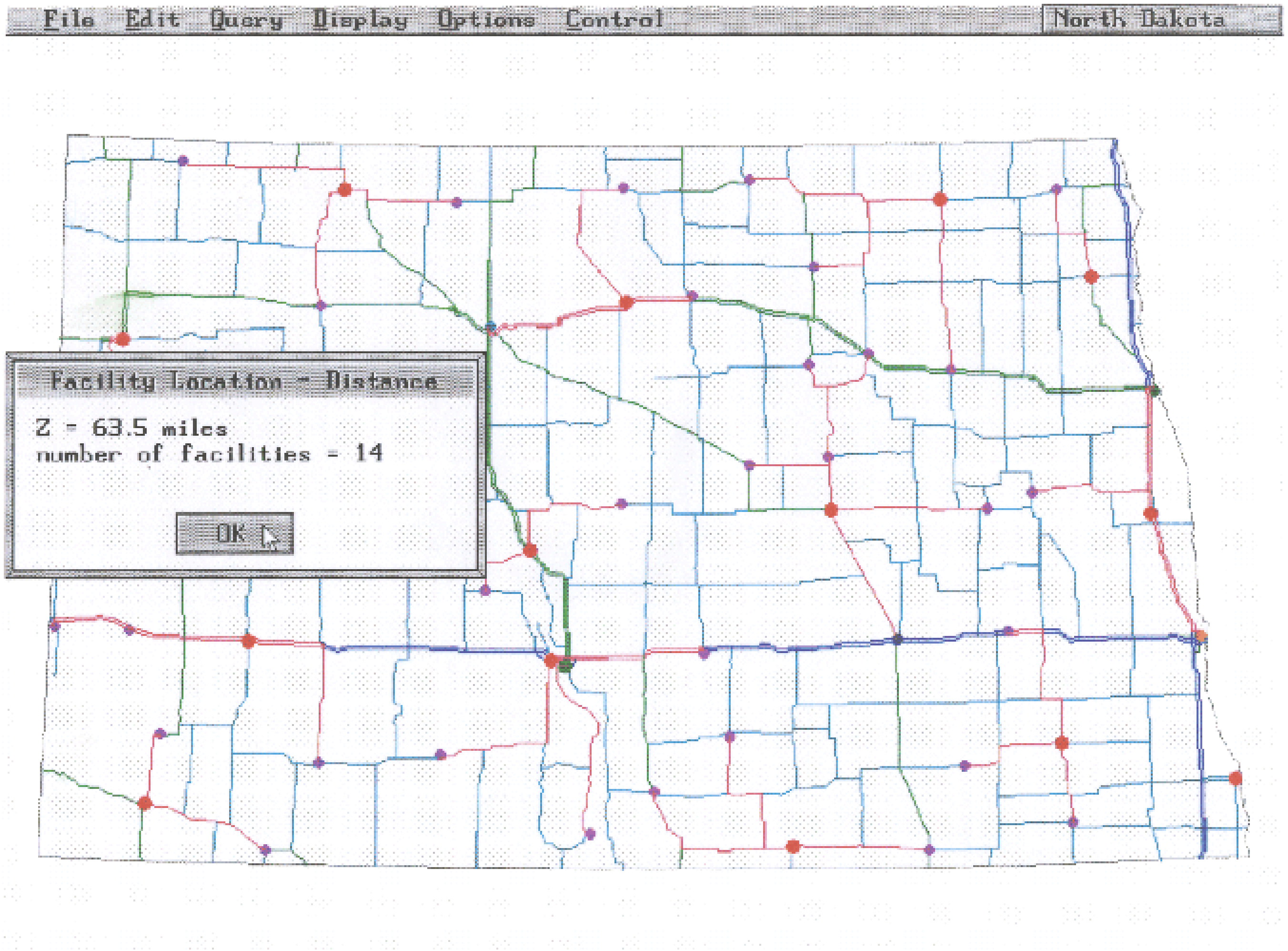

Figure 10. A solution to a p-center facility location requirements problem. Facilities to be established are shown as red dots. Sites they serve are connected to them by red lines.

The mathematical problem of finding a complete tour that visits a set of sites and returns to the site of origin is known as the traveling salesman problem (tsp). Although easy to state and intuitively appealing, the tsp is pro-potypical of a class of mathematical problem that are extremely difficult to solve in practice. A procedure for generating tsp solutions was developed and is supported in GEOTRANS. Figure 11 shows an example solution. To illustrate the data handling capabilities in GEOTRANS along with the modeling, the solution in Figure 11 is calculated over a set of locations that were first generated with an algebraic formula. In particular, the set of cities that had a population decrease from between 40% and 50% between 1980 and 1990 were generated first. A tsp tour was then generated over these selected cities, again illustrating the tight coupling between the data handling and mathematical modeling capabilities in GEOTRANS.

The GDSS is able to handle many network flow optimization problems through the use of a capacitated transshipment problem (CTP) solver. The CTP is a relatively general model that subsumes several other classical optimization problems, including uncapacitated transshipment, generic transportation, assignment, maximal matching, and a host of others. After selecting the "Network Flow" model, the user is prompted to enter the name of the units used to measure the commodity that flows through the network. Supply locations are selected with the left mouse button. The user is prompted to enter the supply value for each location. The process is terminated by pressing the right exceed total supply. Demand sites are entered in a similar fashion. Clicking the right mouse button terminates the input process. An underlying primal simplex solver specialized for the CTP is invoked to generate the optimal solution. After solution, a graphical display shows which supply sites will serve which demand sites at optimality. A window with numerical details of the solution is also displayed. The flow on an individual road segment can be retrieved using the "Query|Identify|Road selection, followed by picking the road segment of interest. An example solution to a capacitated transshipment problem is shown in Figure 12. In this example, there are two supply centers, with supply values of 900 and 1068 units respectively. The figures could be per unit of time for some

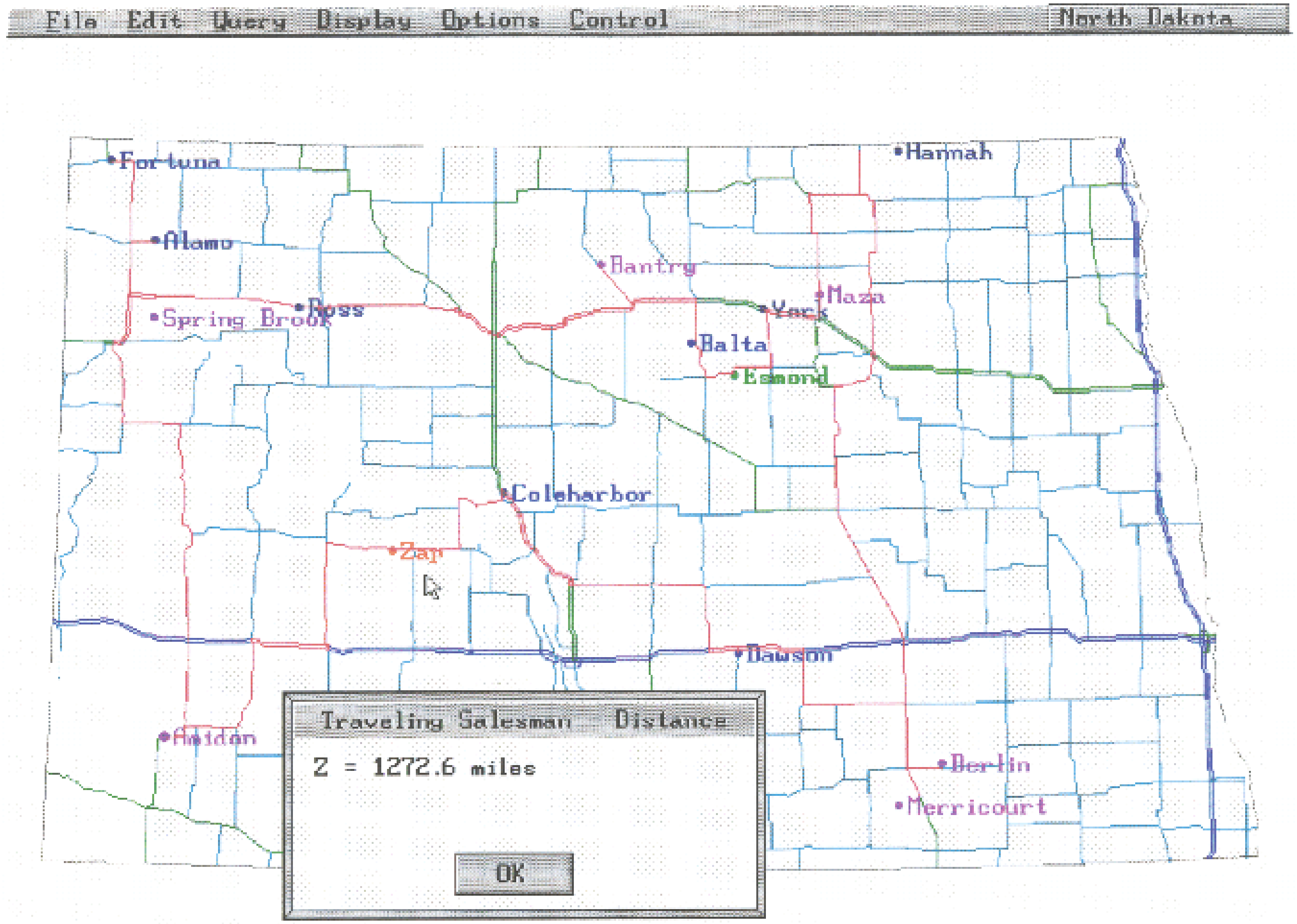

Figure 11. A solution to the problem of finding a minimal distance route connecting all cities that had a population decrease from 40% to 50%. The route is shown in red.

applications. The graphical solution highlights the road segments that would be used to transport the commodity to demand centers around the state. Again, an algebraic specification was used to manage the data, and define the set of demand center sites to consider. Figure 13 shows a zoom into an area of special interest for the solution. A particular road segment has been selected, is shown highlighted in red, and a reporting box appears with the relevant information provided to the user. Capacitated transshipment solutions obtained in this way can also be used to evaluate hypothetical supply and demand center configurations, and if effect be used as a facility location tool as well.

There are features in GEOTRANS that allow easy on-screen editing of maps. This is done by choosing the map object type to edit under the "Edit" menu. Another menu then appears, listing the available edit actions. An action is chosen, followed by choosing a map object to edit. Available actions include "Add" to create a new object, "Move" to place an object in a new location, and "Data" to input a set of supply values for the available demographic fields of the selected object.

The "Road" option allows editing of road segments, which have several data fields that can be altered. When editing any of these fields, there is a prompt calling for an answer to an "Adjust both directions?" question. GEOTRANS stores each road segment as two directed arcs, allowing for different parameters to apply in the different directions. A "yes" response to the question above will change both arcs to the new value which will be entered. Otherwise, only the first of these two arcs in mouse click order will be adjusted.

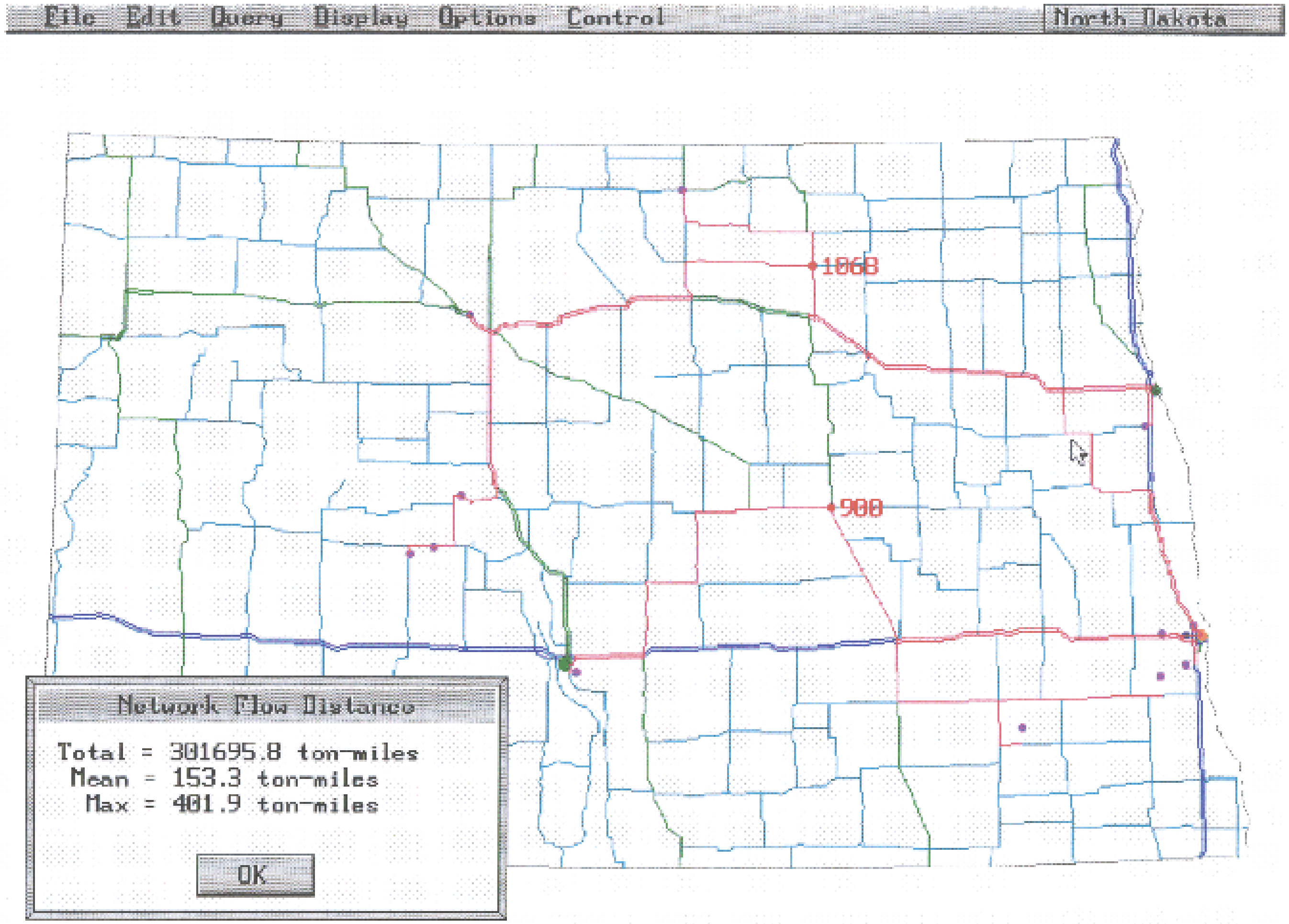

Figure 12. The solution to a network flow problem. Move units from the 2 supply centers to all cities that have a population greater than 100 and population increase greater than 10%.

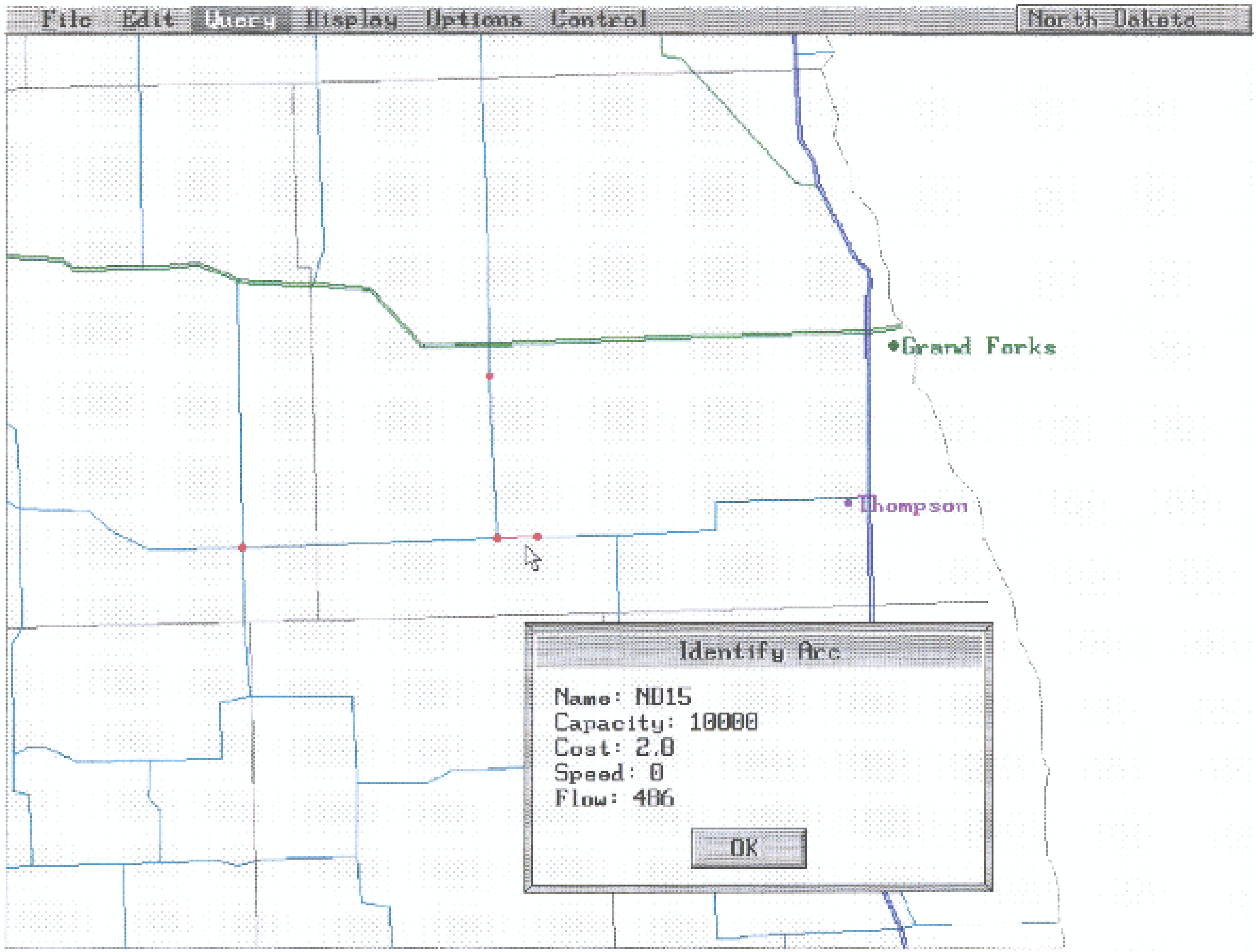

Figure 13. Identify a road segment used in the problem of figure 12. Note the flow on this arc.

The capacity of a link is used by the "network Flow" and "Shortest Path" options under the "Query" menu item. When a weight is entered. "Cost" is either the distance or time to traverse the segment. Each road segment can have a unique speed limit entered by the user. Entering a "0" means that the default speed limit defined in the "Speed" option under "Control" for this road type will be used.

Adding and combining areas is more involved than other editing. An area is composed of a series of border points. So adding a new area requires selecting border points. This is done by clicking with the left mouse button, with the right mouse button indicating the end of the sequence. The area is then automatically enclosed. The name and type of region is entered, and a left mouse click within the region enters new item into the database. The last step is to enter the values for the region's demographic fields.

The "Combine" option is used to merge areas. The first step is to select the type of regions to combine. This is followed by left mouse clicks to select the areas to combine. Areas being combined must have at least two adjacent border points in common. A right click terminates the process. The name and type of the new region is entered, followed by a left click on its center to finalize the process. The demographic field values of this new region are calculated to be the sum of the respective values from each of the combined areas. If the type of the new region is the same as that of the areas which were combined, the old regions will no longer be displayed. However, the old areas can be recovered by deleting the new region using the Remove option within the Area option under Edit.

When a map have been edited, the user is prompted as to whether the new map should be saved before exiting the program or loading another map. Note that a map can be saved at any time by using the Save option under File. Each time a map is saved, the user must provide a name for the new map file. Name of up to eight characters are supported. The file extension "map" is automatically added to the name. GEOTRANS checks for a name conflict, and prompts the user to verify that an old name should be overwritten before so doing.

It is also possible to create a new map on the screen. Using the New option under File enters an environment in which the user is asked for the new map name, the number of demographic fields and the names of each of these fields. Map objects can then be added by using the regular editing functions.

It is often desirable to obtain a printed copy of a map. For this purpose, GEOTRANS can produce files which are readable by Postscript equipped printers. To print a map, select the Print option under the Control item. The user must supply a name for the Postscript output file. The file is automatically supplied with the extension "ps". Such files can be printed after exiting GEOTRANS by directing them to the postscript printer. When the Print option is active, the Auto Redraw option under Control is switched off. This means that the map will not be redrawn unless the user explicitly selects the Show option under Display. The Auto Redraw feature can be used at other times, such as retaining the retaining the output from models on screen; selectively adding labels; and finding cities within regions.

APPENDIX

TECHNICAL INFORMATION

GEOTRANS was developed in a DOS environment to allow the software to be widely available to many users. Input data is used to describe geographical features like road networks and region boundaries, as well as demographic information. The data sets are often quite large, and data structure choices were of great concern. To ensure efficient retrieval of information and solving of problems within DOS, a virtual memory manager was used to ease computer memory addressing constraints. Thus, within the system, data can be paged into the DOS addressable area when needed, and reside in extended memory or disk when not required.

Data is furnished to GEOTRANS through the use of a digitizing tablet or through files that have been externally created.

The minimum system requirements to run GEOTRANS are a 386SX processor, Math co-processor, 2 Megabytes of RAM, with 1 Megabyte configured as extended or expanded memory, a VGA monitor, and a Mouse.

File formats for GEOTRANS maps are as follows:

Map name

Number of demographic data fields

Demographic data field names

Number of cities (one more than the actual number of cities)

For each city:

Kind

X coordinate

Y coordinate

Adjacent highway node

Demographic data

Name

Number of regions (one more than the actual number of regions)

For each region:

  Kind

  X coordinate

  Y coordinate

  Vertex list pointer

  Adjacent highway node

  Demographic data

  Name

Number of vertices

For each vertex:

  Coordinate pointer

    Number of coordinates

For each coordinate:

  X component

  Y component

Number of highways

For each highway:

  Kind

  Name

Number of highway nodes

Number of highway arcs

For each node:

X component

Y component

For each arc from this node:

Node index

Highway index

For each arc with a specified speed:

Arc index

Speed

0

For each arc with a specified capacity:

Arc index

Capacity

0

Number of highways

For each highway:

Kind

Name

Number of railway nodes

Number of railway arcs

For each node:

X component

Y component

For each arc from this node:

Node index

Railway index

For each arc with a specified speed:

Arc index

Speed

0

For each arc with a specified capacity:

Arc index

Capacity

0