Geographic Information Systems: An Important Technology for Transportation Planning and Operations

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A Geographic Information System (GIS) is a computerized data base management system for the capture, storage, retrieval, analysis, and display of spatial (i.e., locationally defined) data. The purpose of this paper is to explain why GIS technology is important to transportation professionals, describe how a number of transporation agencies are using GIS, and provide insight on how to participate in this technology. Transportation agencies are still in their infancy with respect to exploiting the power and possibilities offered by GIS technology. The usefulness of spatially integrated data to transportation is examined and the distinction is made between GIS and other data base systems that use spatial data. The benefits of GIS are summarized, and examples of GIS activities at the FHWA and state highway agencies are described. Sources for digital geocoded data, including U.S. Geological Survey digital line graphs and Bureau of the Census topologically integrated geographic encoding and referencing files, are discussed.

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THE ROLE OF SPATIALLY INTEGRATED DATA IN TRANSPORTATION

Spatial considerations are fundamental to most transportation activities. A transportation system consists of nodes, links, and entities distributed in two- or three-dimensional space. Events happen within this system at a point (an accident or a signal location), along a segment (vehicle volumes or pavement deficiencies), or within a geographical area (the number of people living within two blocks of a bus stop or working in an industrial park).

The collection of highway-related data involves a wide variety of activities: traffic counting, sign inventories, skid-resistance measurements, photologging, accident investigation, recording of construction and maintenance projects and funding, right-of-way surveys, inventories of signs and roadside obstacles, bridge inspection, rail-highway crossing inventories, speed monitoring, pavement condition surveys, geometric design inventories, and other data-collection and maintenance activities. Unfortunately, these various data files within the same transportation agency are typically unrelated to each other, duplicative, and inconsistent.

An integrated highway information system, on the other hand, is a system for collection and storage of highway-related data in such a way that data from different sources that apply to the same point on, or section of, a highway are correlated or linked (*1*).

Because transportation-related data always have a spatial component, the most natural way to associate elements from different data sets is through a consistent spatial referencing system. GIS technology can provide the core of a framework for an integrated highway information system (*2*). As far back as the Roman Empire, highway referencing systems have been used to locate roadway features. Popular systems include milepost, reference post, and paper document methods (*3*). More recently, states have begun incorporating georeferencing systems such as state plane or latitude and longitude coordinates into their data bases.

The following examples illustrate the importance of using a consistent georeferencing system:

- In addition to the data on the drivers involved in an accident, accident analysis requires the correlation of a number of explanatory roadway and environmental variables, such as pavement condition, roadway geometrics, weather conditions, traffic volumes, signage, signalization, and lighting. It is important to observe these variables at both high and low accident locations to determine causality. An easy way to associate these variables is through a common geographical referencing system.
- Transportation-demand modeling makes use of population and employment statistics that have been collected for small, homogeneous areas such as census tracts or traffic analysis zones (groups of census blocks). Trip productions and attractions are developed for these analysis zones, and vehicles or person-trips are assigned to each link in the transportation network. The results of the analysis might be summarized by link, transportation corridor, analysis zone, city, county, or region.
- A pavement management system records the construc-

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tion and maintenance history as well as the condition of roadway segments and assists decision makers in selecting appropriate treatments for deficiencies. Typically, the roadway condition and treatments are printed in tabular form, and it is up to the highway engineer to transfer this information to a base map by hand as a first step in developing actual projects. A map-based interface and geocoded data would greatly facilitate the process of data entry and project development and scheduling. It could also be used to produce any number of statistical reports (such as the number of deficient miles in each jurisdiction) and graphical outputs indicating the condition of the network and the scheduling of projects. These products could be easily comprehended by the engineers, politicians, and citizen groups. Projects could be scheduled to have minimal impact on flow through the network if demographics and journey-to-work data were included in the system. User costs resulting from delays could be determined.

One would assume that agency-wide spatially related data bases would have become commonplace. Unfortunately, this is not the case. Although all state Departments of Transportation (DOTs) use some form of referencing system, the system may not be consistent throughout the organization. Files for different data groups may have been created independently of one another, using different referencing systems or computer formats. In the worst case, some of the data required for analysis may not be spatially referenced at all. Relating the files to create an agency-wide data base has proven to be difficult and costly. Yet, in order to perform meaningful analyses of a transportation system, it is imperative that these different data elements be linked by a common reference framework.

CHARACTERISTICS OF A GIS

Although the integrated data base systems being implemented by the state DOTs represent major improvements in data base design, in most cases the data are not referenced to a geographical coordinate system (e.g., latitude and longitude or state plane coordinates). Rather, integrated data base systems are tied to the traditional milepoint or reference point systems. Therefore, these systems do not provide the data necessary for most spatial analyses.

By contrast, the sophisticated data base engine in a GIS has the ability to associate and manipulate diverse sets of spatially referenced data that have been geocoded to a common referencing system. To permit this it might be necessary, for example, to use software that transforms state plane coordinates and milepoint data to latitude and longitude. A GIS is capable of topological operations; that is, it understands how elements contained in the data base are related to each other spatially and it can perform spatial manipulations on these elements.

A GIS contains two broad classifications of information, geocoded spatial data and attribute data. Geocoded spatial data define objects that have an orientation and relationship in two- or three-dimensional space. Each object is classified as either a point, a line, or a polygon and is tied to a geographic coordinate system. These objects have precise definitions and are clearly related to each other according to the rules of mathematical topology.

In addition to the topological information, a GIS contains the same attribute data that is found in traditional data bases. Attributes associated with a street segment might include its width, number of lanes, construction history, pavement condition, and traffic volumes. An accident record could contain fields for vehicle types, weather conditions, contributing circumstances, and injuries. What distinguishes a GIS from a traditional data base is that this attribute data is associated with a topologic object (point, line, or polygon) that has a position somewhere on the surface of the earth.

BENEFITS OF A GIS

A GIS can lead to new ways of thinking about and dealing with old problems. Because the data is tied to a common referencing system, it is easy to use the same data across applications as well as to associate diverse data sets previously unavailable for joint analysis. Topology permits new questions to be asked and encourages a new style of analysis that is in many cases fundamentally better than those used traditionally.

Because it permits the use of spatial relationships, a GIS adds a degree of intelligence and sophistication to a transportation data base that has previously been unknown. For a segment (a line) on a road network, a GIS system knows what routes (other lines) cross it and whether there is an actual physical intersection. It knows the position of roadside features (points) along the segment; and can tell which census blocks (polygons) are to the right and the left of the segment or within any distance of it.

Rather than being limited to textual queries, it is now possible to perform geographic queries in a straightforward, intuitive fashion. For example, a GIS with the appropriate algorithm and data can easily compute and display the route that will result in the minimum population exposure to a shipment of hazardous materials. With the route drawn on the computer screen, the analyst can see immediately how the logic of the model has bypassed certain population centers. The analyst can create a detour by pointing to a road segment and "deleting" it from the network and then watch the algorithm redraw the path. Similarly, the analyst can ask a series of geobased questions and obtain the answers quickly in an easy-to-understand color-coded display on the screen, hard copy, or disk file. Two examples are the number of low-income residents living within two blocks of a bus stop and the total employment within each traffic analysis zone.

COMPUTER-AIDED DESIGN AND DRAFTING, MAPPING, AND GIS

There are a number of very useful tools available to the transportation professional that, at first blush, might be mistaken for a GIS. However, there are fundamental differences that should be understood. For example, a transportation demand model that has for an interface a graphical representation of a network is not a GIS. Rather than being built on a flexible data base engine, these models use a rigid file structure suitable only for the task at hand. The network, although displaying a graphical abstraction of the nodes and the links, is lacking in topology (spatial relationships).

Computer-aided design and drafting (CADD) systems have revolutionized the cartographic process within most state DOTs. They are used to produce map products nearly as elegant and sophisticated as those drawn by the most experienced cartographer. Line widths, shadings, colors, and symbology can be changed electronically in an instant, and productivity has been greatly increased [for a complete discussion of computer assisted cartography, see (*4*)]. However, at nearly every state transportation agency, this CADD mapping activity is not producing a GIS.

Dueker (*5*) makes clear the distinction between GIS and computer-aided mapping (CAM). He points out that the two terms are often used interchangeably, but they should not be. A CADD mapping system lacks at least one essential ingredient, topology. Each theme (e.g., interstate highways, state routes, or county boundaries) is drawn on its own electronic layer. This is physically equivalent to creating a set of transparent mylar overlays. The observer can see where an interstate and a state route cross, and might even be able to ascertain that there is an interchange at this point, but the computer system has no knowledge about this intersection. Most CADD systems probably can't even specify a route from point A to point B on the same road. The geometry is present, but the topology and network connectivity is missing.

Without topological intelligence, spatial analysis is difficult, if not impossible. For example, determining the number of dwelling units or the length of a roadway within a bounded area like a transportation analysis zone requires both geometric manipulation and appropriately structured data, which most CAM systems do not support.

GIS is a tool whose applications are limited only by the sophistication of the hardware and software, the quality of the data, and the imagination of the users. The following two sections summarize some of the GIS activities on-going at the FHWA and the state DOTs that illustrate the usefulness of this technology.

GIS ACTIVITIES AT THE FEDERAL HIGHWAY ADMINISTRATION

The FHWA Office of Planning has worked closely with the Bureau of the Census, the U.S. Geological Survey (USGS), the City of Columbia, and the Caliper Corporation in a project to assess the applicability of the Census topologically integrated geographic encoding and referencing (TIGER) file for transportation planning and analysis. A number of data sources are used in the demonstration: TIGER/Line file for Boone County, 1980 census data, Urban Transportation Planning Package (UTPP), and accident records and sign inventory compiled by the Columbia Department of Public Works.

The effort clearly illustrates the usefulness of the TIGER/Line file to solve transportation problems. A number of transportation-specific applications of GIS are demonstrated:

- A connected transportation network is built from TIGER/Line;
- The shortest path and traffic assignment are computed for this transportation network;
- Demographic characteristics are displayed and analyzed by census tract and traffic analysis zone; and
- An accident analysis system prototype making use of spatial relationship between accidents and traffic signs is developed.

TransCAD GIS software, developed by the Caliper Corporation, was used for the project. Some results are illustrated in Figures 1 to 5. Figure 1 is a portion of the road network from the TIGER/Line file. In Figure 2, population data from Census tape STF2 has been associated with tracts built from the TIGER/Line file. The tracts are then grouped by population, color coded, and labeled. In Figure 3, accidents and signs have been geocoded by latitude and longitude and are displayed as a layer over the TIGER/Line road network. As with all other objects in the data base, the accidents and signs have a large number of attributes associated with them such as drivers' ages and type of sign. TransCAD permits traditional SQL (Standard Query Language, developed by IBM) and boolean queries such as, "find all accidents within two miles of a high school involving male teenagers who have been drinking." Because it is a GIS, it is also possible to perform spatial queries such as finding all signs within 50 ft of an intersection that is going to be rebuilt or all accidents along a certain stretch of highway.

In Figure 4, a portion of the TIGER/Line road network has been converted to a connected transportation network and the shortest path computed between two points. The origin is assumed to be a retirement home and the destination a shelter. The purpose of the computation is to develop an evacuation route in case of a chemical spill at a factory near the retirement home.

The result of performing a traffic assignment as part of the four-step transportation planning process is shown in Figure 5. The assignments (link volumes) are shown as double bandwidths along the links in the regional network. The bandwidths are proportional to the actual vehicle loadings.

The FHWA Office of Planning has sponsored the development of the Geographic Roadway Information Display System (GRIDS). GRIDS is an interactive microcomputer program that accesses and displays data about the U.S. Interstate highway system. GRIDS produces a map of a state using data associated with state and county boundaries, city location and population, and interstate highway road sections. The GRIDS database is a subset of the data contained in the Highway Performance Monitoring System (HPMS) data base. This information can be displayed in various formats. It is possible to produce statistical summaries, pie and bar charts, and highlight highway sections with certain characteristics in distinctive colors. This concept could be expanded to meet many of the State's transportation data analysis needs.

The FHWA Office of Policy has developed a Highway Traffic Forecasting System (HTFS). The HTFS is a specialized decision support system that is designed primarily to analyze truck size and weight issues. It can also be used to analyze a wide variety of other policy issues that affect the highway network. The current model uses a simplified representation of the national Interstate highway network. Routines generate freight traffic and assign it to the network. The network uses Bureau of Economic Analysis regions as nodes with single link inter-

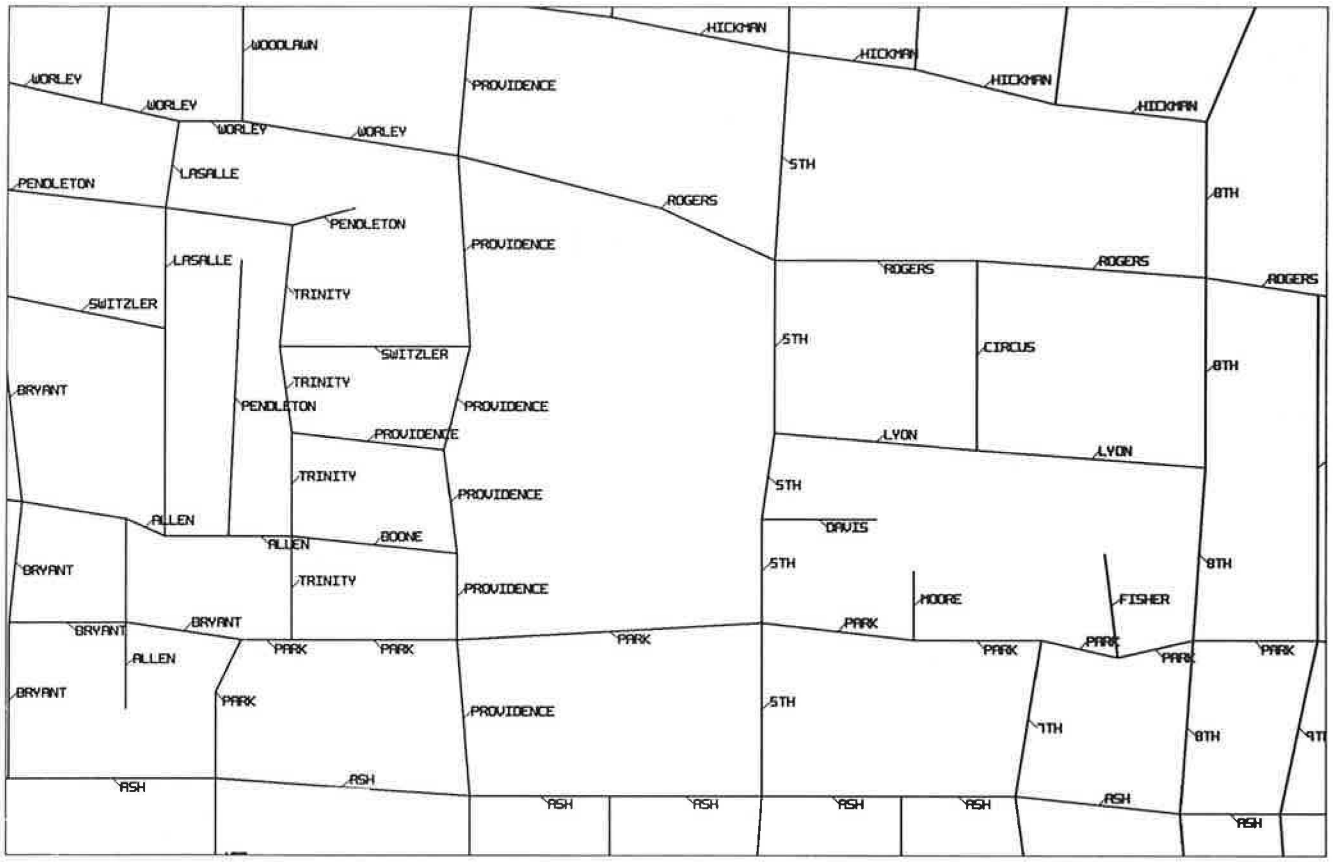

FIGURE 1 Boone County TIGER file—road network.

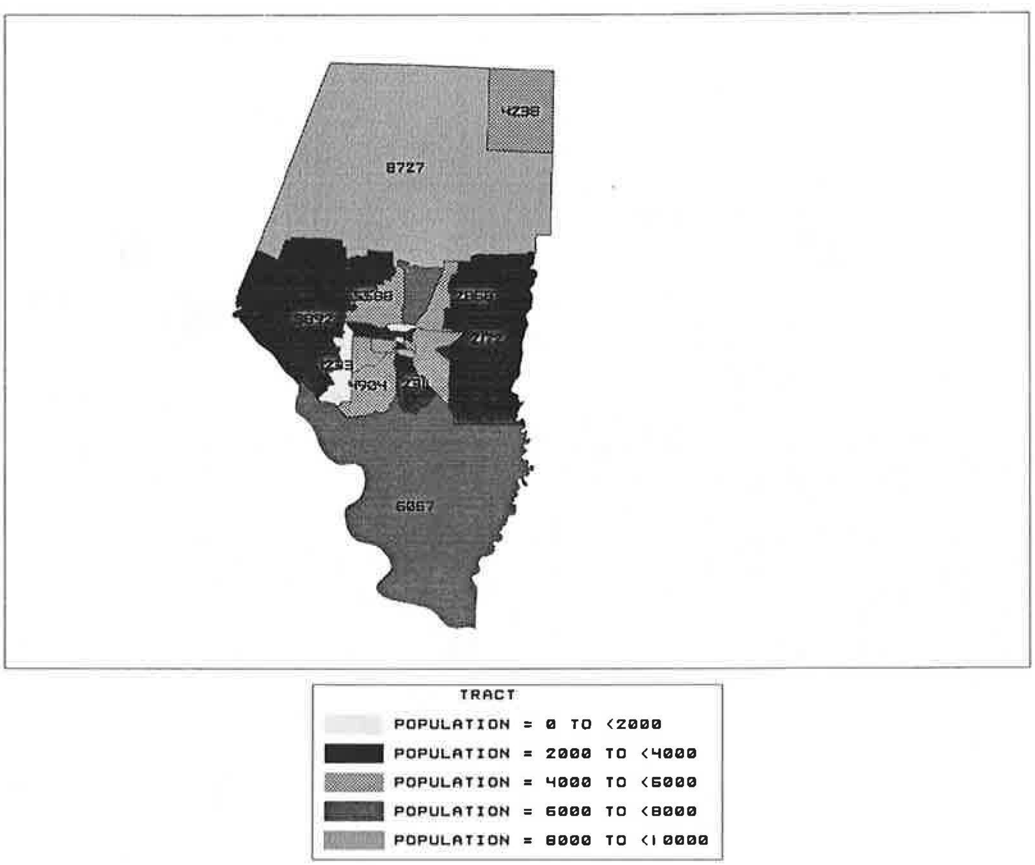

FIGURE 2 Census tracts grouped by population.

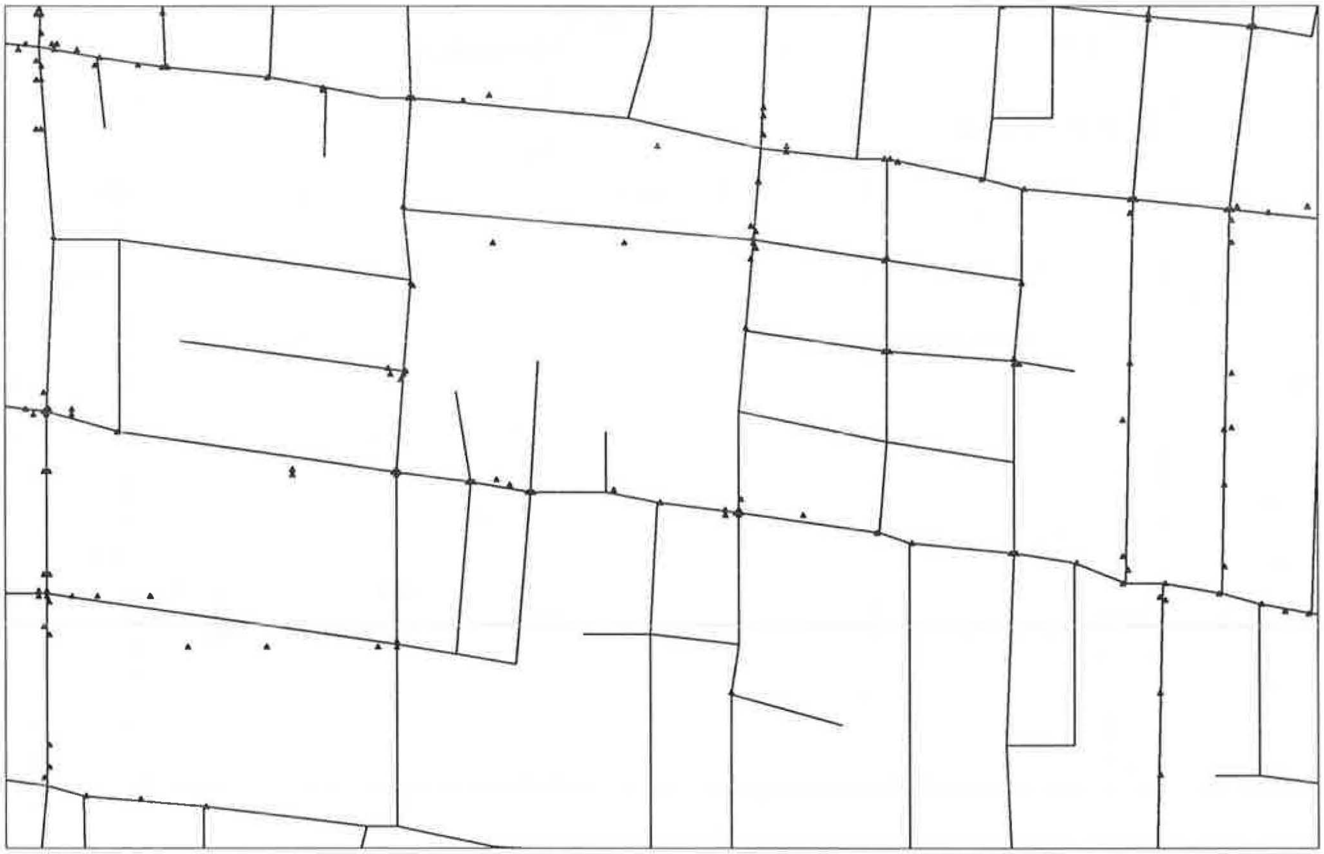

FIGURE 3 Accidents and signs geocoded to TIGER file.

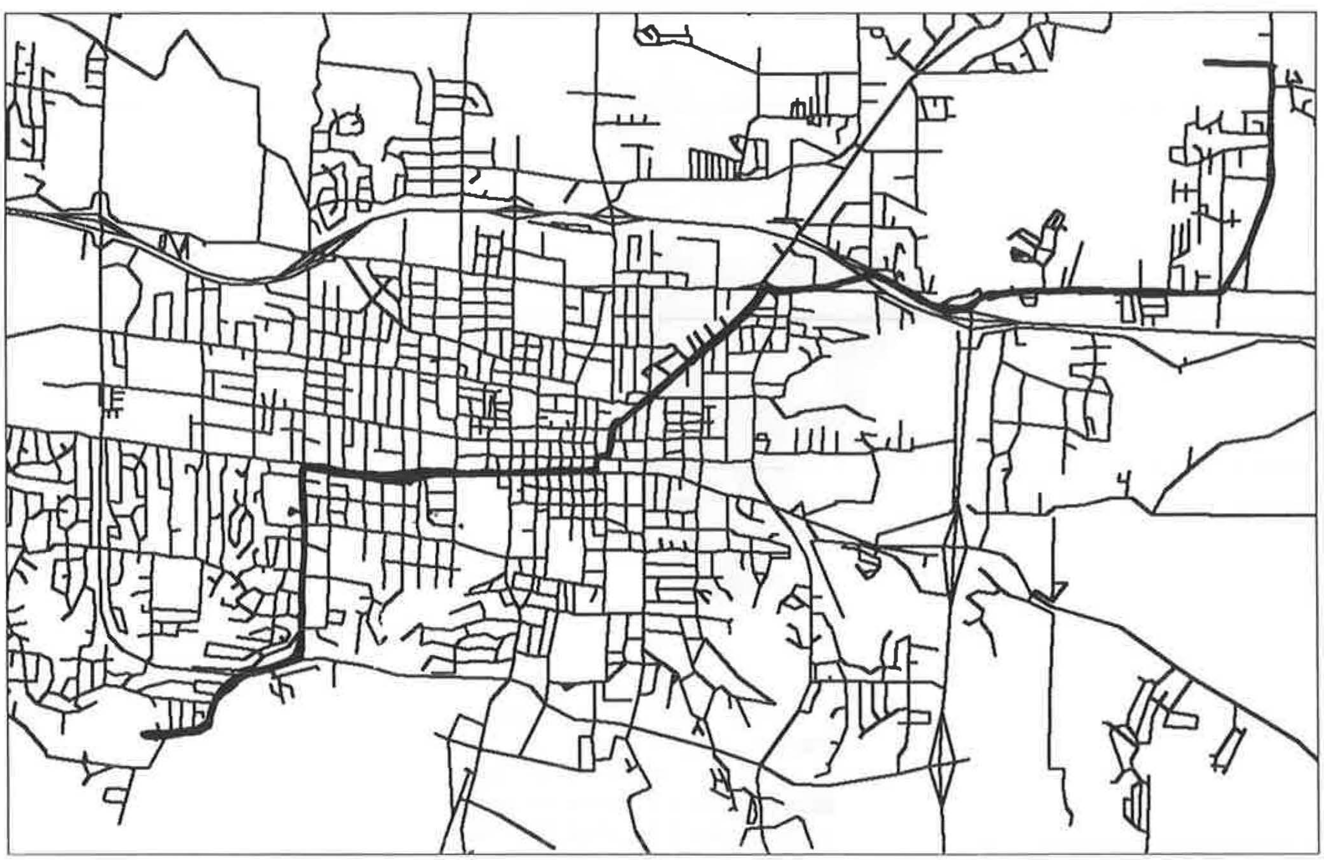

FIGURE 4 Shortest-path evacuation route.

FIGURE 5 Traffic assignments shown as dual bandwidths.

connections. The current network model generates a relative distribution of Interstate (long-haul) freight traffic among 10 geographic regions. When truck size and weight regulations change, the distribution of traffic among vehicle types and regions will also be changed by the model. The model is being converted to run on a microcomputer using Caliper Corporation's TransCAD GIS software (*6*).

The FHWA Office of Engineering and Highway Operations Research and Development is developing a nationwide databank of pavement research results (*7*). The mainframe computer model permits other geographically based nonhighway data, such as weather records, to be accessed for statistical and other analysis needs. The data base is designed to maintain compatibility with other current and proposed nationwide systems. Plans are to move the model to a microcomputer.

GIS ACTIVITIES AT STATE TRANSPORTATION AGENCIES

Several state transportation agencies are doing interesting research and development in the general area of GIS. This section summarizes a number of these activities.

Alaska—Integrated Highway Information System

Alaska's Highway Analysis System (HAS) is a mainframe data base of highway-related information and a collection of computer programs to process and analyze the data and to produce reports (*8*). The data base contains a number of files that had in the past resided on paper, personal computers, or in isolation on the mainframe. The HAS contains highway inventory, traffic, accidents, project history, HPMS, pavement conditions, bridges, signs, permit locations, right-of-way location information, and railroad crossings. HAS also contains information to integrate any of the above data to photolog and cartographic data bases. One interesting feature is that the user is able to choose the method most comfortable for "viewing" the data. A user can locate events on the roadway according to a route name and a milepoint from the beginning of the road, by a displacement (feet or miles) from a point (e.g., an intersection or a reference marker), by engineering station, or by state plane coordinate. This is made possible by using a common x,y,z coordinate georeferencing system.

Idaho—GIS Coordination Among State Agencies and the USGS

The State of Idaho has formulated a policy to encourage the use of GISs when such use enhances the overall cost effectiveness of administrative functions or improves productivity (*9*). It is the state's policy to acquire and support GISs through well-planned implementation strategies that include: (a) development and maintenance of data standards for base category data, statewide exchange data, and project data; and

(b) development and maintenance of contracts for state agency use covering the purchase of GIS software and hardware. To implement this policy, Idaho has established a statewide Geographic Information Advisory Committee that has responsibility for developing data standards for GISs and for overseeing GIS activities, including the purchase of GIS hardware and software. Idaho also has established a work share agreement with the USGS for the creation of the 7.5-min digital line graphs for the State.

Virginia and Tennessee—Feasibility of Using Global Positioning System in a Mobile Unit to Collect Roadway Data

The Virginia DOT and the Virginia Transportation Research Council have instituted a study to determine the feasibility of using a mobile unit at speeds of from 30 to 35 mph to collect selected roadway data on secondary, primary, and Interstate roads in Virginia using Global Positioning System (GPS). The study is designed to answer a number of questions related to the feasibility of using GPS: (a) the rate of travel in the vehicle on the various types of roads as data are collected; (b) the accuracy of the collection of the roadway items (number collected versus actual number in place); and (c) the cost per mile to collect data on the various types of roads (*10*). The Tennessee Department of Transportation has conducted a similar study (*11*).

Wisconsin DOT—Integrating Photolog Data into a GIS

The Wisconsin Department of Transportation (WisDOT) has been using photolog to assist in the planning, design, and operation of the state highway system since 1975. The system creates 35-mm camera images every 0.01 mile (52.8 ft). It also collects horizontal and vertical vector displacements of the vehicle's bearing and slope and calibrates these numbers to the photographs. The photo images are transferred directly from the negatives to a video disk. Each disk can hold up to 24,000 frames or 240 miles of highway. A microcomputer controller allows interactive random access by either frame number or highway and log-mile. Search and scan capabilities are available, including the ability to advance the frames at simulated speeds. Any frame on the disc can be randomly accessed in less than 1 sec.

WisDOT has integrated the photolog with its GIS (*12*). It is no longer necessary for the analyst to know the appropriate log-mile. One need merely point to a map location, and the system will retrieve the correct image. This permits access to all data about a specific location in a coherent, logically integrated manner.

ADDITIONAL APPLICATIONS OF GIS TO TRANSPORTATION

The last two sections have discussed a number of ways that the FHWA and state transportation agencies are using GIS. This section presents some additional applications.

Bridge Maintenance and Management

The application of GIS to bridge maintenance and management provides opportunities similar to those for pavement management (discussed in the section on spatially related data). In addition, detailed drawings and inspection records of each bridge could be maintained on laser disk and accessed through the GIS.

Traffic Engineering

The FHWA has developed a number of sophisticated traffic optimization and simulation models. A GIS could be used as a front-end processor to a collection of these models. The GIS would handle all data entry, editing, and display, including the real-time display of traffic patterns.

Highway Safety

The applicability of GIS for accident analysis has previously been discussed. The technology currently exists to take GIS into the field. Police officers could enter accident reports directly into a lap-top computer. On country roads it is often difficult to pinpoint the exact location of an accident. If the officer could display a detailed map of the area, including sufficient shape points, on the computer screen, he or she could more easily identify the exact milepoint location and use the cursor keys or a mouse to record it on disk. The officer could also enter the side of the road, lane, or other locational information. In the future, it may be economically feasible for each patrol car to have its own GPS receiver for automatic geographic coordinate determination.

Relations with Public Interest Groups and the Legislature

A large part of the work performed by the planning office in a transportation agency involves preparing materials for presentation to the public or elected officials. A GIS that integrates the agency's data base will make this process considerably easier and less time consuming and will provide better organized information for these groups.

Transportation-Demand Modeling

Transportation-demand modeling has been discussed, in part, in the section on spatially referenced data. A few additional points should be made. Historically, transportation-demand modeling has required the tedious building of abstract travel networks involving large numbers of nodes, links, and population and employment centroids. This entire process, including the data creation and editing, algorithms to solve the travel demand estimation, assignment to links, mode choice, and display of results can now be accomplished within a GIS. A GIS will make it easier to perform subarea analysis and to modify the traffic analysis zone structure as required by the focus of each study.

Routing of Hazardous Materials

The shipment of hazardous materials involves a tradeoff between cost of shipment and exposure to population centers. A GIS with the appropriate optimization algorithms can be used to find the "shortest path" between two points, where "shortest" is some function of cost, population exposure, and risk. The GIS can then print out the route and suggest departure times to minimize the potential for traffic accidents. A GIS that combines road, rail, air, and water networks could provide even better solutions to this growing problem.

SOURCES OF DIGITAL CARTOGRAPHIC INFORMATION

A GIS requires digital data with geographic coordinates. Dildine (*13*) lists a number of methods to obtain geocoded data:

- *Use of existing digital data.* There are a number of files available from federal agencies and private providers. These include the USGS digital line graphs (DLGs) and the Bureau of the Census TIGER file. These files are described in detail in the next section.
- *Scanning.* Scanning is the process of electronically reading a map and converting it into a raster (point) image. Since a raster format can not represent a connected network, it must be edited, converted into a vector format of links and nodes through the process of vectorization, and edited again. This process is most successful when the map being scanned is drawn clearly and contains only one map feature.
- *GPS.* The Navigation Satellite Timing and Ranging System (NAVSTAR), more commonly known as Global Positioning System (GPS), is a satellite system being developed by the Department of Defense. Presently, six satellites providing positioning information are in orbit. This six-satellite constellation can be used for measurements only during a limited time each day. An 18-satellite constellation providing 24-hour coverage is expected to be fully operational between 1990 and 1992. These satellites will then provide very precise three-dimensional information on a continuous basis (*14*). Today the time window for collecting coordinates is limited to 4 hours per day because of an insufficient number of satellites. A further complication is that this window changes daily and may not occur during daylight hours. However, it is safe to assume that GPS will soon have a major role in surveying and mapping. This technology potentially offers at least a 6:1 increase in speed over hand digitizing.
- *Image Processing to Update Map Features.* In this process, a recent aerial photograph is superimposed over a GIS basemap. The operator is able to identify new features while the software identifies features that have changed. The operator then enters all modifications into the GIS.
- *Photogrammetry.* Photogrammetric techniques provide a high degree of accuracy, but they are not necessarily any more economical than hand digitizing. This technology could be used effectively for updating base maps (*13*).
- *Hand Digitizing.* Hand digitizing is the slowest method of inputting cartographic base data. It is an appropriate method when no potential for automation exists, usually because of poor source documents or when the project is small in scale.

DIGITAL DATA BASES FOR TRANSPORTATION

There are a number of excellent sources of digital data available to the transportation professional.

Digital Line Graphs

The USGS National Mapping Program produces a number of digital map products at large, intermediate, and small scales for the United States. The principal data source is the National Digital Cartographic Data Base (NDCDB). Currently, the NDCDB contains base categories of digital cartographic data that include: geographic and other coordinate reference systems, hydrography, hypsography, transportation, boundaries, miscellaneous culture, geodetic control, and vegetative and nonvegetative cover. In addition, geographic names and the land use and land cover and associated mapped categories of census tracts, political boundaries, hydrologic units, and federal and state land ownership are included in the NDCDB (*15*).

There are a number of digital products produced and sold by USGS. The DLG files are digitized layers for transportation and hydrography at 1:24,000 (1 in. equals 2000 ft), 1:100,000 (1 in. equals 1.5 miles), and 1:2,000,000 (1 in. equals 30 miles) scales. The DLG transportation data are composed of topologically structured link and node records depicting the roads and trails found on the source material. The 1:100,000 series is complete for the continental United States. The 1:2,000,000 series maps are complete for the the entire United States. The 1:24,000 scale maps are available for some locations. The 1:100,000 DLGs were prepared from source materials originally drawn at 1:24,000 scale. They contain attributes that describe the road classes, but character fields (such as street names) are not supported. A major use of the 100,000 DLG is in the Bureau of the Census' TIGER file (*16*). Other products include digital elevation models at 1:24,000 and 1:250,000 scales and land use and land cover at 1:100,000 and 1:250,000 scales.

The 1:2,000,000 scale is too small for most state transportation purposes. By contrast, the 1:100,000 and 1:24,000 DLGs offer sufficient detail for most applications. However, to use the DLGs, a number of complex operations must be performed. First, the individual quads must be edge matched to join corresponding links. Next, routes must be identified and names assigned to the links. Finally, attribute data in the agency's data base, which is probably referenced by milepoint, need to be attached to the DLGs that are geocoded in latitude and longitude. Because of the large amounts of data involved, these steps should be automated using sophisticated software.

Since the 1:100,000 DLGs are available for the 48 contiguous states, they provide a quick and inexpensive way to build a GIS. As the 1:24,000 DLGs become available, they could be substituted for the corresponding smaller-scale data.

Census TIGER Files

As part of its preparation for the 1990 Census, the Bureau of the Census, in cooperation with the USGS, has been building a topological file containing every street and block face in the

United States. The availability of TIGER could be important in how transportation agencies, particularly those with a local or regional focus, establish GISs. [For a more detailed discussion on using TIGER for transportation purposes, see (*17*)]. The GBF/DIME files used in the 1980 census have been edited to remove topological errors (e.g., block boundaries are now guaranteed to achieve closure). These have been merged with USGS 1:100,000 scale DLGs (topological map files) for all areas of the country not covered by GBF/DIME. The result is a seamless, nationwide data base that will provide the foundation for the 1990 decennial census (*18*).

The transportation data in TIGER is derived from the following three sources:

1. GBF/DIME—within urban areas previously covered by DIME data; not quadrangle based;
2. Extended DIME—new files created by the Census Bureau to extend their DIME data to the nearest 7.5-min quadrangle border; and
3. 100,000 DLG—all remaining areas (*16*).

The first product of use to the transportation community is the TIGER/Line file, an extract of selected information from the TIGER file data base organized as a topologically consistent line network. Each street or block side (including selected nonstreet features) is coded as a separate record in the TIGER/Line file. Associated with each record are the census geographic area codes found to the left and right of the feature segment represented by the record, the name of the feature (including the relevant census feature class code identifying the segment by category) and, for selected areas, the address range and associated ZIP code of the street segment.

The TIGER/Line file contains record types that identify segment records, shape records, selected 1980 geographic area codes, and additional feature name and address information applicable to the segment. The shape records provide coordinate values that describe the shape of the segment. Generally, shape records will be available in areas outside the area covered by the 1980 GBF/DIME files. The Census will make TIGER/Line files available on a county basis (*19*).

CONCLUSIONS

Transportation agencies are still in their infancy with respect to exploiting the power and possibilities offered by GIS technology. I have attempted to explain GIS from the point of view of the needs of the transportation professional. Examples of GIS undertakings by FHWA and the states have been described along with a summary of sources for digital geocoded data. These examples show there is no shortage of opportunities to apply GIS technology to transportation problem solving.

However, there are a number of difficult questions that will have to be answered along the way. How does the GIS relate to the agency's mapping activities? Can an existing cartographic data base, such as the DLGs, be used? Is there an easy way to link milepoint-referenced attribute data to the coordinate-based GIS? How is this enormous quantity and diversity of data kept up to date? How is the issue of network overlay dealt with so as to minimize data redundancy but not lose necessary detail? What should be the structure of the computer environment?

With the attention that GIS is currently receiving by the transportation community, it seems certain that these questions will soon find answers. As computer hardware continues to become less expensive and more powerful, and as the software continues to grow more sophisticated, cost-effective GIS-based solutions to traditional transportation problems will become more and more common within the transportation community.

REFERENCES

1. D. W. Briggs and B. V. Chatfield. Integrated Highway Information Systems. *National Cooperative Highway Research Program Synthesis of Highway Practice No. 133.* TRB, National Research Council, Washington, D.C., 1987.
2. T. L. Nyerges and K. J. Dueker. *Geographic Information Systems in Transportation.* Prepared for the FHWA, Office of Planning, HPN-22, Washington, D.C., 1988.
3. W. T. Baker et al. Highway Location Reference Methods, National Cooperative Highway Research Program. *Synthesis of Highway Practice No. 21.* TRB, National Research Council, Washington, D.C., 1974.
4. *Regional Computer Assisted Cartography Conferences Summary.* Cosponsored by the Pennsylvania Department of Transportation, the Washington State Department of Transportation, and the FHWA, Office of Planning, Washington, D.C., 1988.
5. K. J. Dueker. Geographic Information Systems and Computer-Aided Mapping. *American Planning Association Journal*, Summer, 1987.
6. R. R. Schmitt. *Geographic Information Systems and the Transportation Studies Division.* Internal memo, FHWA Washington, D.C., 1988.
7. D. M. Freund and C. G. Conley. *The Pavements Databank: A Research Application of a Geographic Information System.* Presented at the 25th Annual URISA Conference, Los Angeles, Calif., August 1988.
8. K. R. Fox. *Description of Alaska's Highway Analysis System.* Boeing Computer Services, Seattle, WA, 1988.
9. M. Sety. *Policy Statement for Geographic Information Systems for the State of Idaho.* Idaho Geographic Information Advisory Committee, Boise, Idaho, 1988.
10. D. C. Wyant. *Feasibility of Using Global Position System in a Mobile Unit to Collect Roadway Data.* Virginia Transportation Research Council, Charlottesville, VA, 1988.
11. W. Aldridge. FHWA, Tennesse Division Office, series of memos and reports.
12. D. Fletcher. *Integrating Photolog Data into a Geographic Information System.* Wisconsin Department of Transportation, Madison, WI, 1987.
13. G. Dildine. *Geographic Information Systems Task Force, Feasibility Report.* North Carolina Department of Transportation, Division of Highways, Raleigh, N.C., May, 1988.
14. NCHRP, *Kinematic Differential GPS Satellite Surveying.* Project No. 20-23, National Cooperative Highway Research Program, TRB, National Research Council, Washington, D.C., 1988.
15. U.S. Geological Survey, "Guidelines for Acceptance of Digital Cartographic Data into the National Digital Cartographic Data Base," Digital Cartography Program Office, Reston, Va., 1987.
16. L. Batten. *Geographic Information Systems Research Utilizing 1:100,000 Digital Line Graph Data.* U.S. Geological Survey, Reston, Va. 22092, 1988.
17. H. J. Simkowitz. *Using the Census TIGER/Line Files for Transportation Planning.* Presented at the National Conference on Effective Planning Techniques for Small and Medium-Sized Areas, Phoenix, Arizona, December 6–8, 1988.
18. R. A. LaMacchia, S. G. Tomasi, and S. K. Piepenburg. *The Tiger File: Proposed Products.* Geography Division, Bureau of the Census, Washington, D.C., 1987.
19. G. Boudriault. *Topology in the TIGER File.* Geography Division, U.S. Bureau of the Census, Washington, D.C., 20233.

Publication of this paper sponsored by Committee on Transportation Data and Information Systems.