Application of Geographic Information Systems to Rail-Highway Grade Crossing Safety

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The application of geographic information systems (GIS) is especially relevant to transportation-related fields because of the spatially distributed nature of transportation-related data. The application of GIS to the management of transportation data can result in reduced costs and time savings. The development of a GIS application for management of safety-related data for public at-grade rail-highway crossings in the state of Delaware is discussed. The objective was to develop a GIS application that would enable better management of safety-related data for rail-highway grade crossings by integrating data from various sources and referencing data to their actual spatial location on the base map. The GIS application enables analysis and interpretation capabilities such as visual access and display, spatial analysis, query, thematic mapping and classification, and statistical and network-level analysis. The work was a continuation of an ongoing project that resulted in the integration of rail-highway grade crossing safety data from various sources, such as the Federal Railroad Administration and the Delaware Department of Transportation into a data base management system and the selection and implementation of the U.S. Department of Transportation (USDOT) accident prediction model into the system. The development of the rail-highway grade crossing safety GIS application is described and the creation of the spatial base map; conversion of existing rail-highway crossings attribute data into a GIS acceptable format; the interface with the USDOT model; and the prioritization, query, manipulation, analysis and editing features of the GIS application are presented.

Developments in the rapidly changing field of information technology have resulted in the availability of better hardware and software, more computing power with faster processing speeds, higher information storage capacity, higher-level queries and operating systems, and more efficient communication of data. All of these advances, including better graphics capabilities as a result, are having a direct and positive impact on the use and development of geographic information systems (GIS).

The application of GIS is especially appropriate to transportation-related functions because of the ability of GIS to provide a coordinated methodology to draw together a wide variety of information resources under a single, visually oriented umbrella and make them available to a diverse user audience (*1*). The benefits of GIS application lie not only in the integration and availability of diverse information within an integrated system, but also in the analysis, interpretation, and query facilities developed to suit specific needs of the diverse elements of the user community.

Many transportation agencies are investigating the applicability of GIS as a cost-saving and decision support tool. GIS applications can increase productivity through better availability and processing of data in functions such as map drafting, infrastructure maintenance, cost estimations, inventory management, operational safety and hazard analysis, demand forecasting, land use and rezoning impact studies, and environmental impact analysis, as well as others (*2*).

Most GIS softwares and systems are equipped with the available analysis, processing, query, and interpretation functions of conventional data base management systems. The feature that distinguishes GIS from conventional data base management systems is the ability to perform spatial analysis. Spatial analysis, mainly in the form of overlaying and buffering, allows the user to explore relationships between different layers of data by referencing and the display of features and their attributes in one layer to the features and attributes contained in other layers. It is also possible to run several algorithms and models that are commonly used for such transportation-related applications as shortest-path, origin-destination tables, traveling salesman, and routing models. The facility to link up to several other packages and procedures for planning and statistical analysis also give access to more data-processing capability. A better perception of results is the result of the visual display and query facilities found in GIS.

Because they are essentially spatially distributed, rail-highway grade crossing safety data are suitable for GIS analysis. Development of a GIS application would allow for not only query and visual display of crossings but also analysis of the relationships between crossing location, land use, population density, and proximity to other features in the vicinity of the crossing. The development of a GIS application would ultimately result in an aid to resource allocation for accident reduction at crossings.

This paper discusses the development of a GIS application for safety evaluation at rail-highway grade crossings in the state of Delaware. The development of the application includes location referencing of the current safety attribute data base for public at-grade rail-highway crossings in Delaware and the linkage of the GIS to an empirical model that determines the accident hazard index for individual crossings on the basis of attribute information. Location referencing of the current data base, linkage to the empirical model, analysis, interpretation and query facilities created, and benefits of the application are discussed.

SAFETY ANALYSIS FOR RAIL-HIGHWAY GRADE CROSSINGS: A REVIEW

The responsibility for inventory and management of public at-grade crossings in Delaware lies in the hands of the Delaware Department of Transportation (DelDOT). In Delaware there are 548 rail-highway crossings of which 265 are public at grade. During a period

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of 9 years, from 1981 to 1991, there were 71 train-automobile accidents, of which 10 resulted in fatalities (*3*). An earlier part of the ongoing study resulted in the identification of the most feasible empirical model for determining the accident hazard index; the development of a computerized data base that includes all safety-related inventory information; and the calculated accident hazard index for all public at-grade rail highway crossings in Delaware.

Data related to safety analysis of rail-highway crossings in Delaware comes from a variety of sources. One source of data is the Federal Railroad Administration, which maintains information on the city and county codes, railroad code, highway number, crossing type, and position of the crossings. Each crossing is assigned a unique DOT-AAR (Association of American Railroads) crossing identification number that is based on the milepoint on the approach road. This is basic information pertaining to the type of the crossing and its actual location.

Other significant information fields include the type of protection device, number of day and night trains passing through, crossing surface, maximum timetable speed, number of traffic lanes, estimated annual average daily traffic (AADT), and accident information. All this information can be obtained from several sources, including inventory records of railroad companies and field studies. The additional information required is the number of accidents, and this was obtained from the DelDOT Bureau of Traffic.

Other information required for resource allocation at crossings includes site-specific and qualitative information such as sight distance along the road and the track, number of school buses and hazardous materials carriers using the crossing, actual speeds on roads, and land use. Because most of the information is subject to frequent change, data must be constantly updated. Some of the data exist in the form of spreadsheets and others exist manually in the form of inventory sheets and tables.

The previous work resulted in collecting the statistically significant information necessary for applying the U.S. Department of Transportation (USDOT) accident index and storing the calculated accident index in an American National Standard Code for Information Interchange (ASCII) format file. The resulting integrated data base consists of 25 different fields of information. The form of the computer data base is indicated in Table 1.

TABLE 1 Format of Computer Data Base Developed for Rail-Highway Crossings Safety Data in Delaware

COLUMN	CONTENTS
1-7	DOT-AAR Inventory Number
8	County Code
9-10	City Code
11-27	Street or Road Name
28-33	Milepost
34-35	Number of Day-through trains
36-37	Number of Day-switch trains
38-39	Number of night-through trains
40-41	Number of night-switch trains
42-44	Maximum timetable speed
45	Number of Main tracks
46-47	Number of Other tracks
48	Protection class at crossing
49	Is highway paved?
50	Pavement marking
51	RR advanced warning signs present
52	Crossing surface
53	Number of traffic lanes
54-55	Highway system code
56-61	Estimated AADT
62	Is highway divided?
63	Number of accidents in last 9 years
64	Number of fatalities

Shortcomings in the Existing Program for Rail-Highway Grade Crossings Safety in Delaware

The first part of the study resulted in the integration of crossings-related safety data from various sources into a single accessible file format and linked the data base to the USDOT model (*4*) for assessing the hazard potential at the crossings.

Before the development of the GIS application, the user, when presented the data in a text file output could not have a perception of the actual spatial situation of the crossing, which is also crucial to the resource allocation decision-making process. The user had to go through the manual process of looking into a hard copy map to relate the information to the spatial location, which for a large data base of several hundred crossings can be time consuming. Additional information, such as land use, proximity to schools, and other qualitative information, was also not readily available to the user. Furthermore, the data base was not location referenced in a form that is compatible for access into GIS.

BRIEF REVIEW OF GIS

Several definitions have been coined for GIS. One of the appropriate definitions by Dueker and Kjerne (*5*) describe GIS as "geographic information system—a system of hardware, software, data, people, organizations, and institutional arrangements for collecting, storing, analyzing, and disseminating information about the areas of the earth."

A GIS is basically an integrated, computer-based, spatially referenced data base management system. The components of a typical GIS system include a data base component, a hardware component, and a software/interfacing component. The data base component in GIS is in the form of two distinct data bases: one is the graphic data base and the other is the nongraphic or attribute data base.

The graphic data base is a description of the map features and is composed of geo-coded spatial data that define objects on a two- or three-dimensional surface and identify their relationships by categorizing and defining them either as points, lines, or polygons that are tied to a common referencing system (*6*).

Spatial data can be obtained from various sources. One is the scanning or digitizing of hardcopy maps, satellite imagery, and photogrammetric sources (*7*). There are also primary sources of digital data, such as the topographically integrated graphical encoding and referencing (TIGER) files of the U.S. Census Bureau and other digital data bases that are commercially available.

The U.S. Census Bureau developed the TIGER files, which identify every road segment in the United States along with information on street labels and census information, county partitions, statistical information, national partitions, and geographic catalogs, all referenced in a latitude-longitude coordinate system (*8*).

The nongraphic, or attribute data bases, refer to data elements that describe the characteristics of features on the spatial maps or those of events occurring at spatial locations.

The crux of the GIS system is the linkage between the nongraphic data and their graphic position or location. The most common way to achieve this linkage is to have an identifier stored with each nongraphic data record that corresponds to the identifier stored with its actual spatial location in the graphic data base. The management of nongraphic data bases can also be done using any of the commercially available data base management software that are compatible in input and output format for import and processing in GIS.

Two distinct components can be seen in GIS software packages: one is the main component that performs the basic functions of data base management, graphic, and mapping functions. The other is a need-specified set of functions that provide geographic and attribute data analysis, manipulation, edit, and query functions. This component varies according to the type of application package. Transportation-related application packages will be likely to have network analysis, routing, and optimization algorithms linked up and provided for manipulation and analysis.

POTENTIAL FOR GIS TECHNOLOGY APPLICATION

The limitations of the current rail-highway program can be eliminated to a great extent by the application of GIS technology. The main benefits can be perceived in the better perception of the problem because of the presentation of crossings data on a map format in reference to its actual position. Resource allocation decision making would be more accurate because the user also gets a visual input, along with the ability to make spatial and textual queries on the data base.

The present crossings safety data base in Delaware allows only limited manipulation, analysis, or query of the data base. The user is limited in the textual queries and selections that can be made. Viewing and processing crossings attribute data with respect to spatial and topological attributes and relationships are not possible. This limits the user, typically the local crossings expert/railroad division engineer, from considering the area-specific qualitative information that is crucial to sound decision making and which would be available in spatial format in a GIS application.

GIS provides a powerful tool in the form of spatial analysis, which is the characteristic that distinguishes it from other data base management systems. Accessing data from several different layers and exploring the relationships between them—for example, the relationship between crossing safety and proximity of the crossing to a school—is one of the powerful and unique features of GIS.

The ability to perform conditional queries and statistical analysis, create thematic maps, and provide charting and statistics enhances the functional ability of the crossings safety program. The ability to link up to external programs and procedures for user-specific functions, such as interfacing the USDOT model to the location referenced attribute data base, also would be possible. This would allow the data base to use specific external packages such as those for statistical analysis and data base management and then view and query the processed data. Linkage with a knowledge-based expert system that considers site-specific and qualitative information in addition to the statistically significant data to provide decision support to the user is also possible.

Source of Spatial Data

For the development of the rail-highway safety application, the graphic data base requires all rail and intersecting road segments to be labeled, which in effect means road and rail segments, for the state of Delaware. The availability of other attribute information such as land use, population density, and census geography is not actually required for applying the DOT model, but these are significant qualitative factors and are important to sound resource allocation decision making toward mitigation of accidents.

The TIGER data base for Delaware was found to be appropriate and sufficient for all the requirements of the current application. TIGER consists of all city and county and road and rail segment information, and it also has street labels associated with it. This makes possible the identification of the spatial location of crossings and the location referencing of attribute data. In the current data base these attribute data are not in a location referenced form acceptable for building a GIS application. Figure 1 indicates the Delaware base map for the GIS application consisting of rail and road segments.

TIGER has the additional advantage of being in a standard latitude-longitude referenced form, which makes geocoding possible. The availability of census geography information is also helpful, and the ability to append and import data from other sources into most GIS softwares makes TIGER even more versatile for this application.

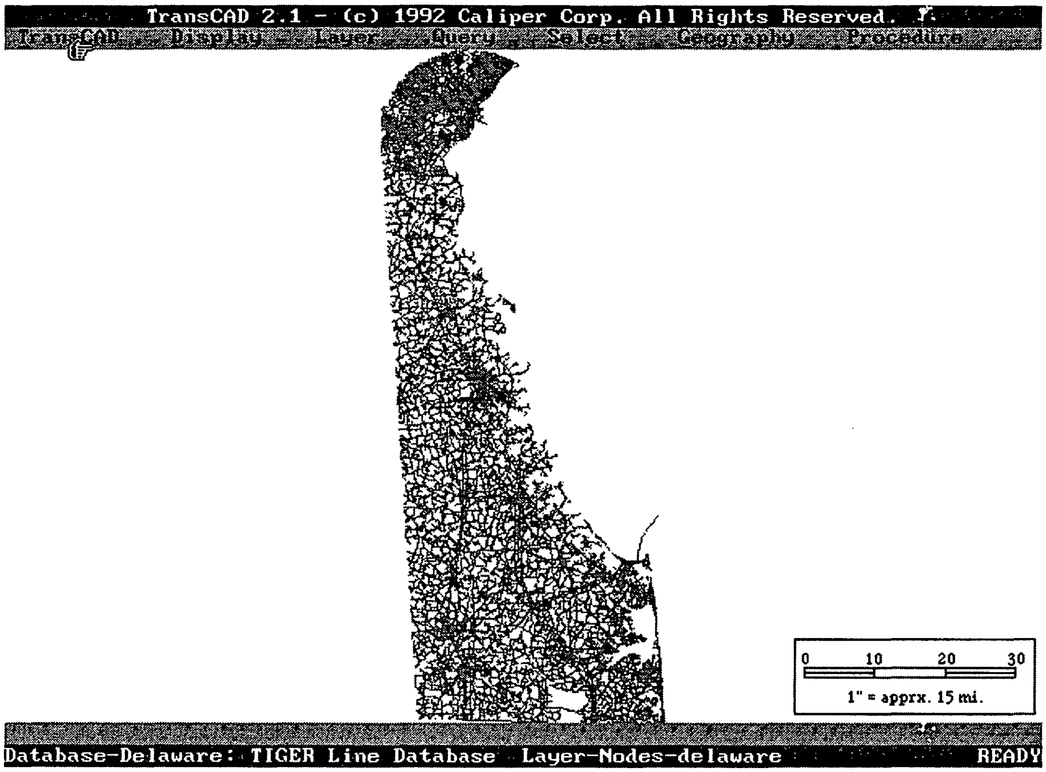
Selection of GIS Software

Several commercially available GIS application software packages could be used for developing such an application. However, because each of these software packages is designed for specific applications, the needs of the current application were appraised, and the package required was selected on the basis of these identified requirements. The functional capabilities required, in general, for GIS software are described in Spear (*9*).

Some of the basic functional capabilities required for the rail-highway application were identified to be as follows:

- Basic GIS textual and geographic query and selection functions;
- Geographic and attribute editing functions enabling editing and updating of the attribute data and changing the location coordinates of entities, if required;
- GIS windowing display, zoom in/out, selection and creation of data base layers, display of features and highlighting;
- Ability to import and export referenced data, ability to operate on ASCII, availability of worksheet format files, ability to translate and accept TIGER files; and
- Ability to link with external procedures, provided there are specific programs and statistical software packages.

The requirements were focused more toward the manipulation and handling of the attribute data. Such graphic processing functions as geographic editing, mapping, feature modification, and



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1 Km = apprx. 0.6 Mi.

FIGURE 1 Base map with rail and road segments created for Delaware using TIGER data.

interactive digitizing largely are not required for the application. Several UNIX-based software packages that could be run on a workstation had the required functions and, additionally, graphic processing capabilities, and multiuser and windows operation capability at a much higher cost.

While considering the requirements of attribute data representation, external linkage, and manipulation and processing, the objective was to identify a low-cost, microcomputer-based GIS software, which need not require advanced graphic processing functions. TransCAD (*10*) transportation GIS software was found to be suitable and was selected for building the application.

DEVELOPMENT OF RAIL-HIGHWAY GIS APPLICATION

The first step in developing the GIS application was creation of the base map for Delaware. TIGER files were used to create the base map on which the crossings locations could be displayed. The features included in this base map, which are indicated in Figure 1, are the rail and road links for the entire state.

Once the base map was developed, the next step involved creating the location referenced attribute data base that contains safety-related attribute information for public, at-grade, rail-highway crossings in Delaware. A program was then developed to execute the USDOT model on the crossings safety data and estimate the accident index of each crossing. This program was interfaced to the GIS application to enable it to directly access data from the geocoded attribute data base and pass the results back to the GIS to enable display and analysis with respect to the crossing location. The last two steps in the development of the GIS application are the analysis and interpretation of data and the presentation of results in the form of charts, tables, thematic maps, and hard-copy generation of the same. All these steps are described in the following sections.

Location Referencing of Attribute Data

The existing data base had location reference information only in the form of city, county description, road labels and milepoint on approach, apart from the DOT-AAR identification number. For the GIS, the data records need to be in one of the standard coordinate systems.

If the information is in latitude and longitude coordinates, the input data for a point data base needs to be in a single file. If it is in some other coordinate system, the GIS has the ability to convert to the latitude-longitude system on provision of the local and world coordinates of any three points on the data base (*10*).

The only location reference information available consisted of the crossing city, county, street, and railroad names and railroad milepoint information. The milepoint data could not be effectively used because it was inaccurate and inconsistent.

Some of the crossings records were location referenced by a simple program that searched for a match in the strings consisting of the railroad and street names for a crossing record with the respective fields in the node layer data base for Delaware. If a match was found the coordinate information from the node layer record was attached to the crossing record in question. Many of the records could not be geocoded in this manner because of the inconsistencies in the rail and road name strings between the TIGER data and the crossing records for Delaware. For these crossing records, direct interactive conversion of records by identifying the actual spatial location, querying on the coordinates at the actual location, and appending the location information to the individual records was performed.

Using the available information on the city and county and road name, the approximate area in which the crossing is located was estimated. Using the zooming and scaling options (Figure 2), the area was zoomed into and the intersecting road and railroad names were matched with those of the segment labels in the map to determine the exact spatial location of that particular crossing.

A geographical query into the node layer of the data base at that point reveals the relevant name, identification (10) number, and latitude-longitude information. Either the latitude-longitude or ID field data could be appended to the existing record. This process was repeated for all crossings, until location referencing was done for all data records. The location referenced data base was imported into GIS, and a separate layer was created for storing these data. This method, although interactive in nature, was the only feasible way to geocode the crossings data base. The advantage of this was the location referencing into a latitude-longitude system that can be accepted for other GIS applications and, also, converted to any other GIS acceptable coordinate system.

Linkage to DOT Model

The data base consists of 25 fields of data, of which the 25th field is the USDOT accident hazard index, which reflects the hazard potential at the crossing. The USDOT model must be run to obtain the modified accident index every time any of the significant attributes for any crossing changes. The USDOT model needs to be interfaced as an external procedure with the GIS.

The program developed for running the USDOT model takes in data in ASCII file format, along with the identifier field, calculates the hazard index, and returns the modified information in an ASCII file that can be imported into the crossings data base layer. Command directives are used to dump the changed records, run the external program, and import the results file into the application data base layer. The linkage to the USDOT model and external programs is done from a menu created as indicated in Figure 3.

Analysis and Interpretation of Data

The availability of all required safety data in a single format and under a single application enables the analysis and interpretation of the nature of the data and the relationships. GIS has conditional query functions and the facility to classify and interpret information on the basis of a theme. Color coding, representative icons, and highlighting were applied to display processed and significant data values, such as dangerous crossings on the basis of a high value of the computed accident index and so forth. The general capabilities of the rail/highway grade crossing GIS application are shown in Figure 4.

The most important feature available to the user is the spatial analysis capability. The GIS application allows the user to view the crossings in reference to the location of entities in other layers. The user can perform buffering to display and estimate the number of

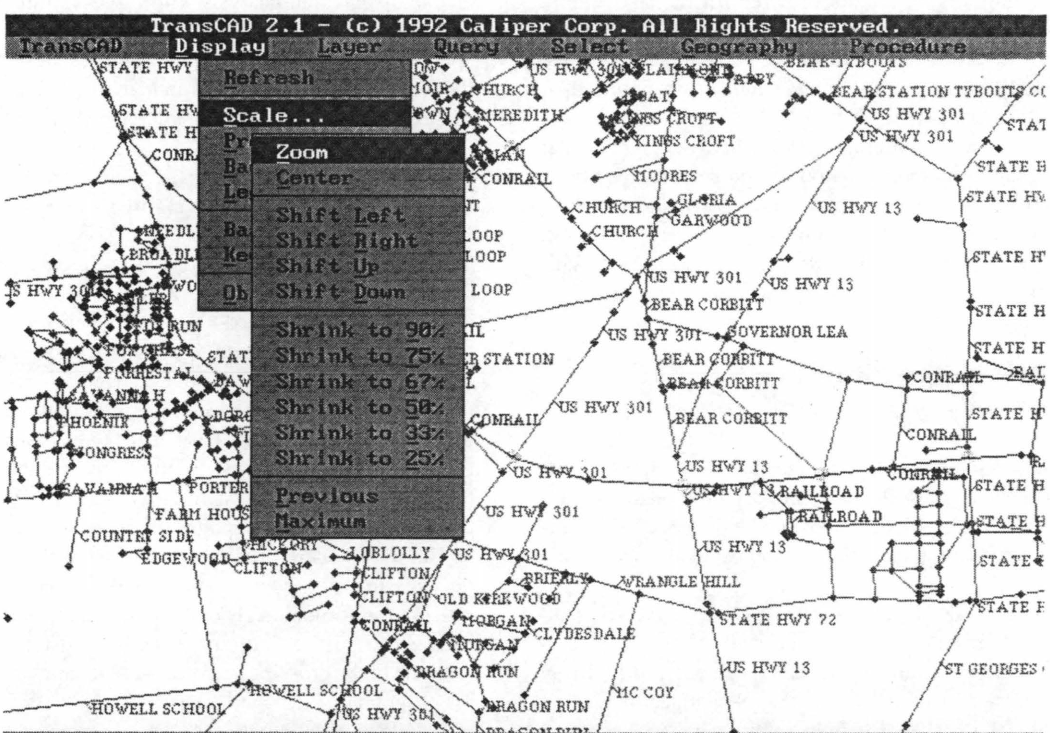

FIGURE 2 Scaling and zooming into the approximate area of desired crossing location.

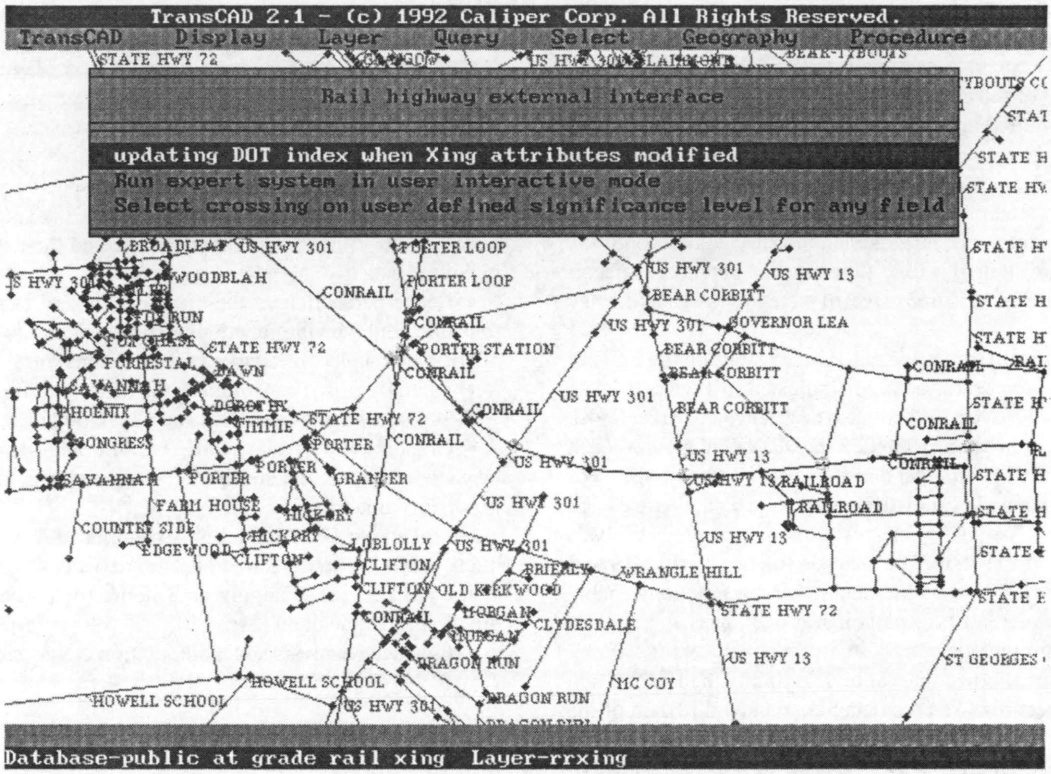

FIGURE 3 Linkage to external procedures (USDOT model).

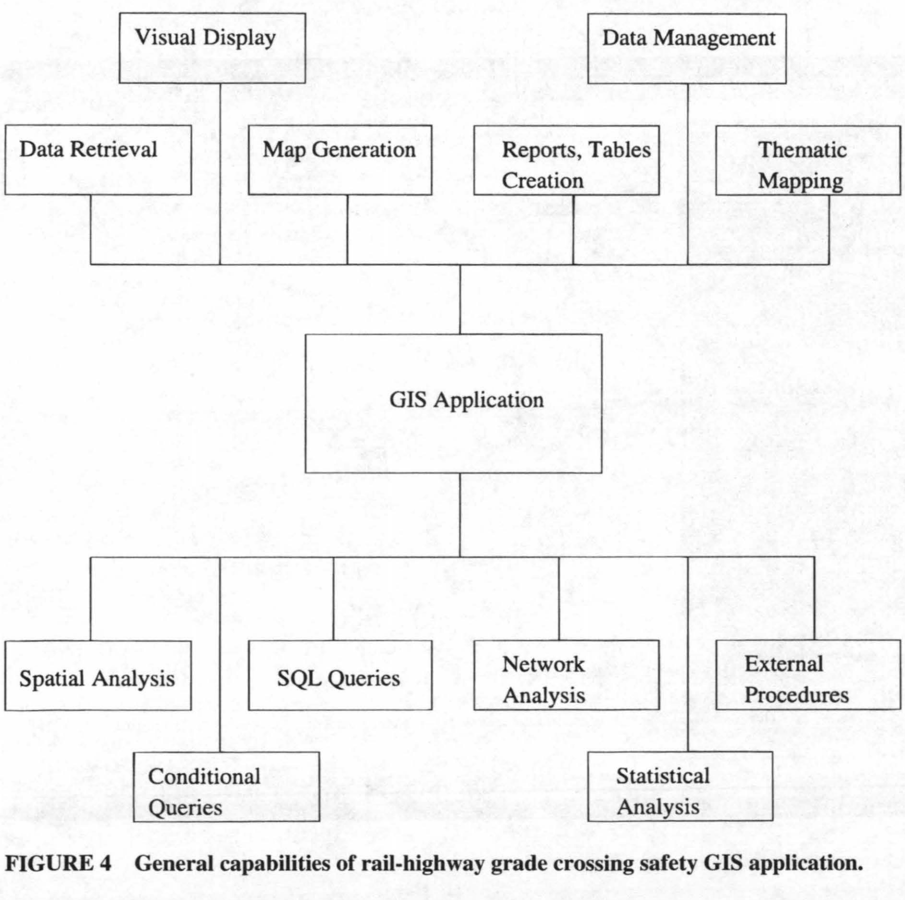

FIGURE 4 General capabilities of rail-highway grade crossing safety GIS application.

objects of a specific type that lie within a specified distance of the crossing—for example, the number of schools within a mile of the crossing. The user can also perform overlaying to assess the land use in the vicinity of the crossing.

The user can query into any crossing and view the attribute data associated with it as indicated in Figure 5. Some of the query conditions created are shown in the menu created in Figure 6. Conditions are created to reflect the strategies for identification of deficient, significant, and hazardous attribute values, and the resource allocation strategies used to reduce the potential for accidents. In this case, the conditions created were to select and display crossings.

Thematic maps were created to classify crossings on the basis of traffic, accidents, or hazard index, as indicated in Figure 7. Data records based on any given field can also be arranged and displayed. Statistical analysis functions in the GIS include calculation of mean values and variances of particular data items over spatial ranges. For more detailed and complex statistical analysis, the data base can be linked to statistical analysis packages such as Statistical Analysis System (SAS), and the results of analysis imported into GIS and viewed and presented on the base map. Charting functions enable the production of pie and bar charts in various forms,a sample of which is shown in Figure 8.

Linkage to external procedures allows flexibility in manipulation and selection of records from the data base on identification of the specific nature of the requirements. A program was developed that enabled selection of records on the basis of a user-specified level of significance, expressed as a percentage, for any field, and display of the selected records/crossings in the digital base map.

RESULTS

A GIS application for integration, graphic display, and processing of rail-highway crossings-related safety data was developed. The features of the GIS application are as follows:

- Possibility of interfacing with need-specific procedures and analysis. Integration of relevant and significant safety-related data from various sources into one data base and the location referencing of the data.
- Better perception of the crossings hazard because of query, selection, and viewing functions in GIS, leading to less possibility of error and neglect of factors in decision making.
- Spatial analysis capability in the form of buffering.
- Statistical analysis of data and generation of results in charts.
- Graphic map display with zooming and scaling allows the inspection of data at a specific crossing and in a quick and easily understandable form.
- Linkage to DOT model gives automated updating of hazard index values on modification of attribute values.
- Updating and changing data items for crossings using edit functions are quick and easy.
- Enhanced analysis and manipulation are possible.

SUMMARY AND CONCLUSIONS

The development of a GIS application for safety evaluation at rail-highway crossings demonstrates the benefit of GIS in the form of

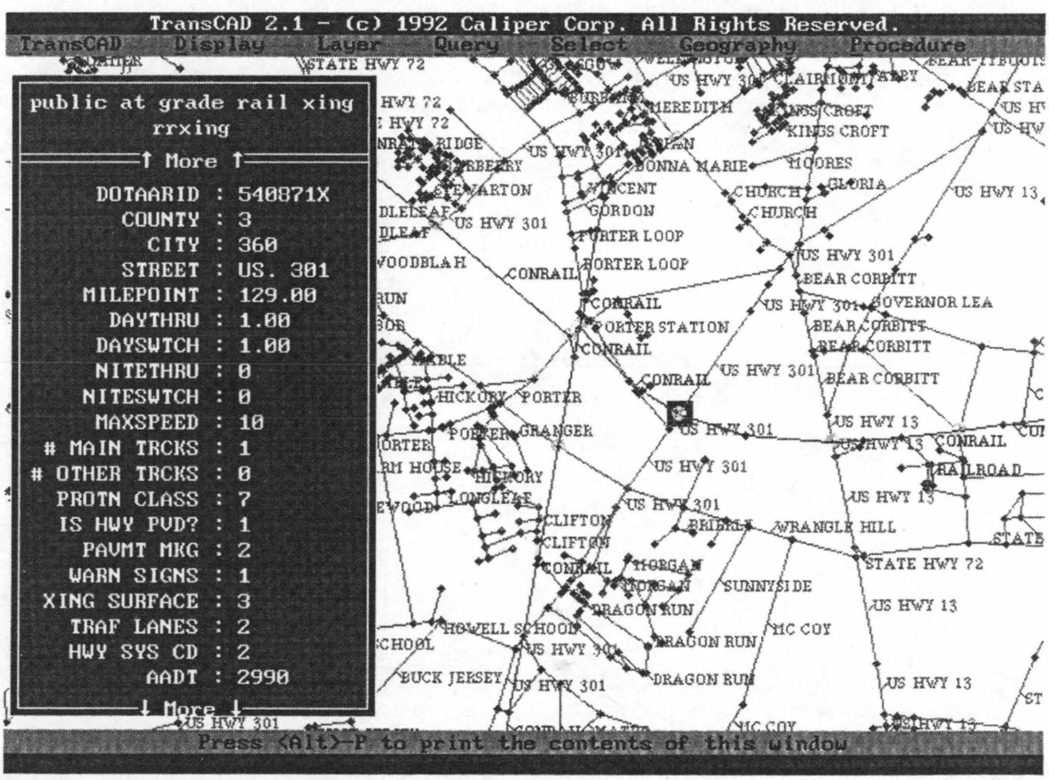

FIGURE 5 Query into crossing showing safety attribute data.

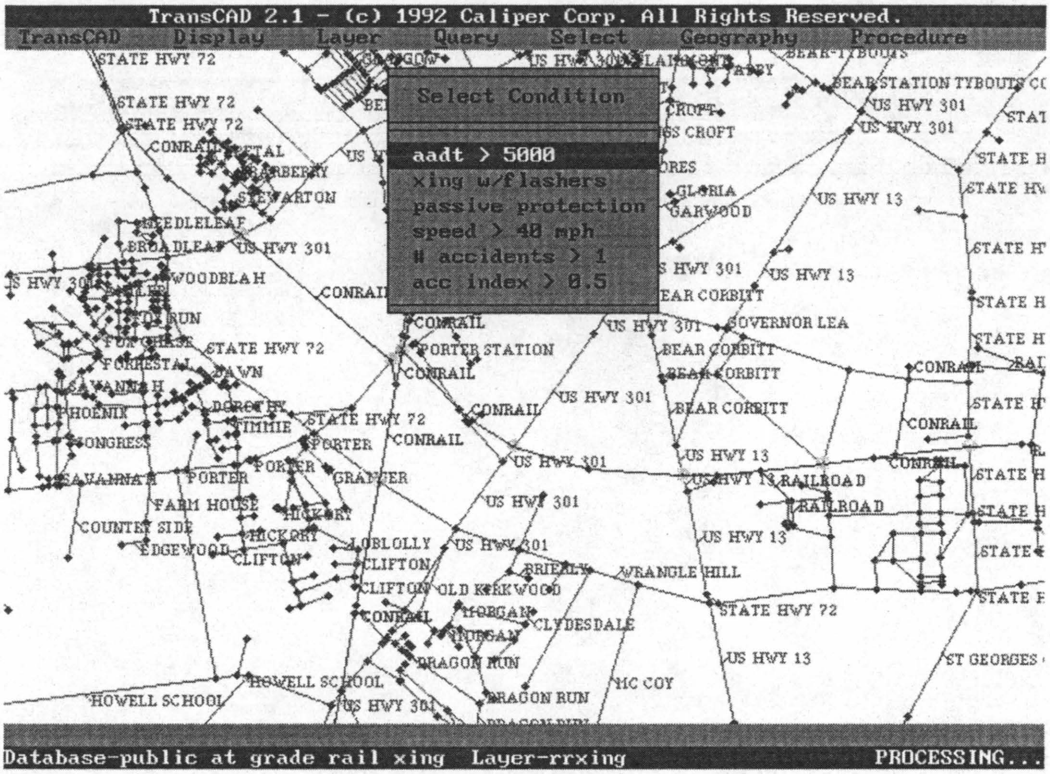

FIGURE 6 Conditions created for display of crossings with attribute values according to nature of queries.

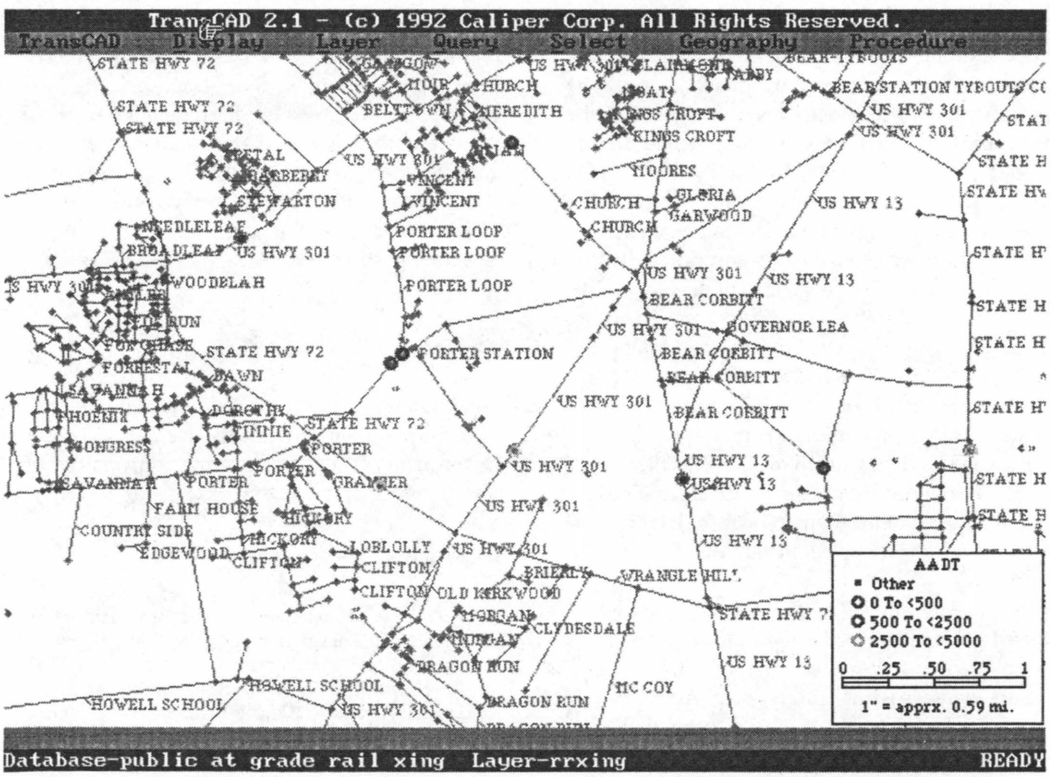

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FIGURE 7 Sample of thematic map created for display of crossing data according to desired nature of classification.

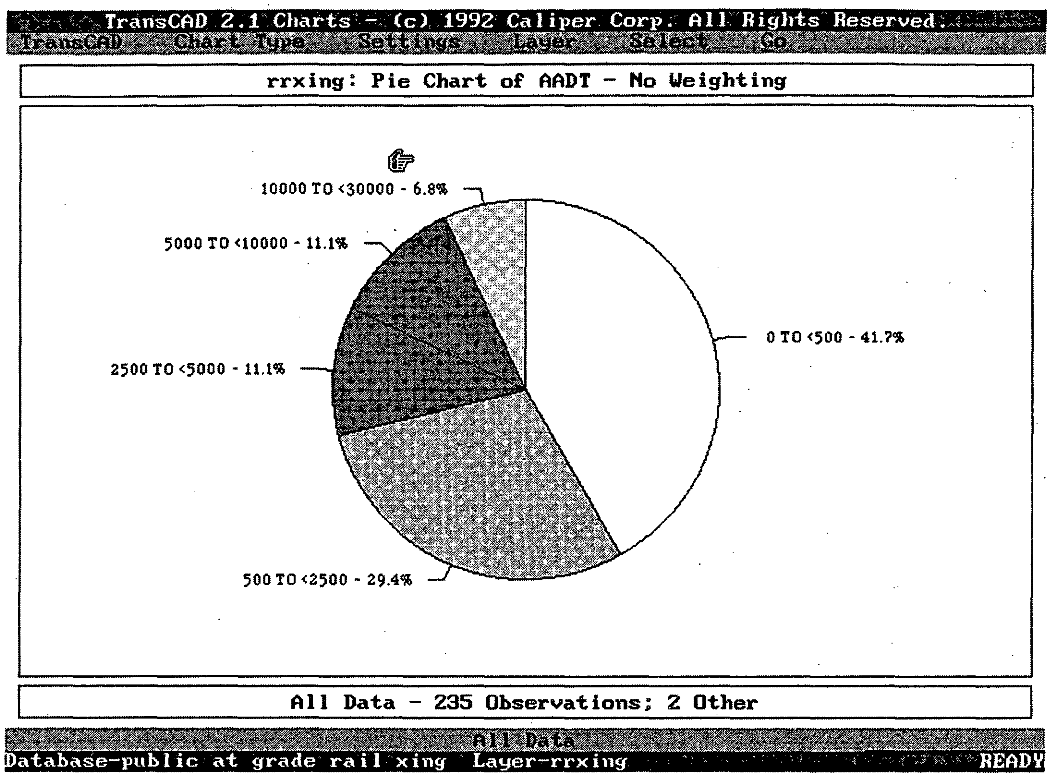

FIGURE 8 Sample pie chart of presentation of results of processes on data.

savings in time and costs through the availability of data from one source and better decision making as a result of better perception and analysis. The location referenced attribute data base could be incorporated into a multiuser, client-server system, making the application and the data base available to a wide variety of users and applications.

The GIS application developed here is a low-cost application developed on a stand-alone 80486 processor-based personal computer. The bulk of the effort involved was in location referencing and keying in attribute data. The system thus developed is a low-cost one. The costs involved are the cost of procuring hardware and software and the labor cost associated with developing the application. For the Delaware data base of 265 public, at-grade rail-highway crossings, the effort involved 200 to 250 person-hours of work. For a larger state, with a few thousand crossings, the effort involved in data conversion would be much more unless there were sufficiently accurate information, such as railroad milepoints, which would enable automation of the entire process of location referencing and thus save a considerable amount of effort in the process.

The project demonstrates the benefits of integration and availability of safety-related information for resource allocation strategy development at a single source and in a user-friendly display form. Integration of rail-highway crossing safety data from diverse sources was achieved. The availability of analysis, manipulation, and result presentation capabilities in the form of an interface to the USDOT model; the statistical analysis functions of the software; the need-specific conditional query; the presentation of attribute data and hazard potential in charting; and thematic map forms all result in cost and time savings through quick and effective analysis of the safety data base.

Because transportation-related data are spatially distributed it is compatible with and benefits from representation in a GIS. The application of GIS to transportation network data, as in this application, results in quantifiable benefits in efficiency through automation of data handling, integration of disparate but application-related data, and expanded capabilities for analysis and manipulation. The savings in the form of reduced labor requirements compared with manual processing can outweigh the costs of developing a GIS system.

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