GIS Integrated Pavement and Infrastructure Management in Urban Areas

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Infrastructure management is the process of properly coordinating, systematically evaluating, and effectively maintaining the infrastructure related to basic services. Infrastructure management system links those activities required for these actions, such as planning, design, construction, maintenance, rehabilitation, and evaluation, through a series of rational, well-ordered analysis procedures. Effective management of pavement and other infrastructure in the urban area can greatly increase the service life of these facilities and reduce user costs. Efforts to apply geographic information system (GIS) to urban roadway and infrastructure management are summarized. A user-friendly application program, GIS-URMS, which was developed under this research, is described. In addition, some important issues with regard to developing implementable GIS applications are discussed.

The urban roadway network is a major component of any municipal infrastructure system. Effective management with systems methodology can greatly increase the service life of these facilities and reduce user operation costs (*1*). To achieve such objectives, many municipal transportation agencies in the United States have operational pavement management systems (PMSs) in one form or another. As a further development and improvement of the management technology for transportation systems, many transportation agencies are currently investigating the adoption of geographic information systems (GISs) for transportation applications (*2,3*).

GISs are computerized data base management systems with unique capabilities of managing and manipulating spatially referenced data and presenting it in an easily understandable graphic format. GIS can perform two major functions to support management decision-making processes in many diverse fields such as natural resources, environmental protection, transportation management, and municipal infrastructure management, to mention a few. One function is to generate computerized visual map displays for accessing, editing, and presenting data from different sources; the other is to provide a platform for data integration so that a common location reference system can be developed (*4*). The applications of GIS in the transportation community are growing rapidly. To evaluate the potential applications of GIS in urban roadway and infrastructure management systems, efforts under research at the University of Texas at Austin include

- Conceptual evaluation of GIS technology,
- Review and comparison of available GIS software,
- Identification of digital geographic data for urban areas,
- Development of a pilot application, and
- Conclusions and recommendations for implementing this technology in urban areas for pavement and infrastructure management.

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WHY GIS?

Although GIS applications for pavement and infrastructure management are still at their early stage compared with applications in other areas, infrastructure management in urban areas strongly suggested that there is a need for such technologies. To address urban infrastructure management in an effective and practical way, an advisory panel was set up with panel members from the Public Works Departments from cities in Texas. The advisory panel meet periodically at the University of Texas at Austin to discuss practical issues regarding urban infrastructure management. From the panel discussions, several important aspects with regard to developing GIS applications were noted. These are described as follows.

Infrastructure Management from Perspective of City Planners

Although the traditional infrastructure management systems have been in operation for a long time, city planners in most cities are now either trying to improve the existing systems or seeking a new management system approach for their infrastructure. The general idea that emerged from the discussions with the advisory panel was to develop an overall or comprehensive management system so that all the infrastructures such as pavement, bridge, water supply, waste water, gas, electric, and such could be integrated on a common platform to improve managerial decisions. This concept of integrated overall infrastructure management system is illustrated in Figure 1, where GIS is the common location reference system (*5*).

Feasibility of Integrated Management System

Because of the unique geographical location of municipal infrastructure systems, a common location reference system can be used to integrate the subsystems outlined in Figure 1. Whereas electricity supply and pavement are normally along street lines, water supply, waste water, and gas are normally under the street pavement, as illustrated in Figure 2, special considerations need to be made for those elements that do not follow the direct street courses (*5*).

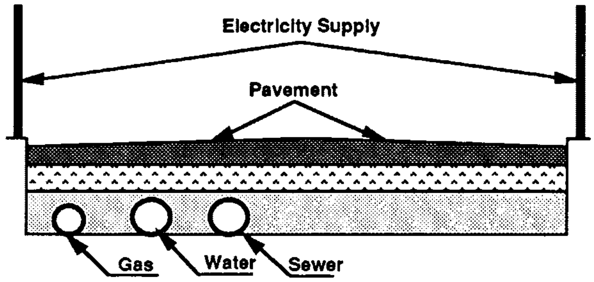

FIGURE 2 Example of common location reference system.

Availability of Technology

The significant decrease in the price of personal computers and the dramatic improvement in their performance have enabled more and more agencies to afford the investment in PC platforms. GIS development has now entered a period of expanding applications, and PC versions of GIS packages are available at an affordable price (*6*). In fact, PCs are now almost a commonplace in most cities' public works departments. Some of them have already had some sort of GIS packages. Austin, and even smaller cities like Round Rock and Georgetown, Texas, own and operate PC Arc/Info GIS packages.

Current Practice

Some cities are now developing integrated infrastructure management systems as illustrated in Figure 1 and some are planning to do so. As an example, efforts are under way in Georgetown, Texas, to develop an integrated management system that coordinates water, waste water, electric, and pavement management systems with PC Arc/Info.

PLATFORM AND GIS PACKAGE

A pilot GIS application for Urban Roadway Management System (GIS-URMS) program was developed for demonstration and to serve as a starting point for cities willing to implement GIS integrated infrastructure management solutions. The computer platform used for developing GIS-URMS was a 486/33MHz PC with 200MB hard disk.

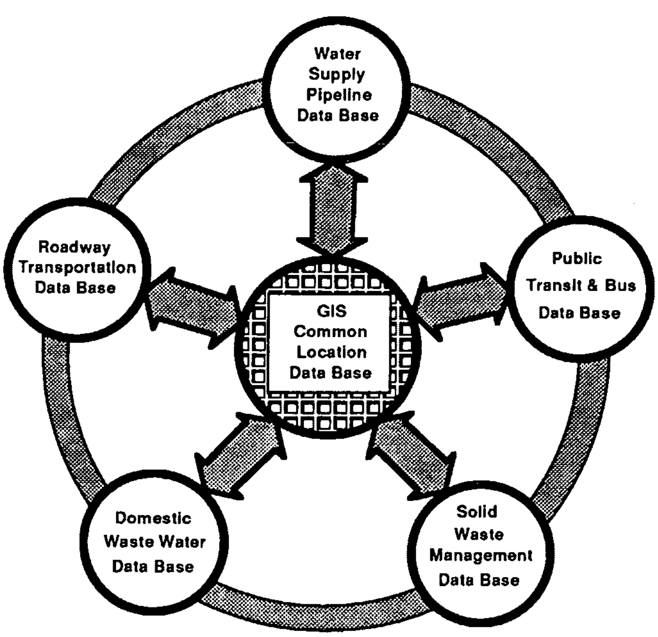

FIGURE 1 Concept of integrated overall infrastructure management system.

From a literature evaluation of several GIS packages, PC Arc/Info, a GIS package developed by the Environmental Systems Research Institute, was selected to develop the pilot applications. PC Arc/Info is one of the most widely used GIS packages for personal computers. The package consists of six separate modules (*7*):

- PC Arc/Info StartKit,
- PC ArcEdit,
- PC ArcPlot,
- PC Data Conversion,
- PC Network, and
- PC Overlay.

PC Arc/Info can be run on any 286, 386, or 486 PC with DOS 3.1 or higher, 640K or more RAM, a minimum of 40MB hard disk storage, 1.2MB or 1.44MB floppy disk drive, and a math coprocessor. A parallel port is required for the PC Arc/Info hardware key that copy-protects the software. An EGA/VGA or compatible monitor is recommended for the various interactive graphics operations. Two serial ports are usually required if a digitizer and a plotter are desired, and a modem is needed for host communications.

GEOGRAPHICAL DATA BASE

The city of Austin, Texas, was selected to conduct the pilot study. TIGER (Topologically Integrated Geographic Encoding and Referencing)/Line files provided the digital geographical data used to develop the geographical data base for the pilot GIS-URMS. The TIGER files obtained are for the county of Travis, Texas. It is inefficient to use all the blocks in Travis County as the geographical data base for the Austin area. The extra blocks outside the Austin boundary consume disk storage space and increase the processing time required by various operations. To establish a geographical data base that contains only the street segments of the Austin area, several spatial data operations were conducted using PC Arc/Info. The boundary data for the Austin area was first extracted from the City90 file, which contains all the city boundaries in Travis County. The extracted Austin boundary file was then used to intersect with the block file Block90 to get the geographical data base for Austin area.

PAVEMENT ATTRIBUTE DATA BASE

The pavement attribute data is from Austin's pavement data base, PIBASE. PIBASE was supplied in dBase III+ format with 126 data fields. Included in the data base is major pavement information such as riding condition index (RCI), surface distress index (SDI), annual average daily traffic (AADT), and so on. RCI values were rated on a scale from 10 to 0 (best to worst). Thirteen types of distress were considered for flexible pavements: rippling and shoving, raveling and streaking, flushing and bleeding, distortion, excessive crown, progressive edge cracking, alligator cracking, potholes, map cracking, longitudinal and meandering cracking, transverse cracking, wheel track, and patching. These distress manifestations were then combined on the basis of their extent and severity, in order to calculate an SDI. An SDI value of 10 stands for a perfect surface, whereas a value of 0 indicates a totally unacceptable surface. Other data such as pavement geometric dimensions, layer thickness, and maintenance and rehabilitation (M&R) history are also included in the data base.

LINK BETWEEN GEOGRAPHICAL AND ATTRIBUTE DATA BASES

The TIGER file (geographical data base) and pavement data (attribute data base) are maintained separately in the system. The two data bases can be dynamically linked together by the control program when the connection is necessary. The linkage is accomplished through a common item in both data bases, taking advantage of a relational data base management system. The common item used for this purpose is the pavement segment identification. Figure 3 illustrates the data linkage concept.

The most important advantage of this dynamic connection between the geographical data base and the attribute data base is that each of the data bases can be updated or modified separately. Both geographical data and attribute data are associated with a time variable. The data base needs to be updated for any change of geographical features. TIGER files are also subject to periodic updates by the U.S. Bureau of the Census. Pavement condition data changes with time and the attribute data base must be updated to reflect such condition changes.

CONCEPTUAL DESIGN OF GIS-URMS

Figure 4 illustrates the conceptual structure of GIS-URMS. The user accesses GIS-URMS through a user-friendly, menu-driven interface. The interface takes any command sent by the user to actuate the control program written in the PC Arc/Info's Simple Macro Language (SML). Connected to the control program are a series of function modules, including draw, label, query, list, applications, utility, clear, and quit. The outputs from GIS-URMS are various pavement condition maps, reports, and statistics with corresponding bar charts. The geographical data base (TIGER block file) and the attribute data base (pavement condition data from Austin) are separately maintained and will be dynamically connected to each other where such a connection is required by the control program. The control program is also open for development of an interface with URMS (*5,8*) or any other management system.

FUNCTION MODULES

Using the SML provided with PC Arc/Info, various functions were programmed as modules under different levels of the control menu. These function modules are depicted in Figure 5 and discussed as follows.

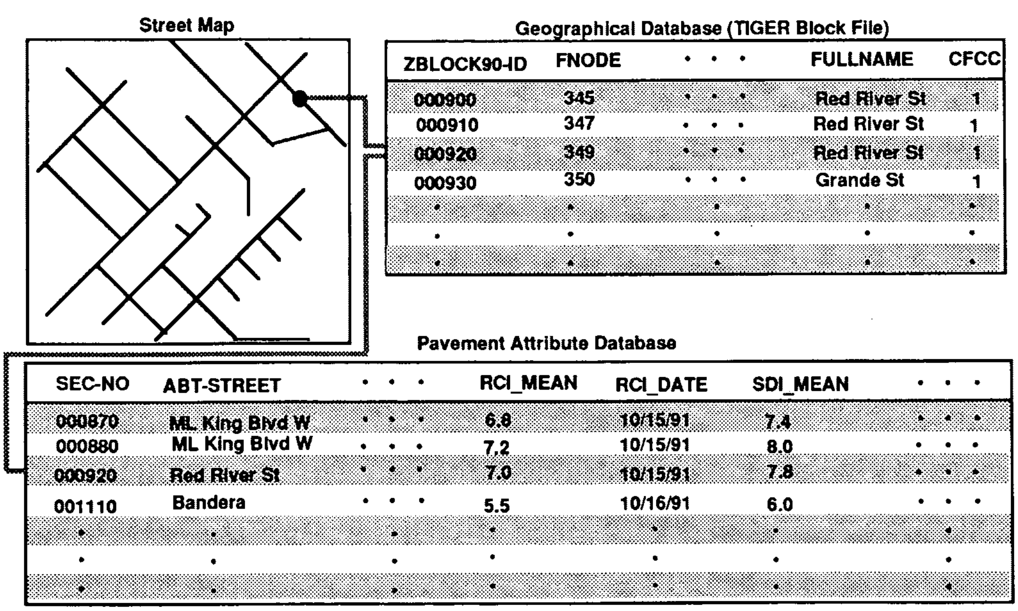

FIGURE 3 Link between geographical and attribute data bases.

Draw Module

Drawing different types of maps is a basic function of any GIS application package. Under the draw module of GIS-URMS, the user can choose the specific map (coverage) to be drawn with the desired color. Sixteen colors are provided with a color selection menu for the user's interactive use. A "zoom" function is included in this module so that the user can examine a specific area of interest in detail.

Label Module

In certain instances it is convenient for the user to put street names on the map so that streets can be identified easily; in other cases it is better to draw the map without street names for a clearer overall view of the area of interest. Using the Label function, street names can be attached easily to the corresponding streets or removed from the map simply with a touch of the mouse.

Query Module

One of the most important features of a GIS is its interactive graphic querying capability. The Query function lets the user identify any feature in the map interactively with a mouse. Information concerning any specified feature will be displayed within a designated window.

List Module

Information from both the geographical data base and the attribute data base can be retrieved through the List module. It could be all the information available in the data base for that block or a portion of the data that meet certain specified conditions. The information retrieved can be either displayed on the screen or written to a text file for further processing.

Selection Module

Map features or pavement segments that meet certain user-defined criteria or conditions can be selected and displayed on the base map and color-coded. Once the selection menu is activated, the system prompts the user to provide the name of the base map (coverage) from which the features are to be selected and then for the criteria or conditions for the selection. For example, the user can select or display all the pavement sections with a traffic volume equal to or greater than 1,000 or for all the streets with a specified street name, etc.

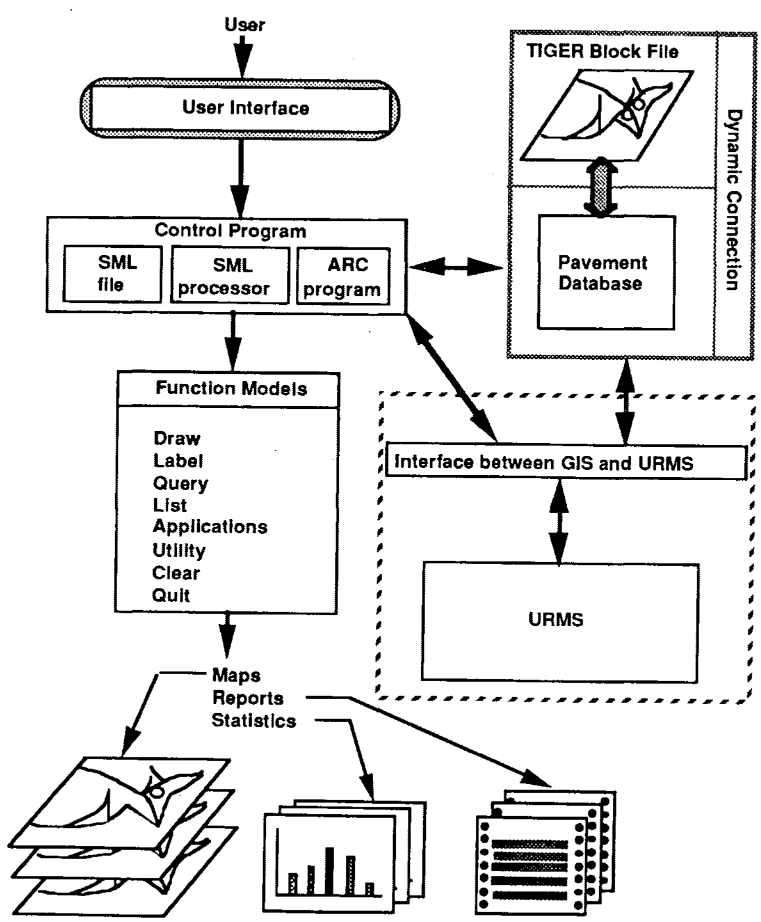

FIGURE 4 Conceptual design of GIS-URMS.

Network PMS

Under Network PMS, pavement conditions such as RCI, SDI, AADT, M&R recommendations, and subgrade soil condition (Soils) can be classified and displayed on the map. Associated with the condition map are the statistical information and corresponding bar chart for each class of information.

The outputs from GIS-URMS are various pavement condition maps, reports, and statistics with corresponding bar charts. The control program is also open for developing an interface with URMS or any other management system, as mentioned previously (*5,8*).

CONCLUSIONS AND RECOMMENDATIONS

On the basis of the research on GIS technology reported in this paper and its potential applications in pavement and infrastructure management, some important issues with regard to developing implementable GIS applications are as follows:

- Because of the significantly improved performance and decreased cost, PCs are capable enough as platforms of developing GIS applications for urban roadway and other infrastructure management in small and medium-sized cities.
- TIGER/Line files are a good source of digital data for developing GIS applications in urban roadway and other infrastructure management; it is recommended that these files should be first evaluated for potential use before digitizing data from existing maps.
- PC Arc/Info is a powerful and flexible GIS package. The SML featured with PC Arc/Info can be used to develop customized user-friendly applications.
- Because of its modular structure feature, the developed GIS-URMS is open and easy to interface with pavement management systems or any other infrastructure management systems.
- Because the link between geographical location data base and attribute data base is the most important step for the realistic implementation of GIS, an algorithm for automatically linking a geographical data base and an attribute data base should be developed in future research.
- The basic segment unit in TIGER/Line files is a street block, but in practice the pavement segment used for maintenance and rehabilitation is usually more than a block long. To make TIGER/Line files more useful for urban roadway management, an algorithm for performing dynamic segmentation should be developed so that practical maintenance and rehabilitation segments can be generated with TIGER/Line files.

In summary, the development process of pilot GIS-URMS demonstrated that GIS is a powerful and flexible tool for integrating geographical location information with attribute data for pavement and infrastructure management and also for graphical display. The

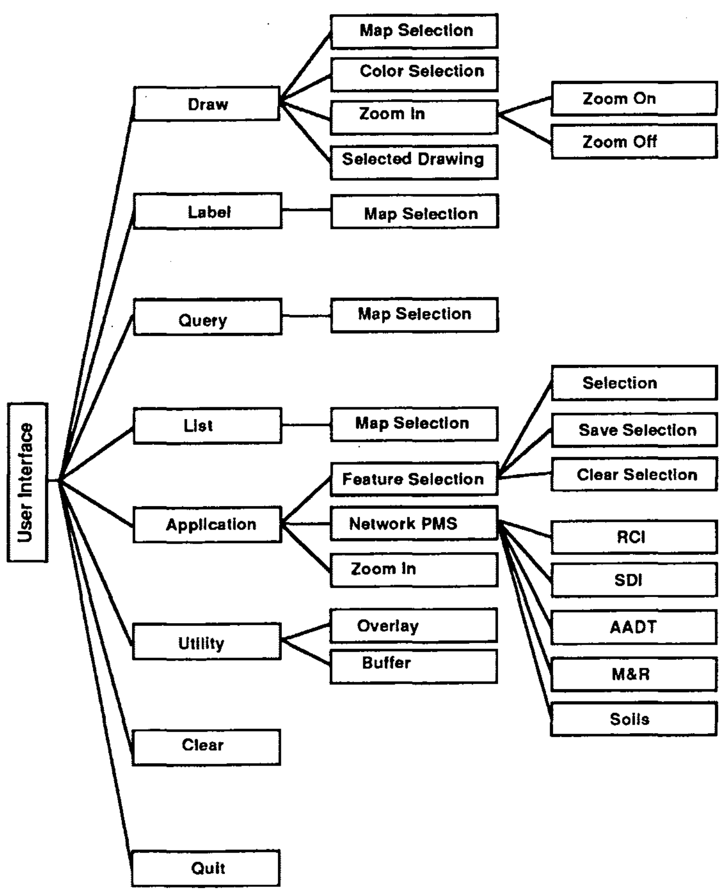

FIGURE 5 Major function modules in GIS-URMS.

user-friendly, menu-driven interface of the GIS-URMS greatly simplifies GIS application procedures. In addition, because of its modular structure feature, the GIS-URMS can be easily modified for other municipal infrastructure management applications.

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