GIS As a Tool for Pavement Management

Carlos Chang Albitres
28 April 2003

Texas A&M University
Department of Civil Engineering
CVEN689 Applications of GIS to Civil Engineering
Instructor: Dr. Francisco Olivera

Abstract

Maintaining roadway infrastructure takes great amount of time and money. Billions of dollars are invested annually on road maintenance to ensure the mobility of people and goods. However, deteriorating road conditions, increasing traffic loading, and shrinking funds have presented a complex management challenge to the maintenance and rehabilitation process. It requires evaluating pavement network conditions, deciding on maintenance strategies, setting rehabilitation priorities, and making investment decisions, which together make a pavement management system (PMS).

A Geographic Information System (GIS) is a powerful tool to manage and analyze data referenced to a geographic location. Pavement section information stored in textual databases can be linked by location and attribute in geographic maps using GIS. A GIS-Pavement Management System (GIS-PMS) can be used to integrate geographic and tabular data to retrieve information rapidly and effectively. The major advantage of this system is in serving as an analytical tool to perform queries and visualize the results in theme maps. A practical case explores the capability of a GIS-PMS to visualize the impact of maintenance and rehabilitation strategies through “what if” theme maps that can be used to justify budget request for public fund investment.

Introduction

The Federal Highway Administration (FHWA) defines a Pavement Management System (PMS) as “a set of tools or methods that assist decision makers in finding cost-effective strategies for providing, evaluating and maintaining pavements in a serviceable condition”. A PMS is designed to provide objective information and useful data for analysis so that agency’s managers can make more consistent, cost-effective, and defensible decisions related to the preservation of a pavement network.

The power of a Geographic Information System (GIS) relies in its capacity to capture and analyze the topological interrelationships of geographic infrastructure features. A GIS-Pavement Management System (GIS-PMS) can manage tabular and geographic data in the framework of an integrated database. The system can generate theme maps to show the information stored in the database or to visualize the results of customized queries in “what if” theme maps.
The purpose of this project is to experience the capabilities of a GIS – Pavement Management System (GIS-PMS) as an analytical tool to assist an agency in the planning and funding allocation process for pavement maintenance. The general objectives of the project are:

- To explore GIS capabilities as a tool for Pavement Management
- To develop a case study to show the applications of a GIS-Pavement Management System

The pavement management system (MTC – PMS 7.5) sponsored by the Metropolitan Transportation Commission (MTC) of the San Francisco Bay Area is used in the project. MTC is the transportation planning, coordinating and financing agency for the nine-county San Francisco Bay Area. MTC functions as both the regional transportation planning agency and for federal purposes, as the region’s metropolitan planning organization. The current version of MTC – PMS was developed by the Metropolitan Transportation Commission, Association of Oregon Counties and Marion County, Oregon in 1999 to improve pavement maintenance and rehabilitation techniques and practices in the region. More information about MTC-PMS is found at [http://www.mtcpms.org](http://www.mtcpms.org).

MTC provided most of the data in electronic database formats containing tabular and feature datasets. The information corresponds to the street network of the city of Hayward which is a community of 144,304 residents located at the heart of San Francisco Bay in Alameda County, California. The city website is [http://www.ci.hayward.ca.us](http://www.ci.hayward.ca.us).
Literature Review

The application of systems engineering and basic management concepts to manage highway infrastructure assets is not new. Pavement Management Systems (PMS) with different levels of complexity has been used within the last 20 to 30 years to assist agencies in the development of maintenance and rehabilitation programs. Due to the constraints of computer science to manage data, the applicability of PMS were limited at its early stages to store and retrieve data. Over the last 20 years the methods and tools available for PMS have progressed with the advance in technology. New technology to collect data; procedures to assess functional and structural pavement condition to identify treatments needed; deterministic and probabilistic prediction models to forecast future pavement conditions; ranking procedures to prioritize which pavement sections in need of treatment should be budgeted when funds are constrained; and methodologies to evaluate the impact of different maintenance and rehabilitation (M&R) strategies are now available.

Without any doubt, a powerful tool to assist decision-makers to maintain the road network in a desired condition level due to political and funding constraints is needed. A GIS-Pavement Management System (GIS-PMS) is the latest generation of these tools. The use of GIS as a tool for Pavement Management System is relatively new. This tool gives the decision makers a “better vision” to decide where to allocate funds and how and when to allocate them. The ultimate goal in this process is to identify the optimum maintenance and rehabilitation strategy for the road network by applying the “right treatment” at the “right time” for the sections in need. The possibilities of a PMS-GIS to generate theme maps to visualize information provide by the system is unlimited due to the flexibility and versatility of current technology. This new approach to analyze data is explored in this project through a case study.

Fig. 2. Generation of Theme Maps using GIS
Methodology

There are several issues to cover in the integration of geographic data with tabular data. The process starts with the development of a base map. The data stored in different formats is gathered from several sources. The first step is to link the pavement management sections in tabular data to the geographic street centerline segments in the maps in a “clean” database. The tabular data is in tabular database format, such as Microsoft Access format (mdb files) or Dbase format (dbf format), and the road or street network geographic data is in a vector format (shapefile format).

Fig. 3 Tabular Data in Microsoft Access Format

Relating Pavement Management System (PMS) and GIS street segments is the first task. It is observed in this task that some PMS and GIS segments have a “one to one” or “one to many” relationships while others have a “many to many” relationship. Another issue to overcome is that GIS street feature datasets could include streets who are not managed by the City such as State and Federal Highways. A “clip” procedure to extract only those streets within the Corporate city boundary is required. A query to select and remove the State and Federal Highways within the city limits is also needed.

There are usually discrepancies in the spelling in the street names in the two data sets that needs to be corrected prior to linking. A “clean up” data procedure is required before the name matching could proceed.
Once the linking process is successfully completed, the exploration of the use of GIS to visualize the data starts. The generation of theme maps with current data and “what if” maps to visualize the outputs from queries is performed during the process. A step by step description of the process is provided with the case study.
Application, results and discussion

The street network of the City of Hayward located in Alameda County, California is used to show the application of the methodology. Electronic files with tabular and vector data format were provided by the Metropolitan Transportation Commission of the San Francisco Bay Area. MTC-PMS 7.5 is the software used to assist in the pavement management analysis and ArcView 3.2 to generate the theme maps. The California Coordinate System (CCS) Zone 3, NAD83 is used as the horizontal datum.

An Arcview 3.2 extension “Hayward’s PMS/GIS” is used in the process by loading HaywardPMS.avx file. The extension allows to join or link tabular data in MTC-PMS 7.5 and vector data in ArcView 3.2 creating a new attribute table with basic information. The objectives of the project goes beyond the scope of “Hayward’s PMS/GIS” capabilities and application. Other database management and GIS techniques were used to link the data and generate customized theme maps.

![Hayward’s PMS/GIS ArcView 3.2 Extension](image)

Fig. 6 Hayward’s PMS/GIS ArcView 3.2 Extension

A description of the theme map generation process for each step of the management procedure follows.
Network inventory

The street network is divided into basic management units which are called “uniform sections”. This uniform sections are the “links” in the line feature dataset. A management section is identified as a segment of street, or road that has the same construction history, traffic (especially truck traffic), functional classification, and condition along its entire length. Inventory data is collected and stored in the database for each management section.

The data stored in the database network inventory is displayed visually by customized theme map. A theme map with functional street classification was generated as a first example. The streets are classified based on its function in arterial, collector, or residential/local class. Colors to differentiate the functional class are selected in the legend.

The total street network length is 596 miles of which 25.9% of the network is composed by arterial streets, 17.1% by collector streets, and 56.9% by residential/local streets. This percentage can be calculated either by MTC-PMS 7.5 or by summarizing the functional classification field using ArcView 3.2. The street network replacement cost is estimated in $290 million dollars.

Fig. 7 Street Network Classified by Functional Classification
Chart ArcView 3.2 is used to generate a bar chart to summarize functional class. The capabilities of this tool are limited to basic charts.

A second example of a customized theme map is applied to visualize the year of construction of the streets classified in groups of 25 years.

Fig. 8 Chart generated in ArcView 3.2 to show functional classification

Fig. 9 Street Network Classified by Year of Construction
**Condition assessment**

The condition of the pavement is measured in terms of the Pavement Condition Index (PCI) based on distresses observed on the surface. Distresses are rated by a team of agency personnel walking on the pavement surface or standing on the curb. The distress survey information is used to calculate the PCI to rate the pavement condition on a scale from 0 to 100 with higher values indicating better condition. Five condition categories are defined. Type I includes pavements with little or no distress and PCI values from 100 to 70, a pavement in this category may be described as “excellent” or “very good”. Type II includes pavements with a significant level of distress which is predominantly non load-related and PCI values from 70 to 50, a pavement in this category may be described as “good” or “fair”. Type III includes pavements with significant level of distress that is predominantly load-related and PCI values from 70 to 50, a pavement in this category may be described as “good” or “fair”. Type IV includes pavements with a major distress and PCI values from 50 to 25, a pavement in this category may be described as “fair” or “poor”. Type V includes pavements with extensive amounts of distress and PCI values from 25 to 0, a pavement in this category may be described as “very poor” or “failed”. A theme map to visualize the current pavement condition was generated. Pavement condition expressed in terms of PCI is shown in the map.

Fig. 10 Street Network Classified by Pavement Condition Index
The average PCI street network is 65 which characterizes a network in good to fair condition. From the total street network, 54.4% of the street network is in very good condition, 20.7% of the street network is in good to fair condition, 26.1% of the network is in fair to poor condition, and 8.8% of the network is in poor condition or has failed.

**Forecasting pavement condition**

Once the condition of each pavement section is determined in terms of PCI, a procedure to predict future condition is required to identify what and when maintenance or rehabilitation treatments are needed. To project the pavement condition, a “family performance curve” based on the performance of existing pavements versus age is used.

![Pavement Deterioration Model](image)

**Fig. 11 Pavement Deterioration Model**

**Determination of maintenance and rehabilitation treatment needs**

Based on pavement condition the treatments needed for each section are estimated for each year of the analysis period. A decision tree relates the condition of the pavement management section with a maintenance and rehabilitation treatment.

A theme map is used to visualize the maintenance and rehabilitation treatments needed in the next three years.
Fig. 12 Maintenance and Rehabilitation Treatments in the Next 3 Years

Budget needs over a twenty year period are shown in a chart created in ArcView 3.2. A total amount of $52 million dollars are needed in for a twenty year period.

Fig. 13 Budget Needs over a Twenty Year Period.
**Budget scenarios**

When limited funds must be allocated among a number of different projects, some method of identifying which projects are considered the most important must be developed. Pavements in good condition have lower user costs and pavements in poor condition have higher user costs. In addition, the longer the pavement remains in good condition, the longer the pavement provides lower user cost. The area above the PCI curve indicates the extra user cost and the area under the curve is the pavement user utility or non-cost benefit. Cost effectiveness analysis is used in this model to rank the sections and prioritize the needs.

![Cost Effectiveness Analysis](image)

**Fig. 14 Cost Effectiveness Analysis to Rank Sections**

A twenty year time budget analysis is carried out. Five budget scenarios are studied. The first budget scenario considers unlimited funding. The second budget scenario considers no funding. The third budget scenario considers 80% of budget needs available. The fourth budget scenario considers 60% of budget needs available. The fifth budget scenario considers 40% of budget needs. In all cases, 10% of the funds are considered for preventive maintenance. The budget scenario calculations were performed in PMP 7.5 which shows the results in tabular form. The results are used to generate customized “what if” theme maps in ArcView 3.2. Data in tabular form is exported by a “joining” or “linking” procedure to visualize the information in the theme maps. Only some theme maps are shown in the next figures since the possibilities of queries are unlimited and varies upon the user’s needs.
A theme map to visualize the treatments in the next twenty years is generated. In this theme map the treatments needed in the next year are highlighted.

Fig. 16 Treatments Needed in a Twenty Year Period
Theme maps to visualize the impact of funding constraints are generated. A theme map showing the streets in poor condition at the end of the twenty year period shows that almost the entire street network will be in poor condition or will fail if no funds are available. Another set of theme maps shows the streets in good condition at the end of the twenty year period for a 80%, 60% and 40% of needed funds available. It is seen from the theme maps that the percentage of streets in good condition reduces substantially when less funds are available to cover the needs.

Fig. 17 Streets in Poor Condition at the End of Year Twenty for a No Funding Budget Scenario
Fig. 18 Streets in Good Condition at the End of Year Twenty for a 80% Funding Scenario

Fig. 19 Streets in Good Condition at the End of Year Twenty for a 60% Funding Scenario
Fig. 20 Streets in Good Condition at the End of Year Twenty for a 40% Funding Scenario

Fig. 21 PCI evolution for Different Budget Scenarios
A plot of PCI evolution over the twenty year period for different budget scenarios shows that with 60% of funds available the average street network PCI remains in the average current condition which is a PCI value of 65.

A new approach to visualize data is explored using GIS. The line feature dataset is converted into a PCI grid to manipulate the data in raster format. Neighborhood Statistics Analysis is performed with the PCI grid.

The PCI average grid theme reflects that most of the streets are in good condition. The areas where the PCI is below 50 are identified in brown. Areas without data are also highlighted in white.

Another PCI grid using the minimum value is generated with Neighborhood Statistics Analysis to visualize zones in which streets in poor condition are being propagated even though the average PCI in that zone reflects an area in good or fair condition. This theme grid visualizes in brown the potential corridor zones that could need attention in a short or medium term in spite of the PCI average value of the zone.
Fig. 23 Minimum PCI Grid Theme Generated with Neighborhood Statistics

Fig. 24 Average PCI Grid Theme and Street Network Line Feature Theme
A view theme overlapping the average PCI Grid theme and the Street Network Line Feature Theme is shown. It is observed the good correlation between both view themes since the grid theme was generated from the same data source than the feature theme.

A surface PCI slope theme is generated to explore if some additional information can be inferred from this theme map. Even though is hard to visualize its significance, the zones with greater variation in the PCI can be identified. These areas has a higher slope which means that there are PCI segments with a higher rate of change in the PCI value within that zone.

![Fig. 25 A Surface PCI Slope Grid Theme and Line Feature Shape Theme](image)

The sample theme maps generated in the case study shows how useful is a GIS application in order to visualize existing data stored in the database or new information generated by a Pavement Management Software.
Conclusions

In this project it has been shown that one of the major benefits of an integrated GIS-Pavement Management System (GIS-PMS) is its flexibility to visualize the data in theme maps to support agencies in the funding allocation process and justify their budget request for pavement maintenance and reconstruction treatment. This is accomplished with the implementation of the graphic capabilities of GIS to manage data in order to generate “what if” customized theme maps according to the user’s needs. In this sense, a GIS-PMS is a powerful tool to visualize the impact of maintenance and rehabilitation strategies, and budget scenarios.

The possibility to integrate a GIS-PMS with other infrastructure management systems by a global GIS system as the heart of a central database is feasible. This tool will allow the agencies to share, and compare information among databases, avoiding project conflicts and making more coherent decisions. The applications of a Global Integrated GIS-Asset Management System at the planning level with the advance of today’s technology are truly unlimited.
References


12. Francisco Olivera, Application of GIS to Civil Engineering, Class Notes CVEN 689. Texas A&M University, Civil Engineering Department, Spring 2003.