Geographic Information System for Pavement Management

Pavements are one of the critical elements of the highway transportation infrastructure in the United States. Billions of dollars are spent annually maintaining and rehabilitating pavement. However, deteriorating pavement conditions, increasing traffic loads, and limited funds present a complex challenge for pavement maintenance and rehabilitation activities. A Pavement Management system (PMS) identifies the needs, helps to allocate funds, supports decision making, and maintains good pavement conditions under the constraint of limited funds. Traditional pavement management systems for highways/airports have been built using the pavement condition index (PCI) by MicroPAVER software, which was designed to minimize pavement maintenance budgets. Although MicroPAVER represented major advancements in the 1970s, they are nearly obsolete particularly in terms of their usefulness in the management of pavements at airports that serve large carriers.

A well-designed geographic information system (GIS) provides a platform on which all aspects of the PMS process can be built. The resulting system, GIS/PMS, represents a significant enhancement of all aspects of the PMS process. A variety of spatially integrated data are important to pavement management decision making. GIS technology is shown to be the most logical way of relating these diverse, but relevant, data. The components include data collection, preliminary data analysis and interpretation, system assessment, determination of strategies, project identification and development, and project implementation. Each of these stages in the PMS process is enhanced by GIS technology.

Comprehensive pavement management models require a diverse collection of highway-related data including pavement condition surveys, skid resistance measurements, traffic counts, bridge inspections, sign inventories, photologging, accident investigation, construction and maintenance records and inventories of signs and roadside obstacles. Although these data may be available in digital format, they are typically unrelated to each other, duplicative and inconsistent. The various files may have been created independently of one another, using different referencing systems or computer formats. Popular referencing systems include milepost, reference post, paper document methods, state plane and latitude longitude. In the worst case, some of the data required for analysis may not be spatially referenced at all. As a result, they are difficult to use in a consistent and efficient manner as inputs to a PMS. GIS technology is proposed as a framework for data integration because it provides a means of relating data collected under various referencing systems.

A GIS would enrich the decision-making process by incorporating other types of data that could not easily be brought into the process without the ability to relate data spatially. One of the example is accident analysis requires the correlation of a number of explanatory roadway and environmental variables such as roadway geometric, weather conditions, traffic volumes, signage, signalization, lighting, and pavement condition. A GIS can serve as the integrator of all transportation activities (e.g., pavement management, accident analysis, sign and signal inventories and planning), as well as the link to other agencies with overlapping data needs (e.g., planning, environmental resources, utilities).
A number of essential analytical capabilities that should be included in comprehensive GIS/PMS have been identified (Neelam Jain et.al):

- Data base editor for storing and editing pavement condition data and other data to be used in the analysis;
- Formula editing of data base fields that facilitates the computation of new relationships such as an overall condition rating;
- Univariate statistics (min, max, sum, mean and standard deviation), e.g., to compute the total lane miles with a deficiency rating greater than 90; multiple regression to compute deterioration equations; correlation to compute dependence between possible explanatory variables such as truck volumes, weather, and soil conditions and pavement condition;
- Charting (e.g., pie charts and bar charts) to enhance the understandability of the data and make it easier to communicate results to decision makers, politicians, and citizen groups;
- Matrix tools for creating and manipulating origin-destination tables, travel time matrices, and other one and two-dimensional matrices used in transportation models for shortest path detour determination and traffic assignment;
- A set of useful transportation models and algorithms including shortest path, traffic assignment, vehicle routing (for efficient reallocation of trucks and equipment), and traveling salesman (for the delivery of materials to several construction sites); and
- Links to external procedures such as life cycle costing, decision analysis, shortest path, and traffic assignment.

Conclusions

GIS can be a very important tool in a decision support system by facilitating preparation, analysis, display, and management of highway data in a geographical platform. In particular, pavement management is a decision process that could benefit from the use of a geographical platform provided by GIS, because road networks are inherently geographic. Spatial considerations are not only essential in analyzing the different road related activities, but also can vastly improve the quality of the decision-making process.

Annotated Bibliography

Huang, B; Fwa, TF; Chan, WT, (2004) Pavement-Distress Data Collection System based on Mobile Geographic Information System. Transportation Research Record No.1889, pp 54-62

The research dealt with the development of geographical information systems (GIS) that has shifted significantly from desktop applications to mobile field applications. The author used the concept of integrating the precision location data collection capability of a Global Positioning System (GPS) and the spatial processing power of mobile GIS which provides an adequate system for field workers to collect data with increased efficiency and ease. This research aims to design and implement a pavement-distress data collection prototype for inspecting airport pavement condition, with the aid of mobile GIS. Unlike the traditional paper forms, the data collection system seeks to offer a customized user interface for distress data entry and a spatial query service. Initial preparation of the airport map layers was carried out on desktop computer using a variety of off-the-shelf software. The required files were then transferred to the personal
digital assistant (PDA) for field trials. Two other handheld devices, namely the GPS receiver and digital camera, are attached to the PDA to capture precise location coordinates and digital photos, respectively, of the identified distress. The users are also able to obtain comprehensive search results of the distresses, in both an attribute table and map visualization form. To increase the search efficiency, an indexing method was implemented for the data collected.


This study examined a road surface temperature prediction model in a snowy, mountainous region in Japan. The road surface temperature varied from one segment of the road to another. This was mainly due to the fact that environmental factors were unique at each road segment. In general, the road surface temperature reached its maximum point in the midday and reached its lowest point just before sunrise. However, in a rugged mountainous environment, the road surface temperature does not follow a simple diurnal pattern. This study demonstrated the necessity of road surface temperature predictions at a local scale, rather than a regional scale, since regional forecasts may not depict any local-scale problems, such as road icing. This study used both geographic information system (GIS) and Global Positioning System (GPS) as tools. Results from the road surface temperature predictions are illustrated visually using a GIS program so that any potentially problematic road segments can be identified geographically at different times. The use of GPS facilitated the compilation of various data with respect to their geographic coordinates. The outcome of the study was to help highway maintenance authorities focus their efforts more carefully on potentially problematic road segments rather than on the entire road system. Moreover, they could narrow the time window for maintenance activities, thus saving resources while providing safe road conditions for the general public.


The author proposed an approach that employs GIS application programs written in ARC macro language to calculate the actual length (surface length) along the sloped surface of highway centerlines based on elevation data and the road network geometry. The traditional way to obtain it is to drive cars equipped with a distance measurement instrument (DMI) along roads to measure mileages. This method provides accurate measurements, but it is expensive and time consuming. The calculated GIS results were compared with DMI measurements, which is the most accurate approach presently available to NCDOT. Three filters were applied to remove suspect road segments that have significant errors which are irrelevant to the proposed approach. All remaining segments were grouped by slope and length to evaluate the impact of slope and length on the accuracy. Frequency analysis and root mean square error were determined for all groups. It was found that the proposed method is a technically feasible method with reasonable accuracy. The study also revealed that where there are errors, they occur primarily for road segments with relatively high slopes, short lengths, or both. The meaning of this is that GIS and digital elevation model technologies can be combined and used in lieu of DMI measurements, thus reducing resource demands.

The present paper described the evolution of the key elements of the PMSs over the last three decades and identified the future direction of each element. The key PMS elements are addressed as Functions, Data collection and management, Pavement performance prediction, Economic analysis, Priority evaluation, Optimization, Institutional issues, and Information technology. The author reports that among the significant improvements expected in the PMSs in the next 10 years are improved linkage among, and better access to, databases; systematic updating of pavement performance prediction models by using data from ongoing pavement condition surveys; seamless integration of the multiple management systems of interest to a transportation organization; greater use of GIS and GPS to store, process and display location-referenced spatial data and also provide real time data.


The research addressed the problems of storing continuous data or data that change discretely but very often in PMS such as pavement distress. He summarized three most common approaches for segmenting linear features in a GIS are fixed-length segments, variable-length segments, and dynamic segmentation. This paper introduces an on-the-fly dynamic segmentation approach that combines conventional dynamic segmentation with database manipulation and aggregation operations to more efficiently manage continuous or nearly continuous road segment data in a GIS. The approach was developed specifically to overcome some of the hardships that were experienced with managing pavement-marking retro-reflectivity data being used by the South Carolina DOT.


The author discussed the critical issues related to implementing GIS for Pavement management Systems (PMS). He started by a survey with district pavement engineers, of the issues that were most important for GIS-PMIS based on his or her daily business activities and discussions and summarized them. The development of a comprehensive and practical implementation plan using GIS to enhance the pavement management practice in the Texas Department of Transportation is presented. As the basis of the implementation plan, a "three-stage implementation" concept was used to assess the current practice, define the visionary system, and identify the intermediate solutions. Also presented are several key issues and aspects important to the successful implementation of GIS for pavement management.

The author compared the traditional pavement management systems for airports that have been built using the PCI (Pavement Condition Index) of the FAA endorsed MicroPAVER software, which was designed to minimize airport maintenance budgets with the present map-based systems that have sophisticated analytical tools. The application of GISs for infrastructure management, environmental analysis, and airport operations is becoming commonplace at larger U.S. airports. Integration of infrastructure management in general and pavement management in particular with airportwide GISs provides far greater management capabilities than traditional infrastructure management systems. The author concluded that the development of integrated airport GISs and the availability of affordable, differentially corrected Global Positioning System receivers have resulted in a paradigm shift in methods of infrastructure management.


The main features of a computerized system to provide decision support to the agencies involved in highway maintenance management in Greece are presented. The system includes a database and modules for pavement performance prediction, resource allocation, and project management. In addition, a user interface system with appropriately designed input/output forms and geographic information system data representation improves applicability. The major pavement defects such as cracking (mostly alligator type, longitudinal, and transverse), potholes, corrugations and rutting, bleeding, raveling, and polished aggregate, which results in high roughness and low skid resistance are represented in the system by four parameters: cracking index, index to the first cracking, roughness index, and skid resistance index. Further, a number of possible treatments have been identified and described in terms of materials, methods, machinery, and cost requirements. For each defect, all feasible treatments are considered, and the best maintenance strategy is produced considering relative costs, funding availability, and maintenance needs over time within the network.