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Edited by
Mishac K. Yegian
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A PROTOTYPE PAVEMENT NETWORK DATABASE AND GEOGRAPHIC INFORMATION SYSTEM STRUCTURE

Ying-Haur Lee, Ph.D.[1] and Zhong-Qiang Lu[2]

ABSTRACT

The primary objective of this study is to develop a prototype database and geographic information system (GIS) structure for "network level" pavement management. The concepts of "sampling" and "uniform section" are proposed for domestic pavement network database structure and collection procedures based on the considerations of specific, measurable, achievable, relevant, and timely principles. Relational database structure of a commercial software package is adopted in this study. Many tables of pavement inventory, rehabilitation, traffic, and survey data are recorded using their original data collection formats for the ease of recording and updating. A systematic approach using various sorting and matching techniques is developed to overcome the current deficiencies of such relational databases based on the principle of "dynamic segmentation." Summarized uniform section databases are generated for different survey years automatically. Consequently, a prototype pavement "NETwork Dynamic Segmentation Database (NETDSD)" structure is developed using Microsoft Visual Basic and Access software packages with many user-friendly interfaces for recording, updating, summarizing, query and reporting purposes. A concise GIS presentation feature is also added to the program. This prototype program can be used as the core for future development and integration of our domestic network pavement databases and network optimization analysis.

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INTRODUCTION

Due to the rapid expansion of our domestic highway networks, increasing demands for the planning and programming of pavement maintenance and rehabilitation activities became extremely troublesome and time consuming. The present framework of Taiwan's Pavement Maintenance Management System (PMMS) was originally developed under the ideal considerations of a total pavement management system, which consists of survey, analysis, evaluation, planning and programming, design, construction, material, and environment subsystems [Haas, Hudson, and Zaniewski, 1994]. Without utilizing the concept of "sampling" and identifying the levels of data requirements, a certain fixed length "sample unit" of 100 meters is currently used as the "management unit" throughout the entire pavement network [Taiwan Area National Freeway Bureau, 1997; Chang, 2001]. Such a network PMMS requires the formidable task of mass data collections and compilations. Thus, it has restrained the system from further practical network management analyses due to lack of data integrity. After approaching 20 years of system implementation, the PMMS could barely meet the needs for "network-level" and "project-level" management purposes.

An efficient database structure is the key to the success of a pavement management system. A well-organized database can provide adequate information for pavement network management with convenience and efficiency. Thus, to improve the efficiency of pavement management practices it is crucial to identify the dominating database framework problems correctly. With the promising features of information technology and geographic information system (GIS) in transportation applications, the needs for database integration and geographical representation of the data become inevitable.

The main objective of this study is to develop a prototype database and GIS structure for "network level" pavement management in Taiwan [Lu, 2001]. In management needs perspective, the proposed PMS objectives must be Specific, Measurable, Achievable, Relevant, and Timely (SMART) given the resources available and the prescribed timeframe [Geoffroy, 1991]. The concepts of sampling, uniform section (or management unit), dynamic segmentation, pavement composite index, and network level management are proposed for domestic pavement network database structure in a cost-effective manner. Guidelines for the collections and integration of domestic pavement network databases are subsequently discussed.

PAVEMENT MANAGEMENT AND DATABASE REQUIREMENTS

Pavement management is a process to use any effective methods and approaches to provide road users the acceptable level of the roadway conditions. An effective pavement management system (PMS) often adopts system approach in working with the related information for pavement management and rehabilitation activities. The American Association of Highway and Transportation Officials [AASHTO, 1990] states that the "... function of a PMS is to improve the efficiency of decision making, expand its scope, provide feedback on the consequences of decisions, facilitate the coordination of activities within the agency, and ensure the consistency of decisions made at different management levels within the same organization."

The various PMS activities are categorized into different levels, because the required levels of information detail and complexity are different. Network level adopts simple and highly efficient approach to assist in the selection of maintenance and rehabilitation alternatives, priority programming, as well as budget allocation. Project level PMS involves project-specific technical activities and requires more detailed information. For example, priority programming is conducted at higher management level, which should cover the entire pavement network. The evaluation of maintenance and rehabilitation activities needs more specific pavement-related information, whereas research and special studies require most detailed information.

A pavement section can be defined to have uniform characteristics or fixed length. The advantages of the fixed-length approach is its simplicity and the ease of locating sections, whereas the advantages of selecting the uniform section approach is the ease of data analysis and updates. Characteristics of a pavement section may change from time to time; a pavement section with homogeneous characteristics of material, traffic, construction date, or rehabilitation date may be obtained through the process of dynamic segmentation. Many existing network PMS focuses on the condition and performance of the pavement structure. The functional and structural (or engineering) behaviors of the pavement structure are often evaluated through pavement structural capacity, pavement distress, and pavement safety evaluations.

The required data types usually include section identification, inventory, maintenance, traffic, performance, environmental, and cost related data from various sources. Condition surveys are regularly conducted to collect pavement condition, distresses, and performance data. Composite indices are often used as the combined measure of pavement quality for management purposes. For example, pavement condition index (PCI) or pavement surface distress index (PSDI) is used for structural evaluation, whereas condition rating survey (CRS), present serviceability rating (PSR), or international roughness index (IRI) is used for functional evaluation. Measurements of skid resistance or friction can be used for pavement safety evaluation. Various nondestructive deflection testing (NDT) devices can be used to access the structural capacity or adequacy of the pavement structure.

National Cooperative Highway Research Program (NCHRP) Synthesis 203 indicated that most agencies collect distress and roughness data as part of their PMS [Gramling, 1994; Zimmerman, 1996]. Many agencies collect friction data, but do not incorporate it into their PMS decisions; half agencies collect deflection information only for project-level designs, rather than for network-level planning and programming purposes. Zimmerman (1996) also noted that most pavement management recommendations from a PMS are made at the network level, rather than at the project level. A network-level PMS consists of the following seven basic components: network inventory, condition assessment, database, model development, data analysis, outputs, and feedback loop. The implementation of the ILLINET pavement network rehabilitation management program for the Illinois interstate highway system is a good example. Minimum

pavement data were needed for forecasting the future pavement network rehabilitation needs [Mohseni, 1991; Hall, *et al.*, 1994; Wang, *et al.*, 1995].

DEVELOPMENT OF A NETWORK DATABASE FRAMEWORK

The pavement inventory and condition data are of little value to agency's management needs if they are not well organized and stored in an easily accessible computerized database. The characteristics and features of three widely accepted database types including hierarchical, network, and relational databases have been investigated [Lu, 2001]. Among them, the relational database, which stores information in a series of tables, is the most common type of database for PMS purposes.

Thus, the relational database structure of a commercial software package (Microsoft Access Software) is adopted in this study. Separated tables of pavement inventory, rehabilitation, traffic loading, and condition survey data are recorded with various pavement features in their original data collection formats. The variable definitions and recording units are defined according to the long-term pavement performance (LTPP) database [FHWA, 1999]. The records in different tables may consist of one-to-one, one-to-many, and many-to-many relationships. At different locations (beginning and ending kilometer posts) various features of the pavements will change along the roadway throughout the years. Only the data where features change are indexed and recorded in each table for simplification and the ease of recording and updating. To assure network continuity and data integrity with minimum resources, different sampling methods can be used to obtain yearly condition survey data in different sample units. Under this network database framework the length of management unit or uniform section is no longer fixed, but will be automatically generated according to different pavement feature tables and different survey years through dynamic segmentation technique.

As illustrated in Figure 1, the fundamental principle of dynamic segmentation is to record only the locations where major features change to create uniform sections. A systematic approach using various sorting and matching techniques was developed in this study to overcome the current deficiencies of such relational databases. The following step by step dynamic segmentation procedures have been formulized and coded using the Visual Basic software package to automatically create the summary database from various Access tables [Lu, 2001]:

1. Merge different feature tables including the beginning kilometer posts (BKP) and ending kilometer posts (EKP);
2. Sort the above table (step 1) by BKP in ascending order;
3. Sort the above table (step 2) by EKP in ascending order;
4. Set the BMP of the following records to the EKP of the preceding records of the above table (step 3);
5. Copy the information of each data element from the last record upward to each corresponding blank fields until information changes and repeat the process again till the first record; and
6. Delete those records having the same BKP and EKP fields to obtain the

resulting dynamic segmentation database.

By doing so, various uniform section (or dynamic segmentation) databases can be flexibly and efficiently generated to reflect the fact that pavement features may change throughout the years. This is also one of the major reasons why this network database framework is more favorable than the traditional fixed-length section database structure. For efficiency concerns, under this network database framework each original data source can still be recorded and maintained in its original data formats by their responsible agencies or departments.

APPLICATION OF GIS TO PAVEMENT MANAGEMENT

Geographic information system (GIS) is a specifically designed information system to store and manage various attributes of spatial and non-spatial data, which integrate mapping, graphical representation, and database management techniques. There exist many widely adopted commercial GIS systems such as MapInfo, ArcView, TransCAD, Geomedia, and AutoCAD software packages. The basic GIS features consist of data input, data management, data analysis and summary, and outputs. The applications of GIS to pavement management activities have become more and more popular [Shahin, 1997; Lee, *et al*, 1999; Chang, 2001].

The applicability and advantages of the aforementioned software packages for network pavement management were first investigated [Lu, 2001]. Although there are many advantages of using the existing commercial programs to develop a GIS system, the following important issues are considered:

1. Reduction of data repeatability;
2. Source codes for future improvements, feature enhancements;
3. Chinese user-interface for popularity and convenience; and
4. Applicability to PMS purposes.

In addition, under the above network database framework the graphical representation of a given GIS system must satisfy the management needs of using adjustable section length. Such a requirement is considered crucial in developing an efficient network pavement database with graphical representation features.

A prototype GIS system of Taiwan's highway pavements was initially developed in this study using the Geomedia software [Intergraph Inc., 1999; Lu, 2001]. However, due to the fact that its section length cannot be easily and automatically altered using the above dynamic segmentation databases, it was decided to develop a simplified geographical representation module of the network pavement database from scratch. The major tasks involve digitization of existing maps and creation of cross links between the databases and the maps. In which only those pavement features needed for pavement management purposes are included. The section length is adjustable and can be represented by graphics using the resulting dynamic segmentation databases automatically. Other additional features can be added when necessary. Also note that the latest commercial GIS software packages may have added new dynamic segmentation features which make them more promising for future pavement management needs and deserve our special attentions, i.e., ArcView.

DEVELOPMENT OF A PROTOTYPE PAVEMENT NETWORK DYNAMIC SEGMENTATION DATABASE

Consequently, a prototype computer program for pavement NETwork Dynamic Segmentation Database (NETDSD) structure is developed using the Microsoft Visual Basic and Access software packages. A relational database structure and the existing software package's features are used for the easy of implementation and possible future enhancements. The database structure consists of inputting pavement inventory data, recording multi-year traffic and condition survey data (or historical data), and updating major pavement maintenance information in their original data formats. Dynamic segmentation database may be automatically created based on the historical data imported from different years. The main features of the program include many user-friendly interfaces for recording, updating, integrating, summarizing, query, and reporting of the network pavement databases. For illustration purposes, Figure 2 shows a tabular summary of the resulting dynamic segmentation database under a specific year.

Moreover, a concise GIS module with simple mapping functions in the NETDSD program is developed to graphically represent the resulting uniform sections with varied section lengths for the ease of use, control, and updates. The pavement type, thickness, age, traffic, condition, rehabilitation year of each section is graphically displayed as a line on the screen. The lines are colored to show different pavement attributes. The user can move among sections using the graphical user interface. For example, Figure 3 depicts a simplified example chart display of the pavement conditions along the highway pavement network in Taiwan.

This prototype program can be used as the core for future development and integration of our domestic network pavement databases and network rehabilitation optimization analysis. In a related study, Hung [2001] developed a Windows-based prototype computer program (TKUNET) for the alternative strategies optimization of pavement network rehabilitation management which requires the same minimum amount of network pavement data to be provided by the NETDSD program. In which many user-friendly interfaces could be used to assist high-level pavement management officials in answering lots of "what ... if ..." questions such as the determination of future rehabilitation needs, tabular and graphical query, network summary and presentations of optimized budget allocation problems. The prototype system can be further expanded with ease and efficiency so as to assure the best use of our limited resources for network pavement rehabilitation through minimum time, effort and cost.

CONCLUSIONS AND DISCUSSIONS

The concepts of sampling, uniform section (or management unit), dynamic segmentation, pavement composite index, and network level management are proposed for domestic pavement network database structure in a cost-effective manner. Guidelines for the collections and integration of domestic pavement network management databases are subsequently discussed based on the considerations of Specific, Measurable, Achievable, Relevant, and Timely (SMART) principles. Relational database structure of a commercial software package (Microsoft Access) is adopted in this study. Many tables of pavement inventory, rehabilitation, traffic, and survey data are recorded in their original data collection formats for the ease of recording and updating. A systematic approach using various sorting and matching techniques is developed to overcome the current deficiencies of such relational databases using dynamic segmentation concept. Summary databases are automatically generated for different survey years.

Consequently, a prototype program for pavement "NETwork Dynamic Segmentation Database (NETDSD)" structure is developed. The main features of the program include many user-friendly interfaces for recording, updating, summarizing, query, and reporting of the pavement network databases. Moreover, a concise GIS module with simple mapping functions in the NETDSD program was developed to graphically represent the resulting uniform sections with varied section lengths for the ease of use, control, and updates. This prototype program can be used as the core for future development and integration of our domestic network pavement databases and network optimization analysis. By doing so, a better organized pavement database and efficient network pavement management system can be developed and enhanced.

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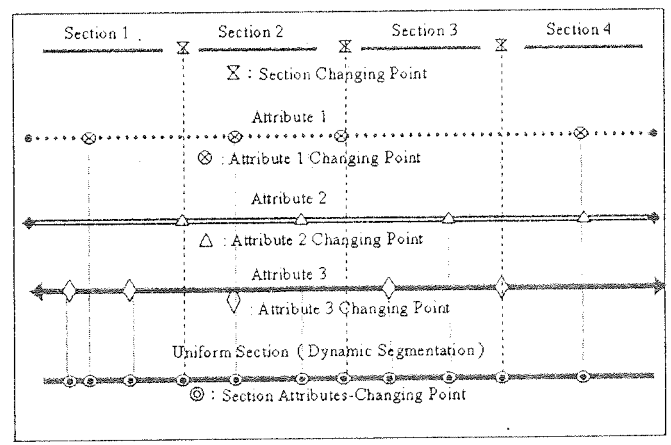

Figure 1. Illustration of the Concept of Dynamic Segmentation

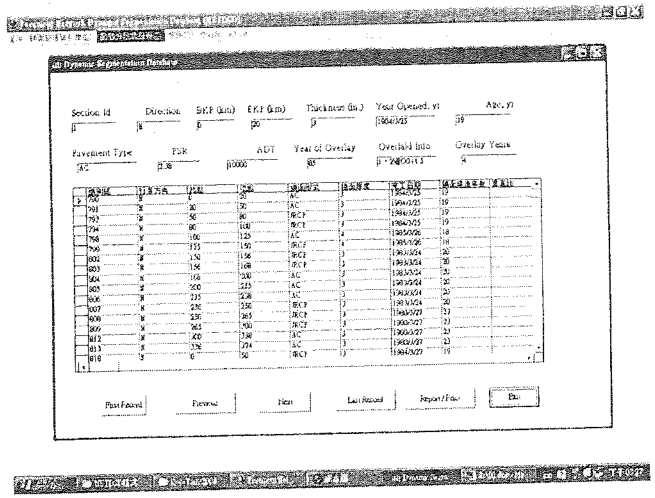

Figure 2. Example Outputs of the Summarized Uniform Section Database after Dynamic Segmentation

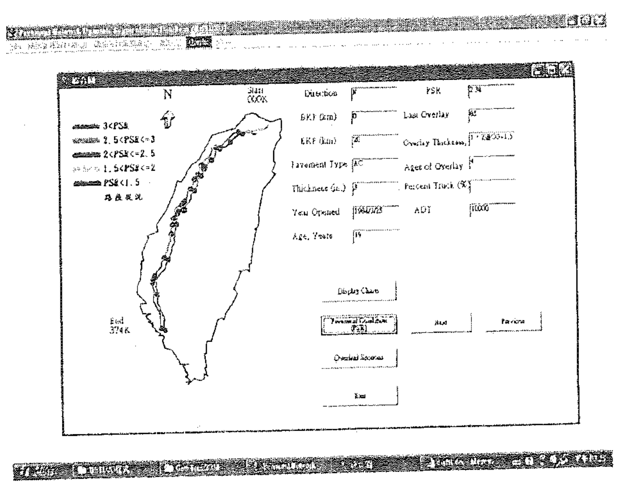

Figure 3. Example Graphical Representation of Pavement Conditions

GEOTECHNICAL PROPERTIES OF OVEREXCAVATED EXPANSIVE SHALE AT A STEEPLY DIPPING BEDROCK SITE

William J. Likos[1], Member ASCE, Ning Lu[2], Member ASCE, Kevin J. Sharkey[3]

ABSTRACT

Infrastructure development in the Rocky Mountain Front Range piedmont near Denver, Colorado is marked by unique hazards arising from underlying beds of steeply dipping, expansive bedrock. Efforts to reduce the occurrence of damaging differential movements among adjacent strata with dissimilar swelling characteristics often include overexcavation, remolding, and recompaction of the on-site materials. This paper examines the geotechnical engineering behavior of two end member materials obtained from adjacent shale strata at a steeply dipping site where overexcavation prior to construction is warranted. The series includes index (Atterberg limits), compaction, suction, and volume change (shrinkage) testing for each end member material as well as mass controlled mixturesof the end members . Linear relationships are noted between the relative mass fraction of the end members and the engineering behavior of the mixtures, thus allowing the swelling potential, compaction characteristics, and volume change characteristics of remolded fill at the site to be predicted from characteristics of the end member soils comprising it.

INTRODUCTION AND BACKGROUND

Steeply dipping bedrock is a geological hazard common along Colorado's Front Range piedmont where steeply dipping sedimentary formations containing discrete strata of expansive claystone are encountered near the ground surface. Problematic formations in the area, most notably the Pierre Shale or other Upper Cretaceous

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