CHAPTER 3: PAPER 43

PAPER 43

Integrating Pavement Preservation into a Web-based Chuning Highway Pavement Management System

Yichang (James) Tsai
Associate Professor, Georgia Institute of Technology, Savannah, Georgia, United States

Yiching Wu
Research Engineer, Georgia Institute of Technology, Savannah, Georgia, United States

Dajin Guo
Deputy Director, Research Institute of Highway, Chinese Ministry of Communication, Beijing, China

ABSTRACT

This paper presents the Chuning Expressway Pavement Management System (Chuning PMS), a web-based PMS integrating the pavement life cycle activities (e.g. design, construction, condition survey, maintenance, etc.) that support pavement preservation strategy and life cycle cost analysis (LCCA). The integration allows the users to track the long-term pavement treatment performance and provide the results to the decision support system. In addition, the web-enabled system provides a common platform for different parties (e.g. pavement engineer, manager, condition evaluation contractor, maintenance contractor, etc.) to share the pavement inventory and efficiently participate in the decision making process. Opened to traffic in 2006, Chuning Expressway is an 84.5-km 4-lane strategic highway connecting the Anhui province and the Nanjing economic region in Jiangsu province in China. The expressway is a typical Private Public Partnership (PPP) project, owned and managed by a private company for 30 years before being transferred to the public. With investment return incentives, the company has supported the development of a PMS to integrate pavement life cycle activities, track pavement treatment methods and corresponding expenditures, perform treatment benefit-cost analysis, and identify the optimal pavement preservation for the system. The system now maintains design documents (plan and profile drawing, pavement structure design, typical section, etc.), pavement survey data (IRI, Falling Weight Deflectometer (FWD), and surface distress data), and detailed truck traffic data (e.g. number of axles and vehicle loads) for establishing a long-term pavement performance forecasting model. With the incorporation of web technology, the Chuning PMS enables engineers to perform a data-driven pavement preservation decision-making process by accessing and integrating various data on a common location reference, and allows roadway maintenance to be performed promptly. This paper presents the benefits of developing such a web-based PMS and with a recommendation for future research.
INTRODUCTION

In 2005, the total expressway mileage in China amounted to 41,000 km, ranking second in the world (China Highway Traffic and Transport Industry Report, 2006). The accumulated mileage of highway at county-level and town-level reached 1.4757 million km, sharing 85.4% of China newly-added highway mileage. According to the plan of Ministry of Communications of China, by 2010, the total highway mileage will achieve 2.1-2.3 million km, and 5 vertical and 7 horizontal national trunk highways will be completed; the total highway mileage will reach 50,000 to 55,000 km. By the end of 2030, the total highway mileage will reach 85,000 km. With rapid growth of highway construction, pavement preservation and management have become an important focus in recent years. The majority of the expressways in China are public-private partnership (PPP) projects. “PPP is defined as a contractual agreement formed between public and private sector partners, which allows more private sector participation than is traditional. The agreements usually involve a government agency contracting with a private company to renovate, construct, operate, maintain, and/or manage a facility or system. While the public sector usually retains ownership in the facility or system, the private party will be given additional decision rights in determining how the project or task will be completed” (US DOT, 2004).

“What distinguishes PPPs from traditional contract approaches to infrastructure development (such as Design-Bid-Build (DBB) project delivery and Pay-As-You-Go public sector financing) is the greater responsibility and risk taken by the private sector partners in return for an adequate return on their investment in the project or coverage of their costs” (US DOT, 2005).

Chuning Expressway is a typical Private-Public-Partnership (PPP) project in China. It is an 84.5-km 4-lane strategic expressway connecting Chuzhou City in the Anhui Province with the Naging economic region in the Jiangsu Province in China as shown in Figure 1. A semi-rigid pavement with 16-cm asphalt on the top of 56-cm soil-cement-lime stabilization is used on the expressway. Chuning Expressway was opened to traffic in 2006. Under the PPP, the private entity invests in the initial construction and collects the revenue through the tolls over the contract period to pay the operation and maintenance cost, repay the construction cost, and pay interest. During the revenue collecting period, the private entity owns and manages the highway. The Chuning Expressway Company was formed in 2002 to construct, operate, and maintain the Chuning Expressway for 30 years. Since the expressway opened to traffic in 2006, the company has restructured to carry on the tasks of operation and maintenance.

The routine maintenance, such as cleaning, crack filling and pothole patching, is carried out by a contractor. The contractor has a patrol team on the expressway to periodically clean the road and identify the needs for routine maintenance. The contractor reports the pavement distresses (e.g. potholes) to the owner and usually conducts maintenance work within 72 hours to ensure the integrity and safety of the roadway. The contractor also performs distress survey quarterly to locate any cracks that can be visually observed on the pavements. The annual pavement evaluation is conducted by the Chuning Expressway Company or the consultants to determine and prioritize the maintenance and rehabilitation activities. Due to limited personnel resources, it is expected that consultants and/or the pavement experts will be involved in making the decisions on the maintenance and rehabilitation activities in the future. With limited personnel resources and strong investment return incentive, Chuning Expressway Company has sponsored the development of Chuning Expressway Pavement Management System using web technology. This paper presents a web-based pavement management system developed in China. This paper presents Chuning PMS with a special focus on utilization of web technology to facilitate pavement preservation and management. This paper is organized as follows. The need for a web-based pavement management system for managing PPP highways in China is first identified. The web-based Chuning PMS is presented. Several cases are used to show the benefits of implementing such a web-based PMS. Finally, conclusions and recommendation of future research are made.
WEB-BASED CHUNING PMS

This section presents the developed web-based Chuning PMS. The Web-based Chuning PMS consists of 1) a database which is designed to keep track of all pavement life cycle activities, from design to reconstruction, and 2) a web-based analysis, visualization and reporting tools that allow the different parties (e.g. pavement engineer, manager, condition evaluation contractor, maintenance contractor, and third parties – consultants and experts) to share the information and functionalities to make the decision-making process efficient, and 3) a set of pavement condition-evaluation procedures easily available on the web. Web-based Chuning PMS consists of six modules as shown in Figure 2. They are the modules of Documentation, Pavement Inventory, Analysis & Reporting, Maintenance, Other Roadway Assets, and Data Management. They are briefly described below:
Documentation Module. This module enables engineers to update various roadway design drawings (e.g. plan and profile drawing, pavement structure design, and typical section drawing), images (location referenced images), and other documents into the system and users can query these drawings and documents. This module provides the function similar to an electronic library for storing and querying roadway design including pavement design documents. Users can select a location (e.g. 15KM) and the type of design document (e.g. pavement structure design). The corresponding drawing of pavement structural section can then be accessed as shown in Figure 3. The drawing shows a semi-rigid pavement designed with 4-cm AK-13, 6-cm AC-20, 6-cm AC25, 36cm CCR, and 20cm LS. Again, this information is available on the web so that engineers and managers from different parties can easily access this information.
2. Pavement Condition Inventory Module. This module contains all the pavement condition evaluation procedures and they are available on the web. For example, users want to know how a transverse and longitudinal crack is measured. Users can access this information through web technology. Figure 4 shows the definitions of different severity levels of transverse and longitudinal cracks along with distress photos. Additionally, this module can be used for pavement condition evaluation training and the knowledge base for identifying and measuring the pavement distresses. All of the pavement condition evaluation information can be easily access through the web at anytime and anywhere. For the pavement condition data collected in the field, this module provides the upload function for engineers to upload the data (e.g. IRI, FWD, and pavement distresses and rating). In addition, images taken on pavement distresses can be uploaded into the system. Once the pavement condition data is uploaded, engineers can perform various queries to access this information from the internet through the Analysis and Reporting module.
3. Analysis and Reporting Module. This module is used to analyze and visualize various data, including pavement rating, pavement distresses, FWD, IRI, and images with different formats. For example, engineers can review and compare IRI on each lane. Figure 5 shows that IRI on the outer lane of both east bound and west bound. The IRI is higher on west bound from 15km to 50km and on east bound from 50km to 95km. This may be related to surface texture or different traffic load. The pavement distresses observed during the condition survey can be visualized as shown in Figure 6.
4. Maintenance Module. This module is used to determine the adequate treatment method based on pavement conditions. Most importantly, the treatment actually applied and the corresponding treatment cost can be recorded. This information will enables us to perform the benefit cost analysis on evaluating different treatment methods (Wu, Tsai, & Pitts, 2006). The benefit can be evaluated based on pavement life from the pavement condition data. Figure 7 shows that the engineer can review the treatment generated by the system and record the actual treatment method and cost. The pavement maintenance guide can also be accessed through the web.
Compendium of Papers from the First International Conference on Pavement Preservation

Figure 7. Treatment record at station 15k-16k and maintenance guide

5. Other Assets Module. This module is to manage the assets other than pavements to demonstrate the benefits of a roadway asset management system. For example, the engineer can query the bridges by station and retrieve the corresponding bridge information as shown in Figure 8. Chuning Bridge is centered at 11+500k with a length of 3,293.5 m. The structure type and span are also listed. The condition evaluations of these assets are not developed yet and they could be evaluated in a separate module. The intent of this module is that the agency would like to extend from this web-based PMS to a complete roadway asset management in the future.
6. Data Management Module. This module provides administrative tools to manage the data and users in the system. The authorized administrator can manage user accounts (e.g., add a new user and remove an existing user), and removal of incorrect data.

The following subsection introduces the comprehensive roadway data collected with a special focus on pavement condition data. They are collected and managed using Chuning PMS. We will discuss more on the pavement condition data measurement in this section. Spatial data integration will also be presented in this section. The cases of data analysis, visualization, and reporting capability of the system will be presented in the next section.

**Comprehensive Roadway and Pavement Condition Inventory**

The Chuning PMS provides a comprehensive inventory of roadways and a few selected assets (e.g., bridges). The data stored covers activities over the pavement life cycle including the design documents, pavement condition survey, maintenance and rehabilitation records, traffic data, and other survey data, including FWD, roughness, and coring data. The design documents maintained in the Chuning PMS include but not limited to roadway design drawings (plan and profile drawing, typical section drawing, etc.), pavement structural design (with layer thickness, material, ESAL, and other design parameters). The database includes construction data (e.g., air void) which is designed to track the impacts on the pavement performance, though the data is not maintained in the system currently. For example, the impacts of high air voids on the HMA can be evaluated through studying the relationship between air voids and pavement performance and specific types of distress (e.g., transverse cracks). Pavement condition evaluations are performed by pavement distress measurement (e.g., distress type, severity, and extent, and pavement rating), Falling Weight Deflectometer (FWD), and International Roughness Index (IRI). Images showing roadway condition and pavement distresses are also recorded. The coring data, including location, layer thickness, and crack depths are recorded. Traffic data, including vehicle type, number of axles, and weight are recorded. The traffic data are very detailed and can provide a detailed traffic spectrum. Some roadway assets data (e.g., bridges) are also stored but their condition assessments are performed in separate systems.

The following introduces the pavement condition data measured and managed in Chuning PMS.
Falling Weight Deflectometer Measurement

FWD is used in the structural analysis to determine the bearing capacity, estimate expected life, and design a rehabilitation plan. According to “Highway Performance Assessment Standards (Ministry of Communications, 2007a),” FWD is one of the required tests upon the construction completion and recommended to carry out the measurement every 2 to 4 years for every 50 meters. A value of 100 (0.01mm), which is equivalent to 390 microinch, is the criteria for identifying potential structure deficiencies. The Chuning-PMS contains two sets of FWD, measured in 2006 and 2008.

Roughness Measurement

Roughness is defined as “an expression of irregularities in the pavement surface that adversely affect the ride quality of a vehicle”. The international roughness index (IRI) developed by the World Bank is used to quantify roughness. IRI is also a required test upon construction completion, and is recommended for carrying out the measurement every 2 to 4 years for every 50 meters. A value greater than 3.5 m/km indicates the pavement ride quality is poor. The Chuning-PMS contains two sets of IRI measured in 2006 and 2008.

Traditionally, images have not been incorporated into the PMSs or utilized efficiently in the PMSs. With the advances in roadway image collection technology, more roadway images will be available at a low cost. The use of images can provide good visual interpretation of the asset condition and the before-and-after comparison. The images are stored with a time stamp, location information, and the particular asset it is associated with.

Pavement Distress Measurement

Pavement condition data is essential to any PMS. A pavement condition evaluation procedure was developed to instruct the surveyor on how to identify, measure, and record the different distresses. The procedure is based on the Technical Specification of Maintenance for Highway (Ministry of Communications, 2007b) and Georgia’s Pavement Condition Evaluation (Georgia Department of Transportation, 1998). An online manual was developed with the images to illustrate the distress and severity. Engineers can easily access the definitions of pavement distress types and their severity levels, and their measurement methods through the internet. Figure 4 shows the definition of the transverse and longitudinal crack. It first describes that the transverse and longitudinal crack is typically caused by weathering of asphalt concrete surface or shrinkage of cement treated base materials or the reflective cracking from the semi-rigid pavement base. This type of distress is not load related. Sometimes, longitudinal cracks could be caused by the non-uniform settlement of embankment. Longitudinal cracks typically occur parallel to driving direction and are not located on the wheel paths. Figure 4 also shows the distress measurement method. Pavement condition raters choose a 21 meter sample section from each 200 meter segment. Raters need to record the severity and the total length. In addition, raters need to record pumping if there is any. There are two severity levels. Severity level 1 is when the crack width is less than or equal to 3mm; severity level 2 is when the crack width is greater than 3mm. The on-line manual shows a more detailed description.

Note that currently the procedure described is a manual data collection approach, but the system is not limited to the manual approach. The data collected using the automatic approach can also be uploaded and analyzed in the system.
**Bridge Information**

A few of the bridge survey items specified in the “Code for Maintenance of Highway Bridges and Culvers.” (Ministry of Communications, 2004) is included in the Chuning-PMS to demonstrate the capability and benefits of an asset management system.

**Data Integration**

In order to support spatial and temporal analysis, all the data is associated with location information and time stamps. The location information can use either a linear referencing system (LRS) or a geo-reference system that locates point location with x-y coordinates. Most of the data, like FWD, IRI, and pavement distress data, are linear-referenced using three attributes (direction, lane number, and station), and the coring location is geo-referenced with x-y coordinates. The system internally converts the geo-referenced data to the corresponding location on LRS using dynamic segmentation function. With the information, the pavement inventory can be related and analyzed spatially and temporally.

**APPLICATION CASES**

This section uses three cases to demonstrate the benefits of using web technology to support pavement preservation and management.

**Case 1: Effective pavement condition monitoring and preservation using web technology.**

Different parties (e.g. pavement engineer, manager, condition evaluation contractor, maintenance contractor, and third parties – consultants and experts) can communicate efficiently using web technology through the developed Chuning PMS. The objective is to achieve timely and effective pavement preservation and management. The roadway pavement condition can be monitored and preserved timely.

The contractor performing routine survey has a patrol team on the highway biweekly to identify surface deficiencies, such as potholes and cracks. The locations of the deficiency, as well as corresponding images, are collected. The contractor reports the survey results through web-based PMS by uploading the data into the system. The upload can be accomplished remotely via web access, as shown in Figure 9a. Figure 9b shows a transverse crack was observed at station 34+762 on the two-year-old pavement on March 2008.

The decision maker (e.g. pavement engineers and managers) can review the report and corresponding images, and issue a work order to the maintenance contractor or internal work crew. In Chuning Highway Company’s case, the routine maintenance is carried out by the same contractor conducting the survey.

The maintenance contractor performs the maintenance works and reports the completion of the work with corresponding images through the web-based PMS by uploading the data onto the system. Figure 9c shows the crack seal was applied to the transverse crack and submitted to the system in May 2008.

The owner can monitor the pavement condition and review the maintenance work from remote sites. If the owner was not satisfied with the work, the owner can take necessary actions. Note that the system does not mean to replace any of the existing quality control procedures; it just provides an effective means to manage data and to facilitate the communication among different parties (e.g. pavement engineer, manager, condition evaluation contractor, maintenance contractor, and third parties – consultants and experts) for different pavement preservation activities so the pavements can be monitored and maintained promptly. In the future, a mobile device (e.g. cell phone) can be used for taking pictures and submitting the data via a wireless connection.
Figure 9a. Chuning PMS Modules.

Figure 9b. Image submitted by contractor after condition survey
Case 2: Web-based pavement condition analysis, visualization, and reporting.

In addition to biweekly highway condition routine surveys, intensive pavement distress survey, FWD, and IRI, are performed to evaluate the pavement condition and to identify the needs for maintenance and rehabilitation. A pavement distress survey is performed every year to record various distresses, such as load crack, block crack, and rut; and IRI and FWD measurements are made every 2 to 4 years for every 50 meters. These surveys and measurements require different equipment and techniques and are carried out by different contractors. All the contractors submit the data via predefined formats into the system. Figure 5 shows data integrated from different sources. The blue dots are the values on the outer lane of the positive direction, and the pink lines represent the averaged value among the different lanes. The pavement rating is fairly good, ranging from 93 to 100 with an average of 99.77, since the pavement is only two years old. The average FWD is 10.07 (0.01mm) with a minimum of 3.3 (0.01mm) and a maximum of 28.5 (0.01mm). The IRI ranges from 0.44 m/km to 2.98 m/km and the values are higher than the average after the station 60K+000. With the system, survey data from different contractors/sources can be integrated spatially to support the analysis and visualization as well as determining the best maintenance and rehabilitation method.

Figure 9c. Image submitted by contractor after crack sealing
Case 3: Roadway emergent response using web technology.

The need for a timely decision-support system can be best illustrated via emergent or special events, such as unexpected weather damage to the roads. A heavy snow hit the southern provinces in China in late January 2008. Severe weather led to expressway closure and airline flight cancellations, which choked the transportation system at the beginning of the travel season for the Lunar New Year. The snow also caused significant damage to the roadways. Shortly after the snow, the government called immediately for the maintenance and rehabilitation plan to restore the expressway to the expected service level. At the time, the managers were away from the office and needed to make decisions on the plan. There were many phone conversations involved reporting the road condition and reaching decisions on the plan and the cost estimates. The Chuning-
PMS can provide another communication mode to assist the decision-making process. With the web capability, the manager can remotely access the on-site pavement condition information (e.g., images), and make informed decisions efficiently during the special event. The manager can also use the system to make decisions while having meetings in Beijing to achieve timely and effective management.

**CONCLUSIONS AND RECOMMENDATIONS**

With a strong investment return incentive for an expressway built with PPP, a web-based Chuning PMS is developed to take advantage of web technology to facilitate the effective communication among different parties (e.g., pavement engineer, manager, condition evaluation contractor, maintenance contractor, and third parties – consultants and experts) for making a timely pavement preservation decision. The following list the benefits of the developed PMS.

1. Chuning Expressway is a typical PPP project newly constructed in 2006. We have designed the PMS to integrate roadway design data, pavement design data, traffic data, pavement condition evaluation data, maintenance activities, and maintenance cost so the entire life cycle activities/data can be effectively utilized to support a timely and cost-effective decision on pavement preservation and management. [For example, the pavement structural design section and roadway design profile for at a specific location can be reviewed along with the recent pavement distress to make adequate pavement preservation decision.]

2. Development of an electronic and web-based library to store and to retrieve roadway design document, including plan and profile drawing, pavement structural design, and typical section drawings. Pavement engineers, managers, pavement survey contractor, maintenance contractor, and consultants can easily access this historical document based on the location of interest using web-based technology.

3. Distress classification and measurement methods are available on the web. The developed system can serve as a knowledge base and also the training guide on how to perform pavement condition assessment. Engineers and managers can access this information anywhere and anytime. The pavement maintenance guide is also available on the web to provide maintenance guidance.

4. Web-based routine pavement deficiency monitoring, work order issue, application of maintenance activities, and maintenance quality checking. The system enables routine pavement deficiency survey contractors to upload pavement deficiency data along with images showing deficiencies. The engineers in the company can review them before issuing work order. The completed maintenance work along with images can then be uploaded to the system. The engineer can track and verify the routine maintenance works performed by the contractor.

5. The actual maintenance activities along with their costs are recorded so they can be used to support the actual life cycle cost analysis to evaluate the effect of different pavement preservation strategies.

6. Detailed traffic data are recorded, including vehicle type, number of axles, and weight. They can be used to develop reliable pavement performance forecasting model. The detailed traffic spectrum has the potential to support M-E model calibration.

The future research as listed below can further enhance Chuning PMS to efficiently manage the pavements and other assets.

1. Training and certification for the personnel performing the pavement condition data collection to ensure the data quality.

2. Enhanced pavement condition data quality control routine can be developed to ensure the quality of survey data (e.g., pavement distress, IRI, and FWD). For example, the completeness of the data, the abnor-
mal values, and the comparison to the historical data can be checked to ensure data quality. A pavement rating increase without any treatment or an even rating for a few years does not follow the nature of pavement deterioration and can be flagged for review to ensure the data quality.

3. Development of Chuning expressway pavement performance forecasting models after more data are collected so the model can be used to predict the actual pavement preservation needs.

4. Incorporation of other roadway assets (bridge, guardrail, pavement marking, and sign) to develop a comprehensive asset management system. The activities of different assets can be integrated and coordinated spatially and temporally to save money by minimizing the duplicated works. For example, by consolidating a pavement resurfacing project and a safety project to install raised pavement marker at the same location, the duplicated traffic control cost and pavement marking cost can be saved, and the number of traffic disruptions can be reduced.

5. Utilization of roadway images to access roadway condition and to check the roadway maintenance work is very timely and effective. There is a need to develop a standard to collect these images to ensure the image quality and to ensure the important location information is recorded.

ACKNOWLEDGMENTS

The writers are grateful for the financial support of the Chuning Company. The writers would like to thank Mr. Guang Ho from Anhui for his knowledge and encouragement on the project, and Dr. James Lai, Professor Emeritus from Georgia Institute of Technology, for his knowledge and advice. The writers would also like to thank many individuals from GeoTransolution LLC and Beijing Luqiaotong International Engineering Consulting & Project Management Co., Ltd. who contributed to the project.

REFERENCES


