Road Map to Develop Methodologies for Determining Remaining Pavement Service Life

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ABSTRACT: Pavements are a vital component of the transportation system and represent a substantial investment. Pavement condition is an important indicator of overall highway system performance. The monitoring and evaluation of pavement condition is an essential part of pavement management. Ideally, determining the remaining pavement service life would assist in making decisions about preventive maintenance, preservation, rehabilitation, or reconstruction. There are several approaches being researched and developed to acquire and to analyze data on pavement condition. This paper will discuss a strategic road map to develop methodologies for determining remaining service life of pavements. The paper will present the current state-of-the-practice in the U.S. as well as opportunities for developing other analytical procedures.

KEY WORDS: Pavements, remaining service life, pavement management, methodologies.

1 BACKGROUND

The focus of the U.S. Federal-aid highway program is to provide Federal financial resources and technical assistance to State and local governments for constructing, preserving, and improving the National Highway System (NHS), a 160,000-mile (257,495 km) network that carries 40 percent of the Nation's highway traffic. The program also provides resources for over a million additional miles (1,609,344 km) of urban and rural roads that are not on the NHS. The program generally does not consider future conditions and service life in determining funding levels and allocations.

The Federal Highway Administration (FHWA) and State departments of transportation (DOTs) are facing a number of issues and challenges including preserving aging infrastructure, dealing with increased traffic volumes and freight movements, and operating under limited funding. Traffic volumes and freight movements are expected to nearly double in twenty years. To accommodate the demands on an aging U.S. highway transportation infrastructure, additional resources will be required for preservation, improvement, and operation of the system.

Pavements are a vital component of the transportation system and represent a substantial investment. The condition of pavements is an important indicator of overall system performance and an essential part of pavement management. Although the expected service life of a pavement is a criterion in the design phase, subsequent management decisions must take actual pavement site conditions into consideration to accurately predict and extend the service life. Due to the typical long term life of pavements, highway agencies tend to overlook

preservation treatments (e.g., restoration) and even the application of rehabilitation treatments until the pavement is in a condition that is well past any possibility of economic opportunity.

A proactive approach to protecting or maximizing investment in pavements involves periodic assessment of the pavement condition to determine deficiencies and predict deterioration patterns. Many pavements on the NHS are approaching the end of their design life. As-built conditions often vary and result in a major change in the rate of pavement deterioration. For system maintenance and rehabilitation, there is a need to move away from a reactive "fix it when it's broken" approach to a more proactive, planned approach for meeting forecasted needs. Pavement management strategies must be employed at an optimal time in order to attain the most cost effective maintenance and rehabilitation solutions for the structure. Determining the remaining service life (RSL) of pavements is critical for making better decisions about preservation treatments, rehabilitation, or reconstruction. Since at least 1970, numerous methods have been proposed, researched, and used to predict the RSL of pavements; however, there does not appear to be an overall definitive method that is used on network or project levels.

Currently the FHWA projects future investment requirements for preserving the Nation's infrastructure as part of the biennial Conditions and Performance (C&P) Report to Congress. Highway condition and performance data are derived from the Highway Performance and Monitoring System (HPMS), a cooperative data/analytical effort dating from the late 1970s that involves the FHWA and State and local governments. One of the most widely used performance indicators for monitoring pavement condition is ride quality. The FHWA adopted the International Roughness Index (IRI) for ride quality because this index uses a standardized procedure which is more consistent across jurisdictions than other methods and an objective measure that is generally accepted as a worldwide pavement roughness measurement. Ride quality alone, however, is not sufficient for examining future pavement performance or predicting future pavement system needs because it is not always indicative of the structural adequacy of the pavement. It is therefore imperative that other factors be taken into consideration for analysis including traffic, climate, material properties, and construction quality.

The FHWA is preparing a strategic approach to develop methodologies for determining the RSL of pavements. To identify possible methods, the work should include the participation of various program offices (Office of Pavement Technology, Office of Asset Management, Office of Policy, and Office of Research, Development, and Technology) as well as experts in the field, State DOTs, and industry. It is important to recognize that the issue of RSL is already being examined to some extent by several programs.

2   ROAD MAP

Several methods have been researched and used to predict the RSL of pavements. While these methods may provide short-term estimates, they do not provide definite answers that can be attained on network or project levels. Part of the problem stems from variations in the way service life can be defined (CTC et al. 2004). Typically, service life is expected to be a measure in terms of years from the initial construction until the pavement will require major expenditures for restoration, overlays, or other rehabilitation. Service life may also be expressed through performance indicators or condition indices and traffic loadings. Early in the analysis process and as part of the discussions on service life, the key criterion that needs to be defined is the point of failure. It may be expressed in terms of function (e.g., low friction), key distresses indicating major problems ahead, excessive maintenance needs, or structural deficiency (e.g., fatigue damage) and may take into consideration load-related (traffic volume) or material distress-related factors. Other issues include (i) the purpose for

needing the information as far as determining the time until preservative-type rehabilitation is needed rather than complete loss of service; (ii) the requirements being met by results in terms of time or rating; and (iii) the decision on th e key characteristics that should be evaluated.

Knowing the pavement RSL may impact choices made for preservation or restoration treatments, rehabilitation alternatives, and reconstruction to ensure the efficient use of resources. This is a driving force behind the continuing effort to assess the RSL. Several projects throughout the country are exploring the issue to some degree. The projects cover a range of methods in both data collection and data analysis. Current data, technologies, and practices should be considered in determining the most usable form of pavement evaluation. A combination of these items, as well as taking a look at methods developed in other industries, may yield even better results.

In order to use current technology, data acquisition should provide information that can be used and manipulated through data analysis. In some cases the data is collected using rather subjective methods, such as visual inspection of the pavement structure. The analysis is then performed on historical data using relatively complex calculations or models to derive an estimated prediction. For a short-term solution, data on pavement condition contained in existing pavement management databases can be utilized.

In response to the diversity of implications this type of information will have on management decisions and the importance of time, the development o f methodologies should be expedited by following two tracks in parallel as illustrated in Figure 1: (1) evaluate current technology and practices, and (2) explore innovative analytical procedures. The two tracks will also have a link between them as the innovative analytical procedures track needs to include current technology and practices for the component referring to available input parameters. Input and feedback is needed from both internal and external experts to further develop each track and to clearly define the work to be completed.
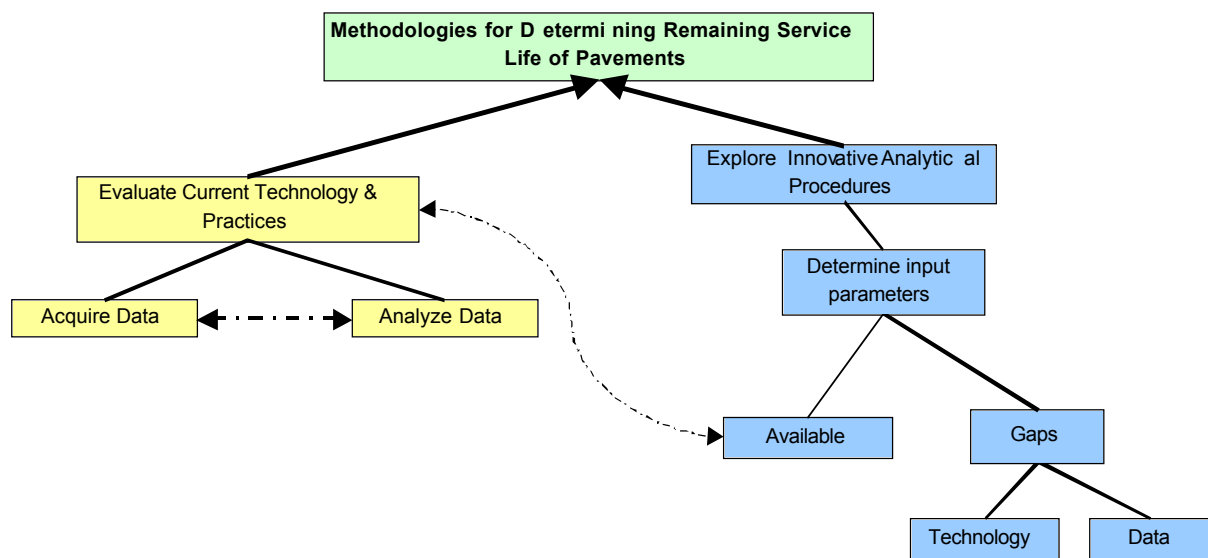

Figure 1: Illustration of parallel tracks to develop methodologies for determining remaining service life of pavements.

2.1 Current Technology and Practices Track

The goal of this track is to identify the current technology and practices that will provide the most usable form of pavement evaluation. It is comprised of data acquisition and data analysis. In order to use current technology, data acquisition must provide information that

can be used and manipulated through analysis. For this track, it is important to identify ways to utilize data on pavement condition that is contained in existing pavement management databases.

This track examines the adequacy of existing tools for analysis of the potential for significant serviceability issues and estimation of the level of investment needed to address or avert such issues for roads in the transportation system. The intermediate goal is to furnish reliable data to enhance decision-making and management of the transportation system. Ultimately, this effort will look at pavement performance over a network in terms of age, loadings, condition and traffic relating to various investment scenarios.

2.2 Innovative Analytical Procedures Track

This track first explores innovative analytical procedures needed to solve the problem, determines the input parameters, and then assesses availability or identifies gaps in data and/or technology. It considers fundamental concepts (in data gathering and analysis, design, modeling, etc.) and material properties to develop analytical methods for solving the issue. There is a clear need to carefully balance important criteria and biased thinking in order to encourage innovation for identifying potential solutions. The range of possibilities includes (i) taking a new look at basic engineering mechanics or materials science for pavements; (ii) adapting solutions used in other fields; and (iii) implementing technology just being discovered.

For the this track, assistance with feasibility studies or brainstorming activities could be requested by contacting organizations such as Volpe, Civil Engineering Research Foundation (CERF), or National Science Foundation (NSF).

3 CURRENT APPROACHES

The FHWA prepares a publication that catalogs a wide range of software packages and state-of-the-art data collection systems that States are using to support pavement management systems (FHWA 2002). In addition to the information provided in the catalog, the following summaries provide information on the approaches being used for data collection and data analysis.

3.1 Data Collection Technology

Relationships can be derived between various pavement characteristics to create conversion factors or indices for analysis. However, re-examining the types of data that are collected may reveal that other basic characteristics should be evaluated either in place of or in addition to the standard data that is currently gathered. FHWA has a study underway entitled "Modification of FHWA Highway Performance Data Collection System and Pavement Performance Models". This project is focusing on identifying the types of data inputs required to estimate pavement RSL along with the issues and concerns that States may face in providing those various data items as part of the HPMS submittal. The project includes bringing several States together into a committee to discuss these and other approaches as an open exchange of experiences. It is anticipated that this committee will provide guidance and input for a second phase of the project.

It appears that the most commonly used method of assessing the pavement condition is by visual inspection or windshield survey. This provides subjective data and requires a significant investment of time and resources. In order to gain insight into the underlying factors, agencies often resort to destructive sampling and testing methods such as coring.

Among other requirements is the need to properly train personnel and maintain equipment to ensure that the sampling and testing are done correctly. In efforts to reduce these expenditures, there is increasing demand to use nondestructive testing and evaluation methods when possible. Nondestructive testing also has the advantages of measuring in-place properties and providing rapid results, while causing minimal damage to the pavement. Recent technological advances have lead to the development of more nondestructive pavement condition assessment tools such as deflectometers, which consider load-related rather than material distress-related factors.

There are projects underway that attempt to make pavement evaluation more objective and automated through the use of highway measurement vehicles equipped with technology such as computers, cameras, sensors, lasers, gauges, profiling devices, gyroscopes, and other data collection instruments. Research is also being conducted using geophysical nondestructive methods including seismic vibrations and ground-penetrating radar to provide objective, network-level pavement condition evaluation and to detect early stage deterioration. These tools provide an opportunity to gather data more efficiently as well as to improve the data in terms of quality, consistency, quantity, and frequency (annually rather than biannually).

There are other innovative methods being considered which look beyond current technology. For instance, the National Consortium on Remote Sensing in Transportation and the National Aeronautics and Space Administration (NASA), along with other entities, are investigating the roles of remote sensing and geospatial technology in pavement evaluation.

3.2 Data Analysis Methods

Data analysis includes utilizing relationships between pavement site conditions and performance. Algorithms, models, and indices that vary from simple to very complex can be used to estimate the RSL. For the FHWA study mentioned in the previous section summarizing data collection, one of the project objectives is to determine approaches for estimating pavement RSL. Initial recommendations from a draft white paper prepared for the project present three potential approaches: (1) use of deflection-based non-destructive/destructive testing, (2) use of pavement visual distress, and (3) use of smoothness/serviceability predictions. These approaches will be considered and modified based on feedback from the committee of States.

A simple approach developed specifically for the HPMS database projects the remaining number of years that any given section of rigid (or flexible or composite) pavement will survive through knowledge of its current serviceability index level, its annual traffic ESALs, and its pavement structure (slab thickness) (Lee et al. 1993). This approach is an empirically-based model, requires very few inputs, and is incremental (e.g., year by year) in nature. It can be used for large networks of pavements for programming purposes.

Another promising approach includes the use of survival curves. Survival analysis is a statistical method for determining the distribution of lives, as well as the "life expectancy", of subjects in an experiment. It is also known as probability of failure analysis and is widely used in scientific and actuarial research as well as in the pavement industry. A number of agencies have developed survival curves for various "families" of pavement types using their pavement management database (Von Quintus et al. 2003). These curves provide the agencies with factual data on the service lives and amounts of truck traffic that their pavements have carried. These survival curves form the basis for predicting the RSL of pavements. For a given family of pavement, such as a specific jointed reinforced concrete, the survival curves for aging and truck traffic allows the estimation of the probability of rehabilitation being applied due to aging problems and due to overloading damage into the future of any given pavement section. This approach requires survival curves for aging and traffic loadings, but requires very few inputs to apply and is also useful on the network level.

As an example of a more complex approach, a new Mechanistic-Empirical Pavement Design Guide developed under National Cooperative Highway Research Program (NCHRP) Project 1-37A provides comprehensive structural analysis tools to predict deterioration based on design features, material properties, climatic conditions, and traffic inputs. (ARA 2004) This procedure provides one of the most promising approaches to prediction of RSL in terms of key types of deterioration: rutting, fatigue cracking, and thermal cracking in asphalt; slab cracking and joint faulting in concrete; and smoothness for either pavement type. It requires a large number of inputs to produce estimates of future deterioration, but is by far the most comprehensive of the approaches to RSL prediction. This approach can be used on the project level and may be simplified for use on the network level.

There are other approaches being evaluated by State DOTs. For example, a method to estimate the RSL of continuously reinforced concrete pavements (CRCP) led to the development of a software program called PAVLIF (Dossey et al. 1996). This program has since been incorporated as a part of a CRCP analysis program used by the Texas DOT. The Texas DOT also funded a project which used artificial neural networks technology to process data collected by a falling weight deflectometer to forecast asphalt pavement performance (Abdallah et al. 1999). Another example is a project entitled "Pavement Forecasting Models". The researchers are using data from Ohio DOT to derive the pavement condition rating (PCR). Once complete, the resulting models will be embedded into the state's existing pavement database to be used in future analysis.

Opportunities to improve the approaches used to determine the RSL of pavements may be pursued by learning about the advances made in other fields as well as other countries. For example, the U.S. Navy has a project that is developing a "next-generation service life prediction model" for concrete waterfront structures called SUMMA™ (Heffron and Buslov 2004). A company in the Netherlands has outlined a procedure for standard pavement evaluation of airfields. The procedure includes using falling weight deflectometer (FWD), performance models, statistical techniques, and pavement classification number (Stet and Diele 2004). Austroads commissioned a study on the current practices of estimating RSL of pavements and bridges in Australia and New Zealand (Austroads 2003). The report's main findings and conclusions suggest issues that are similar to those identified in the U. S., demonstrating the potential and need for a continued exchange of information.

4   SUMMARY

The role of pavements as a vital component of the transportation system continues to drive the importance of determining their RSL. Knowing the RSL has a substantial impact on making decisions about preventive maintenance, preservation, rehabilitation, or reconstruction. The FHWA is preparing a strategic road map to develop methodologies for determining RSL of pavements. As part of the strategy, one track acknowledges and takes into consideration current technology and practices; however there is also a parallel track that seeks to reevaluate the basic principles as well as looking to other fields to explore innovative analytical methods. As presented in this paper, the FHWA is pursuing projects that fall within this strategy by considering the current state-of-the-practice and the opportunities for developing other analytical procedures.

REFERENCES

Abdallah, I., Nazarian, S., Melchor-Lucero, O., and Ferregut, C., 1999. *Validation of Remaining Life Models Using Texas Mobile Load Simulator*. Proceedings of the First Accelerated Pavement Testing Conference, University of Nevada, Reno, Nevada, USA.

Applied Research Associates (ARA), Inc., 2004. *Design Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures.* Final Report, NCHRP Project 1-37A, Transportation Research Board, Washington, DC, USA.

Austroads, 2003. *Remaining Life of Road Infrastructure Assets: An Overview.* Publication AP-R235/03, http://203.42.45.20/mall/austroads_v2/pdfs/537_AP-R235.pdf, (accessed on Oct. 4, 2004).

CTC & Associates LLC, and Wisconsin Department of Transportation RD&T Program, 2004. *Pavement Service Life - rev. 2.* Transportation Synthesis Report, http://www.dot.wisconsin.gov/library/research/docs/tsrs/tsrpavementservicelife.pdf, (accessed on Oct. 4, 2004)

Dossey, T., Easley, S., and McCullough, B.F., 1996. *Methodology for Estimating Remaining Life of Continuously Reinforced Concrete Pavements.* Transportation Research Record 1525, p. 83-90, Transportation Research Board, Washington, DC, USA.

Federal Highway Administration (FHWA), 2002. *Pavement Management Catalog: Data Collection, Data Analysis.* FHWA-IF-02-036, Washington, DC, USA.

Heffron, R.E. and Buslov, V.M., 2004. *Predicting the Remaining Service Life of Waterfront Structures.* http://www.han-padron.com/papers/2004-11.pdf, (accessed on Dec. 3, 2004)

Lee, Y. H., Mohseni, A., and Darter, M. I., 1993. *Simplified Pavement Performance Model.* Transportation Research Record 1397, p. 7-14, Transportation Research Board, Washington, DC, USA.

Stet, M. and Diele, R., 2004. *Standard Pavement Evaluation of Airfields.* http://www.koac-wmd.nl/nl-paver.htm (accessed on Aug. 16, 2004)

Von Quintus, H.L., Darter, M.I., Hallin, J., and Hein, D.K., 2003. *Concepts for Development of Survival Curves and Procedures for Adjustment of Survival Curves to Account for New Technology.* Neutral Third Party Ohio Pavement Selection Process Analysis, Final Report, Appendix E, Ohio Department of Transportation, Pavement Selection Advisory Council, Columbus, Ohio, USA.