100 YEARS TRB MOVING IDEAS: ADVANCING SOCIETY

CENTENNIAL PAPERS

Standing Committee on Pavement Management Systems (AFD10)
Linda M. Pierce, NCE, Chair

Pavement Management Systems: Inception to Implementation

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INTRODUCTION

Transportation Research Board (TRB) Standing Committee on Pavement Management Systems (AFD10) is concerned with the development, evaluation, integration, and application of pavement management systems and the component concepts and models for all types of pavements. Areas of interest include the understanding and characterization of pavement performance, as well as the interrelationships among factors that must be analyzed in making pavement management decisions at both the network and project levels, including budgetary constraints, traffic loads, environmental considerations, strategy alternatives, life-cycle economics, construction, and maintenance.

This paper reviews the history of the AFD10 committee by describing the evolution of pavement management over more than 50 years. Each decade, from the 1960s to the 2020s, is described in chronological order along the evolution of the state of the practice. The evolution of pavement management systems included many players, from government, academia, and industry. Many institutions and associations, including the American Association of State Highway and Transportation Officials (AASHTO), ASTM International, Federal Highway Administration (FHWA), TRB, and organizations from around the world have contributed to the development and advancement of pavement management systems. Throughout all of these efforts, AFD10 has been deeply involved in the evolution of pavement management systems. The ground breaking work in pavement management systems development has contributed to the development of bridge management systems, and later the overall concept of Transportation Asset Management Systems.

THE 1960S

The concept of pavement management had its early development in the 1960s, starting with the American Association of State Highway Officials (AASHO) Road Test. The Road Test not only established the development of pavement design methods based on axle loadings, but also initiated the concepts of expressing pavement performance in accordance with the Present Serviceability Rating, Present Serviceability Index, and Terminal Serviceability Index (HRB 1962).

Quantifying pavement performance led to the idea of managing pavement performance over time. Leading to the concept of a pavement management "system" where long term pavement performance could be optimized in order to implement the lowest life-cycle cost. Holistic pavement management systems were initially published in papers and reports by Hutchinson and Haas, research performed at the Texas Transportation Institute and the

University of Texas, and the National Cooperative Highway Research Program (NCHRP) Project 1-10a (Hutchinson and Haas 1968, Hudson et al. 1970, and Hudson and McCullough 1973).

As part of NCHRP Project 1-10a, a national workshop was held in Berkeley, CA and included experts from a variety of fields. The national workshop, where sharing of expertise, helped to initiate the concepts of systems engineering with pavement engineering. This type of collaboration with would be repeated many times over the next 50 years, as further documented in this article. This history exemplifies the TRB process of working with the research community, industry, and public agencies in moving technology forward.

THE 1970S

The 1970s saw the first implementation of pavement management systems at state highway agencies (SHAs), and the expansion of development outside North America. The first textbook was published, and significant developments occurred in pavement management implementation.

Research Highlights

In the 1970s development accelerated from the initial concepts formulated in the 1960s. Boxes in conceptual diagrams that had been used earlier to illustrate ideas were developed into system components. A number of workshops were held for SHAs to compare ideas progress system development (Terrel and LeClerc 1978). An NCHRP report completed in 1979 compared pavement management system development in 11 state and provincial highway agencies (Hudson, Haas, and Pedigo 1979). It was concluded that agencies were following different specific directions of implementation, but were generally working with the same pavement management objectives. Particularly advanced implementation was noted in Arizona, Florida, Ontario, Saskatchewan, Utah, and Washington State. In 1977, the Utah Department of Transportation (DOT) demonstrated the importance of stating the benefits of pavement management system by coining the phrase “Good Roads Cost Less” (Peterson 1977).

Two important book references on pavement management were are also published in the 1970s. The *Pavement Management Guide* and *Pavement Management Systems* (TAC 1977, Haas and Hudson 1978).

In the 1970s all large computer systems were mainframe based, and there were no commercially available pavement management systems. However, there were large computer applications developed for pavement management, particularly for evaluation of pavement investments (especially in developing countries) and road user costs. The first version of the Highway Design and Maintenance Standards Model was originally developed at the Massachusetts Institute of Technology for the World Bank and in the UK, the Transport and Road Research Laboratory developed the Road Transport Investment Model (Harral et al. 1979, Robinson et al. 1975).

Also in the 1970s, pavement condition survey procedures were documented in order to develop consistent methods for evaluation of pavement performance (Smith, Darter, and Hernn, 1979).

THE 1980S

Both theory and practice of pavement management were rapidly developed in the 1980s. Many of the pavement management concepts and methodologies used today were generated and developed during this decade. SHAs continued their efforts with pavement management systems implementation, periodically and systematically, collect pavement condition data, and utilize

pavement management systems for pavement condition evaluation, performance prediction, and project prioritization decisions.

TRB

In the early 1980s the A2B00 Pavement Management Section was created and chaired by Ron Hudson. The Standing Committee on Pavement Management Systems, designated as A2B01, was formed with George Way (1982 to 1988) as the initial committee chair.

AASHTO

In 1985, the AASHTO Joint Task Force on Pavements developed and published the *Guidelines on Pavement Management* (AASHTO 1985).

Research Highlights

In the 1980's, significant research efforts were being made to address the urgent needs from the highway engineering community. One of the leading efforts was the Strategic Highway Research Program (SHRP), which was funded through a dedicated share of the Highway Trust Fund. In 1981, a Task Group, consisting of members from TRB's Pavement Management section, the AASHTO Joint Task Force on Pavements, and the FHWA, conducted a joint meeting to discuss pilot studies to assess the feasibility of establishing a nationwide database for monitoring long-term pavement performance. With the passage of the Surface Transportation and Uniform Relocation Assistance Act of 1987, the Long-Term Pavement Program (LTPP) became a part of SHRP.

As more SHAs faced the challenges of shifting from construction of new highways to maintaining existing ones, more attention was focused, for example, on pavement condition evaluation, project priority listings, prediction of remaining service life, and cost-benefit analysis of treatments. In 1987, NCHRP Synthesis 135 summarized the results of a nationwide survey of SHA practices and efforts in pavement management (Peterson 1987).

Following the completion of the AASHO Road Test, pavement roughness was recognized as an important indicator of pavement performance. By the 1980s, the International Roughness Index (IRI) was developed in order to establish common measure across different measurement platforms (Sayers, Gillespie, and Paterson 1986).

SHAs were developing mainframe pavement management applications based on their institutional procedures. At the micro-computer level, development occurred with airport-based pavement management systems, specifically, MicroPAVER (Shahin et al. 1986). Also in the 1980s, local agencies became more involved in implementing pavement management, and the American Public Works Association (APWA) developed a local agency version of the PAVER system (APWA 1983). During this decade various researchers also explored use of different optimization techniques for pavement management decision making (Feighan et al. 1988).

International Pavement Management Conferences

In response to the worldwide interests in pavement management, both locally and internationally, the first international pavement management conference was held in 1985 in Toronto, Canada. The conference was attended by 250 participants, representing 75 different agencies. The second international conference was held 1987 in Toronto and attracted 330 participants, representing 33 countries. These conferences covered a variety of topics related to pavement management, including system framework, pavement evaluation, performance prediction, network

optimization, and project prioritization. The TRB A2B01 committee was heavily involved in planning and conducting both conferences.

THE 1990S
The SHRP program is well underway, and FHWA requires SHAs to implement a pavement management system.

TRB
A2B01 committee chairs during this decade included Billy Connor (1988 to 1994) and Katie Zimmerman (1994 to 2000). At the TRB Annual Meetings, regular Saturday (pre-conference) sessions began for the Data Analysis Working Group (DAWG), an international forum to discuss data analysis on pavement behavior.

In the 1990s, A2B01 created three subcommittees, which are still active today:

- A2B01(1), Pavement Management Systems for Local Agencies
- A2B01(2), Pavement Management Systems for Airports
- A2B01(3), International Conferences on Pavement Management Systems

In 1994, A2B01 organized the Third International Conference on Managing Pavements in San Antonio, TX and in 1998, A2B01 organized the Fourth International Conference on Managing Pavements in Durban, South Africa.

AASHTO and ASTM
In July 1997, the National Workshop on Pavement Management was co-sponsored by the AASHTO Joint Task Force on Pavements, the FHWA, the Louisiana Department of Transportation and Development, and the Southeastern States Regional Pavements Committee. The workshop provided an opportunity for pavement management practitioners from the U.S. to discuss the state of the practice, set priorities for future pavement management efforts, and offer suggestions for advancing the technology into the next millennium.

In 1990, AASHTO updated the *Guidelines for Pavement Management Systems* (AASHTO 1990). The initial development of ASTM D5340, *Standard Test Method for Airport Pavement Condition Index (PCI) Surveys* occurred and was adopted in 1998 (ASTM 1998*)*.

Federal Initiatives
In the decade of the 1990s FHWA became directly involved with pavement management implementation. In 1991, the U.S. Congress passed the Intermodal Surface Transportation Efficiency Act (ISTEA). The ISTEA legislation required SHAs to implement a pavement management system. The FHWA became a national advocate for pavement management systems, led the development of Transportation Asset Management, and organized an Executive Seminar on Asset Management in Washington, DC in 1996 (Botelho 1994, Nemmers 1997).

Research Highlights
With the implementation of the LTPP program, there was a research need to develop consistent methods for conducting pavement condition surveys, and therefore developed and published the LTPP *Distress Identification Manual* (SHRP 1990). In 1994, *NCHRP Synthesis 203* was published summarizing *Current Practices in Determining Pavement Condition* (Gramling 1994).

The LTPP program helped to quantify the variation in manual condition surveys, which aided continued development of automated pavement condition survey methods (Rada et al. 1999).

In1995, *NCHRP Synthesis 222* was published on *Pavement Management Methodologies to Select Projects and Recommend Preservation Treatments* (Zimmerman 1995).

THE 2000S

The 2000s was the decade in which the practice of pavement management saw significant progress in development and implementation of data and tools needed for making pertinent decisions in pavement management. At the beginning of this decade, SHAs were researching collection of pavement performance data at highway speeds, and by the end of the decade more than 95% of the agencies were collecting pavement cracking and smoothness data at the network level (Flintsch and McGhee 2009). In the same period, the First European Pavement Management Systems Conference was held in Budapest, Hungary in 2000, and the Roadway Pavement Preservation Task Force convened the First National Conference on Roadway Pavement Preservation, in Kansas City, MO in 2005.

TRB

In the 2000s, the A2B01 changed identification designations to AFD10. Committee chairs during this decade include Tom Kazmierowski (2000 to 2006) and Chuck Larson (2006 to 2012).

In 2001, the committee planned and sponsored the Fifth International Conference on Managing Pavements in Seattle, WA and in 2004, the Sixth International Conference on Managing Pavements, in Brisbane, Queensland, Australia.

During the 2006 TRB Annual Meeting, a session was conducted on the 50th Anniversary of the Interstate Highway System, from which the committee cosponsored an e-circular on *Pavement Lessons Learned from the AASHO Road Test and Performance of the Interstate Highway System* (TRB 2007).

In 2007, the committee co-sponsored the National Conference on Pavement Management in Norfolk, VA and the Fifth International Conference on Maintenance and Rehabilitation of Pavements and Technological Control, in Park City, UT. In 2008, the committee planned the Seventh International Conference on Managing Pavement Assets in Calgary, Canada and in 2009, organized a webinar on Using Pavement Management to Control Costs and Improve Services.

AASHTO and ASTM

In 2001, AASHTO published Provisional Standard PP 44-01, *Standard Practice for Quantifying Cracks in Asphalt Pavement Surface* and First Edition of the *Pavement Management Guide* (AASHTO 2001a, AASHTO 2001b). In 2002, AASHTO published the *Transportation Asset Management Guide*, borrowing key elements from the systems approaches implemented in pavement management systems and bridge management systems (AASHTO 2002). AASHTO published the *Guide for Pavement Friction* in 2008 and revised and published the Second Edition of the *Pavement Management Guide* in 2012 (AASHTO 2008, AASHTO 2012).

The ASTM E1889-97, *Standard Guide for Pavement Management Implementation*, first drafted in 1999, was reapproved, by Subcommittee E17.42 on Pavement Management and Data Needs, in 2002 and 2009 (ASTM 2015a). This subcommittee also revised the 1999 ASTM D6433-99, *Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys* in 2003, 2007, and 2009 (ASTM 2018). In 2000, the subcommittee drafted the first version of the ASTM E1166-00, *Standard Guide for Network Level Pavement Management* (ASTM 2015b).

Federal Initiatives

On August 10, 2005, President George W. Bush signed into law the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU).

As part of the corresponding Innovative Pavement Research and Deployment program, funding for the LTPP program continued, with a set-aside of $10.12 million per year for 2005 through 2009. During this time, the pavement performance and the structure, materials, traffic, and climate data collected under the LTPP program were used in NCHRP projects for re-calibrating the performance prediction models in the Mechanistic-Empirical Pavement Design Guide (MEPDG) (Von Quintus et al. 2009).

In 2008, FHWA began sponsoring a series of regional peer exchanges that provided an opportunity for pavement management practitioners to share experiences and transfer technology (FHWA 2008a). The Pavement Management Catalog, published by FHWA in 2008, listed four public domain software systems and 12 different proprietary software programs (FHWA 2008b). In 2009, FHWA commissioned the development of a Pavement Management Roadmap, which involved workshops held in several locations around the country (Zimmerman et al. 2010). The report laid out the vision for what the state of the pavement management practice should look like in 2020, and which topic areas needed further research and development to achieve that vision.

The Airport Cooperative Research Program (ACRP) was authorized as part of the Vision 100-Century Aviation Reauthorization Act in 2003, with oversight by the Federal Aviation Administration (FAA), and management of ACRP was transferred to TRB in 2005. In 2006, the FAA issued Aviation Circular AC 150/5380-7B, *Airport Pavement Management Program (PMP)*, identifying the essential components of an effective airport pavement management system (FAA 2006).

Research Highlights

In the 2000s, SHAs started a trend to perform more research as part of the FHWA pooled fund process. With the advent of IRI, many SHAs upgraded capabilities for measuring pavement profile. In 2003, Transportation Pooled Fund TPF-5(063), Improving the Quality of Pavement Profiler Measurement, was established. This led to the development of the Profile Viewer and Analyzer (ProVAL) software (FHWA 2007).

There were major research projects conducted in this decade regarding pavement performance data collection and processing techniques, data quality management, and data representation in pavement management systems. Members of the AFD10 played a major role in prioritizing and directing this research. In 2004, the NCHRP Synthesis 334 summarized the state of the practice in Automated Pavement Distress Collection (McGhee 2004). Several SHAs conducted studies comparing emerging automated pavement condition surveys to manual surveys (Timm and McQueen 2004). In the same year, the NCHRP Synthesis 335 reported that GIS systems had been particularly helpful to pavement management practitioners for integrating, managing, analyzing, and presenting data from multiple data sets (Flintsch et al. 2004). In 2009, NCHRP Synthesis 401 on Quality Management of Pavement Condition Data Collection was published, providing a framework for agencies to ensure they were collecting accurate and precise data to make sound pavement management decisions (Flintsch and McGhee 2009).

While most agencies were only using pavement surface condition for pavement management decisions, some agencies recognized the lagging and reactive nature of such performance indicators and explored incorporation of subsurface structural data as leading indicators of pavement deterioration. By the end of this decade, several SHAs, such as Kansas

and Oklahoma, reported using structural condition data for network-level decisions (Hossain et al. 2000, McGovern et al. 2006). In 2008, the NCHRP Synthesis 381, describing best practices for falling weight deflectometer (FWD) usage for both project-level pavement design and network-level pavement management (Alavi, Lecates, and Tavares 2008). In 2009, the UK Highways Agency started network-level collection of pavement structural data using the Traffic Speed Deflectometer (TSD) device (Ferne, Sinhal, Fairclough 2009).

LTPP data was also being used in several research studies to examine the effectiveness of various maintenance and rehabilitation treatments and to determine the optimal timing of preservation treatments to extend the service life of the pavement structures (Hall, Correa, and Simpson 2002, Peskin, Hoerner, and Zimmerman 2004).

In 2004, the final report for the largest NCHRP project to date, Project 1-37A: Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures was published (NCHRP 2004). In addition to the LTPP data, researchers recognized the value of the accumulated pavement management performance data in calibration of the MEPDG performance models to local climate, materials, and traffic conditions (FHWA 2010, Li, Pierce, and Uhlmeyer 2009).

In 2010, ACRP Report 39 provided a data schema, data collection methods, data quality requirements, and other relevant information required for developing specifications and standards for integrating geospatial data into pavement management systems for airfields (Parsons and Ogden 2010).

THE 2010S

The Moving Ahead for Progress in the 21st Century Act (MAP-21), passed by Congress and signed into law by President Obama in 2012, was the key driver of changes in SHA implementation of pavement management, including bridge management, and potentially other asset classes. Unfortunately, the deep recession in the early part of the decade forced many agencies to cut back on resources.

TRB

During this decade, AFD10 was chaired by Edgardo Block (2012 to 2018) and Linda Pierce (2018 to present).

In 2011, the committee organized the Eighth International Conference on Managing Pavement Assets in Santiago, Chile and in 2015 the Ninth International Conference on Managing Pavement Assets in Alexandria, Virginia. In 2017 the European Pavement and Asset Management Conference (EPAM) and the International Conference on Managing Pavement Assets combined for a global event: The World Conference on Pavement and Asset Management in Milan, Italy.

The AFD10 committee sponsored one webinar in 2013 on Improving the Quality of Pavement Management Data and co-sponsored the webinar on Life Cycle Cost Analysis.

AASHTO and ASTM

In the 2010s AASHTO and ASTM continued to update and contribute to standards for pavement management methods, including:

- AASHTO R 43, *Standard Practice for Quantifying Roughness of Pavements*

- AASHTO R 54, *Standard Practice for Pavement Ride Quality When Measured Using Inertial Profiling Systems*
- AASHTO R 57, *Standard Practice for Operating Inertial Profilers and Evaluating Pavement Profiles*
- AASHTO R 85, *Standard Practice for Quantifying Cracks in Asphalt Pavement Surfaces from Collected Images Utilizing Automated Methods*
- AASHTO R 86, *Standard Practice for Collecting Images of Pavement Surfaces for Distress Detection*
- AASHTO R 88, *Standard Practice for Collecting the Transverse Pavement Profile*
- ASTM D5340, *Standard Test Method for Airport Pavement Condition Index Surveys*
- ASTM D6433, *Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys*
- ASTM E1166, *Guide for Network Level Pavement Management*
- ASTM E1777, *Standard Guide for Prioritization of Data Needs for Pavement Management*
- ASTM E1889, *Standard Guide for Pavement Management Implementation*
- ASTM E1926, *Standard Practice for Computing International Roughness Index of Roads from Longitudinal Profile Measurement*s

Federal Initiatives

As noted previously, the MAP-21 legislation, which required comprehensive implementation of performance management procedures for the National Highway System, was signed into law in 2012. However, it took several years to develop the final MAP-21 implementation plans and rules for SHAs and Metropolitan Planning Organizations (MPOs). In 2015, President Obama signed into law The Fixing America's Surface Transportation (FAST) Act, extending MAP-21. AFD10 was heavily involved throughout the MAP-21/FAST evaluation period, and will continue through the implementation efforts.

The implementation of MAP-21 requires every SHA to develop a plan for the collection of quality pavement condition data. To provide assistance for this requirement, the FHWA sponsored the development of a *Practical Guide for Quality Management of Pavement Condition Data Collection*, which was published in 2013 (Pierce, McGovern, and Zimmerman 2013).

Pavement management was also a key part of FHWA's Every Day Counts program, with separate efforts for when, where, and how programs to help SHAs and local agencies with pavement preservation. The FHWA also sponsored research that revised existing methods related to remaining service life and suggested replacing with the remaining service interval (Elkins et al. 2013).

Research Highlights

In this decade pavement management systems became part of a larger national focus on asset management. Especially difficult within asset management was the methodology to allocate resources among various different asset classes. One methodology proposed to address this research need was multi-objective optimization, another was the Analytic Hierarchy Process (Chen et al. 2015, Adams and Carreras 2018).

The use of pooled fund research programs continued, with 29 agencies participating in TPF-5(299): Improving the Quality of Pavement Surface Distress and Transverse Profile Data

Collection and Analysis and NCHRP published Synthesis 501 on Pavement Management Systems: Putting Data to Work in 2017 (Zimmerman 2017).

Expanding concepts of performance management, led by the Washington State DOT, developed new pavement performance measures related to cost-effectiveness at the project level, and related Remaining Service Life, Asset Sustainability Ratio, and Deferred Preservation Liability at the network level (Rydholm and Luhr 2015, Luhr and Rydholm 2015).

THE 2020S

TRB

AFD10 plans to evaluate the Pavement Management Roadmap, originally published in 2010, to determine what research has been accomplished over the last decade, and what research priorities should be developed for the next 10 years. This will hopefully lead to a new roadmap that can be used to guide pavement management research over the next decade.

Federal Perspective

The principal emphasis at the Federal level will likely be implementation and evaluation of MAP-21/FAST requirements and objectives. The first full cycle of implementation will be reported in 2022, so SHAs, local agencies, and MPOs will have experienced the first implementation of pavement management requirements. This experience will likely lead to adjustments, and refinement of direction, as the cycle moves to the second four-year reporting period.

Research Needs

In every decade progress has been made in research and development for pavement management systems. Many changes have occurred in the 50 years since pavement management originated, especially with regard to available tools (e.g., computers, data collection, data analysis, communications). However, the fundamental concepts of pavement management are very much the same as originally outlined by Hutchinson and Haas (1968).

Over the next 10 years, AFD10 will continue to make progress on HOW to implement pavement management concepts. Identified needs can be broken into the following categories:

1. Organizational Implementation
    a. How to make organizational change that is conducive to implementation of pavement and asset management systems?
    b. How to keep staff trained and functioning at a high level of expertise?
    c. How to educate executives and politicians on the (critical) needs for pavement asset management?
    d. How to work with executives to determine what an agency's objectives should be with regard to pavement performance? How good should our roads be?
2. Data Quality
    a. How to develop uniform specifications and standards that result in the data quality that is needed in decision support systems?
    b. How to develop new data acquisition platforms (e.g. drones, etc.) that overcome problems with current data collection methods.
    c. How to better understand the relationship between data quality and better decision making, thereby quantifying the value of information?

    d. How to quantify and prioritize the improvements needed in automated pavement condition surveys?
3. Data Analysis
    a. How to develop performance measures that monitor important pavement management trends at both the network and project levels?
    b. How to evaluate the long-term economic performance of pavements?
    c. How to design and build test sections to evaluate methods and materials for pavement preservation and rehabilitation?
4. Decision Making
    a. How to better evaluate the risk, uncertainty, and variability in pavement management decisions?
    b. How to develop methods for multi-objective decisions (e.g., pavements and bridges) to better allocate asset management resources?
    c. How to optimize pavement management decision making within the larger context of Transportation Asset Management?
    d. How to use performance measures to prioritize resource allocation and make optimal decisions on pavement preservation and pavement rehabilitation?

Moving Forward

AFD10 movement into future decades will be built on the tremendous accomplishments made over the past 50 years. The transportation community recognizes pavement assets consume the majority of transportation funds in agencies across the world. The need for excellent pavement asset management is therefore a top priority for maximizing efforts using scarce transportation resources.

Given the research needs tabulated above, AFD10 will prioritize areas of pavement management research for both short-term benefits and long-term effectiveness. The collaboration among government agencies, industry, and academia that has been so successful with AASHTO, ASTM, FAA, FHWA, NCHRP, and the Pooled Fund program, will continue as we seek solutions to make pavement asset management more successful.

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