30 Years - 20 State DOTs – Trends in Pavement Management observed through real world Implementation at the State DOT Level.

Zavitski, Jeffrey L
Senior Implementation Specialist
Deighton Associates Limited
223 – 7 Brock Street North, Whitby, Ontario, L1N 4H6

Piane, Robert R, P. Eng.
President
Deighton Associates Limited
223 – 7 Brock Street North, Whitby, Ontario, L1N 4H6

Submission Date: August 19, 201
Number of Words: 3865 plus 5 figures
ABSTRACT
Since the first International Conference on Managing Pavement Assets 30 years ago in 1985, there has been continuous enhancement and evolution of pavement management system (PMS) technology to produce more effective recommendations coming out of an agency’s PMS. Improvements in data collection, performance measures, deterioration modelling, dynamic segmentation, treatment algorithms, triggering mechanisms and optimization technologies have led to significant improvements in PMS strategy recommendations as well as the acceptance of those recommendations in both centralized and de-centralized State Departments of Transportation (DOT). Significant efforts have also been invested in methodologies and technologies to integrate PMS into an overall asset management system (AMS) at the State DOT level utilizing cross asset optimization technologies.

This paper will examine the evolution of pavement management from the desktop environment to today’s enterprise pavement management systems within 20 State DOTs that use a common software platform and present significant changes in pavement management methodologies that lead to increased use and acceptance of the PMS recommendations and adoption within the agency. It will also examine current trends that will impact the systems of tomorrow including integration with other decision making tools, capturing field data, and alternative approaches to optimization.

INTRODUCTION
From March 18 – 21, 1985, 30 years ago, pavement management practitioners met in Toronto, Canada, at the first ever North American Pavement Management Conference. Twelve countries were represented which resulted in 75 technical papers being presented along with several workshops to help set state of the art requirements and future directions in pavement management (1). This first ever conference set the direction for future conferences in Toronto, San Antonio, Durban, Seattle, Brisbane, Calgary, Santiago and the 2015 conference in Virginia.

Since the 1985 conference, significant improvements in pavement management technology and pavement management methodologies have all combined to contribute to the advancement of pavement management and more widespread use of the PMS as agencies transition from a pavement management focused model into more of a focus on asset management. Improvements to the fundamental components of pavement management systems: the database, the performance prediction models, the alternative strategy generation models and optimization methods combined with the evolution of computing systems technology, internet technology and GIS functionality have all combine to contribute to the advancement of pavement management systems within an agency. Over the past 30 years, the authors have implemented pavement management systems in 20 State DOTs and have seen significant changes within pavement management. This paper will examine important trends and developments in several areas of pavement management which may help to determine what the pavement management systems of tomorrow may look like.

CUSTOM SYSTEMS and CUSTOM APPLICATION DEVELOPMENT TO COTS SOLUTIONS
In 1985, personal computers were not extremely powerful but becoming more readily available. While mainframe application development could often be a time consuming process to design, program and implement a pavement management system for a state level DOT in a mainframe environment. The State of Iowa was developing a mainframe PMS back in 1985 and thousands
of staff hours were dedicated to capturing data from paper files to help establish a database of
required information to help feed the data hungry PMS (2). The State of Rhode Island was
implementing a PMS using prioritization as the necessary data was not available to support an
optimized rehabilitation plan (3). In those early days, pavement management system tools were
in their infancy and agency after agency would reinvent their own wheel to ensure that their
specific needs were met.

Since those early days, both the State of Iowa DOT and the State of Rhode Island DOT
along with many other State DOTs have migrated from custom developed mainframe
applications to Commercial Off the Shelf (COTS) client / server systems that can be customized
for their agency through configuration and not through application development (4). Advantages
to COTS solutions can include lower development and implementation costs, independence from
I.T. bottlenecks, a large user base, increased functionality, ongoing developments and an
exchange of information from a large user base. Disadvantages can include the lack of true
ownership, a lengthy enhancement cycle and increasing annual support and maintenance costs
(5). As pavement management methodologies have changed through the years, DOT
requirements for COTS systems have kept up with these methodologies and COTS vendors must
be able to adapt to meet the state of the art requirements that today’s sophisticated agencies need
for both pavement and asset management.

Truly flexible COTS solutions allow for inclusion of assets other than pavement assets
for data integration, reporting and analysis. For example, the Colorado Department of
Transportation has leveraged the power and flexibility of its COTS PMS to include analysis of
bridges, culverts, buildings, fleet equipment, ITS devices and maintenance level of service
grades (6). Today’s COTS solutions for pavement and asset management include flexible
databases, user defined performance models, user defined treatment models and flexible decision
trees in order to produce complex alternative strategies for assets being analyzed. Once the
strategies are generated, sophisticated optimization and prioritization methods for project
selection enable resource allocation within and across asset categories.

Most recently, the state DOTs of Ohio, Mississippi and Pennsylvania replaced legacy
pavement management systems with new enterprise COTS solutions through an extensive
Request for Proposal (RFP) process. It appears as legacy systems are replaced, the trend is for
State DOTs to seek COTS solutions to benefit from other state DOTs experience and to remove
some of the risks associated with large in-house or contracted out software development projects.

PERFORMANCE INDEX TO INDEXES TO DISTRESS PROGRESSION AND
TRANSITION PROBABILITY MATRICES
The implementation of the COTS solution for Ohio, Mississippi and Pennsylvania highlight
another trend in pavement management methodology that has changed significantly from the
early days. With the advent of automated data collection in the 1980’s agencies could gather
pavement distress data easier and quicker than ever before. Sure there were problems that
needed to be solved including poor location reference systems and poor data quality, but the
collection of the data using semi-automated and automated solutions paved the way for increased
repeatability and accuracy of the pavement data (7). Early systems adopted the concept of
pavement serviceability which could be predicated based on relationships between various
pavement distresses. Overall composite indexes such as AASHO Road Test Pavement
Serviceability Rating (PSR) (8) and the ASTM D6433 (9) Pavement Condition Index (PCI) were
used to report overall conditions and to trigger maintenance, rehabilitation and reconstruction treatments during early analysis.

With the implementation of COTS solutions agencies could easily manage performance measures being utilized within the PMS and could add measures and remove measures with ease. No restrictions to the number and type of performance measures along with the ability to define any number and type of performance prediction methods, allowed agencies to move beyond a single index to trigger treatments within the PMS. Individual performance measures could be created for roughness, rutting, cracking, patching, and any other pavement distresses measured through manual or automated means. Systems such as the South Dakota Pavement Management System (10) would convert the pavement distress measurements in terms of extents and severities into indexes to be used in the management system using a series of deduct values. Figure 1 presents a sample set of deduct curves for alligator cracking which are used to calculate deduct values based upon the extent and severity recoded for each pavement section (11). Once the deduct values were calculated for each section, the deduct values were subtracted from 100 to get the overall alligator cracking index for the pavement section.

![Alligator Cracking Deduct Value Curves](image)

**Figure 1: Alligator Cracking Deduct Value Curves**

The index values would be predicted by the PMS into the future to develop alternative strategies to pass to the optimization models for various “what-if” budget scenarios. In the 1990s, state of the art PMS methodology had transition from implementing decision trees utilizing only one composite type index to making decisions on multiple indexes to help improve the accuracy of the PMS treatment recommendations.

Most recently, state of the art performance modelling and decision tree methodologies in states such as Ohio, Mississippi and Pennsylvania, have taken distress progression one step further and instead of predicting one overall PCI or even individual indexes, sophisticated transition probability matrices have been developed to predict the progression of extent and severity through time so that pavement treatments can be triggered based on extent and severity as opposed to individual index values. This eliminates the problem of various pavement segments with different levels of extent and severity requiring different fixes having the same index value. In the Ohio PMS (13), ten different combinations of extent and severity are tracked...
through time using three levels of extent (occasional, frequent and extreme) for three levels of severity (low, moderate and high) and then one final category for no distress (null). Transition Probability Matrices (TPMs) are used to transition the extents and severities so that the combinations can be used in the decision trees to trigger very specific maintenance, preservation, rehabilitation and reconstruction treatments. Figure 2 shows an example of a TPM from the Ohio PMS and Figure 3 shows the resulting deduct values for each of the ten possible extent and severity categories.

Figure 2: State of Ohio DOT Transition Probability Matrix Example
Using the TPM from Figure 2, the following deduct progression models are obtained through matrix multiplication:
Using the TPMs and the resulting deduct progression models, the Ohio DOT (ODOT) PMS predicts deduct values based on extent and severity categories and then uses the predicted categories in their decision trees to trigger treatment activities. Figure 4 displays a small sample form one of the ODOT PMS decision trees for the ODOT General System (14). The decision tree uses an overall Pavement Condition Rating (PCR) to categorize treatments and then the specific levels of extent and severity for various distresses to suggest appropriate candidate treatments.
The ODOT PMS generates each of the activities that are triggered by the decision trees (in each BIN) so that the economic optimization has a good mixture of available options for each of the alternative budget scenarios. Resulting bins may have more than one treatment option available to treat the prevailing distresses which result in different life cycle costs and benefits. Once the alternative strategies have been generated, the optimization then has numerous alternative strategies to choose from.

The benefits of this transition from single indexes and composite indexes to distress progression allows for more detailed treatment triggering to repair and rehabilitate specific pavement failures. In systems that rely on a composite index such as PCI to determine treatment selection, two separate pavement assets with completely different distresses could end up with the same PCI even though the two segments might require completely different rehabilitations. Moving from 1 index to indexes to distress progression has enabled state DOTs like ODOT to increase the accuracy of the PMS recommendations.

PMS FOR STRATEGIC ANALYSIS AND TACTICAL PROGRAM DEVELOPMENT
The focus of many pavement management systems have shifted slightly in recent years towards being able to generate realistic treatment options for tactical program development as well as providing a strategic level analysis for determining funding needs across functional networks (system tiers) as well as across regional or geographical networks (15). Not only is Ohio breaking new ground with distress progression and the use of probabilistic models in their COTS solution, they are also using the PMS at the strategic level for budget setting and performance monitoring and at the tactical level for pavement asset management plan development.
Ohio has three functional systems, the Priority network, the General network and the Urban network and 12 districts. Headquarters runs the statewide analysis to determine funding allocation by Priority System and the Overall Network. Once the budgets have been determined for each district based upon the Headquarters network wide analysis, 12 district analyses are then performed using budgets by priority system and one for the overall district regardless of priority. ODOT utilizes three alternative budget scenarios for each priority system (3 budget * 3 Priority Systems) as well as three alternative budget scenarios for the overall district condition. This results in 12 alternative budget scenarios for the headquarters statewide analysis and 12 for each district. These budget scenarios allow the headquarters management and planning staff to develop strategic funding needs and strategic trade-offs between districts and allows the district management and planning staff to develop tactical asset management plans from the 12 individual district alternative budget scenarios.

Additional Performance Measures for Strategic Analysis

In order to aid in using the PMS for a strategic analysis and not just for tactical program develop, agencies are adding in additional performance measures to help track the effects of budget changes on the overall strategic indexes. The Maine DOT is a prime example of a state DOT that has integrated performance based budgeting into its PMS to aid in strategic planning (16). Maine DOT has prioritized the network into Highway Corridor Priorities and has set expected levels of service (Customer Service Levels) for each corridor priority in terms of Condition, Safety and Service. Within the PMS, condition, safety and service performance measures are tracked through the analysis period and each treatment has a defined impact on Condition, Safety and Service as necessary. Some treatments such as preservation treatments impact only the Condition service level, while treatments like reconstruction or major rehabilitation may impact all the customer service level performance measures. Implementing these measures allows the DOT to illustrate how changes to the amount and / or the distribution of funding between categories impact the overall condition of the network as well as the other customer service level measures.

The Colorado DOT (CDOT) has leveraged the power of their COTS PMS to include other transportation related assets including bridges, culverts, buildings, ITS devices, fleet equipment, rockfall hazards and the CDOT maintenance levels of service grades in the analysis (17). For each of the assets, inventory and condition data are used to support a strategic and tactical level analysis that is used for strategic planning and funding distributions. Performance measures for each asset include the underlying condition of the asset and the necessary measures to trigger maintenance, preservation, rehabilitation and replacement strategies as well as the overall performance measure used to set performance goals and budgets. The “slider-tool” functionality as well as the “cross-asset analysis and optimization” functionality available within CDOT Asset Investment Management System (CDOT AIMS) allow for funding allocation trade-offs between these different assets.

Along with the addition of new performance measures to the PMS used for strategic planning, the need for new methods for analysis, optimization and prioritization have become necessary in recent years. Maine’s Level of Service analysis based upon letter grades representing customer service levels requires the ability to set budgets and targets for multiple performance measures. With the inclusion of rockfall and Geo-hazard assets in CDOT AIMS, CDOT will move to a more risk based analysis for rockfall and other assets. Future pavement
management systems will need to include multi-criteria optimization to weigh the impacts of funding decisions amongst multiple criteria.

As the need for cross-asset analysis becomes more prevalent, the trade-off tools that need to be developed will need to be able to optimize on non-traditional measures that might include replacement cost, asset value, sustainability, mobility and impacts on society, the economy and the environment. These asset management tools will also need to depart from their focus on individual asset types and broaden their scope to address the needs of managing across functional classes within an asset type, as well as, across different asset types.

**FIXED PROJECT LENGTH SEGMENTS vs. VARIABLE LENGTH SEGMENTS**

During the configuration of the ODOT pavement management system, ODOT was faced with the decision of what analysis segments to use for the HQ and District analysis. In the early days of pavement management, following the first and second North American Conferences, much time and energy was spent on “dynamic segmentation” and “concurrent transformation”, to automatically generate homogeneous segments for analysis based on condition and pavement characteristics data. The AASHTO cumulative difference method developed in 1986 was an early solution to segmenting the pavement data for analysis (18). Following the data collection phase, the data would be analyzed and homogenous project segments generated based on the condition and inventory data. Each year, depending on the repeatability of the data, new project segments would be generated. Many state DOT pavement management systems including those of Maine, Massachusetts, and many others still use processes to automatically generate analysis segments each year. As the pavement analysis sections change each year, recommendations coming from the PMS analysis would change each year as well making it difficult for the end users of the recommendations to manage program development. End users would also be faced with the challenges of automatic segmentation breaking project limits at locations where a project limit would be infeasible or not practical.

Within the past several years, there has been a change in philosophy in many DOTs to keep analysis segments consistent year over year and to institute a process for maintaining analysis segments much like how other segments are maintained within the DOT. New Jersey DOT, for instance, reviewed video log footage from recent collections and used a combination of automatic segmentation and manual segmentation to develop a set of project segments that are analyzed each year and that are only adjusted when projects are completed. Ohio DOT uses the PCR segments for analysis unless a committed project has been entered to override the PCR segmentation. Utah DOT maintains a Pavement Section Editor, an on-line web based application that allows the regional pavement management engineers to modify project limits based upon recent projects and local knowledge. Changes to the project segmentation are tracked through time so that changes can be validated against project history data, inventory and condition data. This trend will continue into the future as more demands are placed on the PMS to produce consistent, accurate and repeatable results year after year that can be used for strategic and tactical planning.

Developing fixed project sections for analysis can highlight an area where many DOTs still struggle; the area of capturing project and maintenance history. Locations in the network that received projects last year and the specific project details are often not readily available in many DOTs. When condition data is compared from year to year, often increases in condition are witnessed without an explanation. The programming of PMS projects without an indication of maintenance and construction history can lead to poor recommendations and implement
routine maintenance that is not connected to a PMS program can lead to wasted maintenance expenditures. In order to help coordinate the application of projects and maintenance across fixed project sections, Mississippi DOT and Utah DOT are currently implementing on-line construction history modules to help capture maintenance and construction details needed by the PMS. With the capture of maintenance and construction history, fixed project sections may become more accurate and lead to better programming recommendations coming out of the PMS.

PMS DATABASE DEVELOPMENT
Pavement management systems, like technology in general, have evolved over time from stand-alone desktop systems to sophisticated enterprise wide solutions with full web based connectivity. End users – the users of the information and results of the PMS - need access to both PMS functionality and data through web based tools. Increasingly, the PMS itself must be connected to other department wide systems to access data need by the PMS and to provide data from the PMS to other systems.

Enterprise wide pavement management systems such as Louisiana’s PMS, Ohio’s PMS and Pennsylvania’s PMS have sophisticated data needs for integration and analysis. The Ohio PMS pulls data from a Central Oracle Database (COD) built to support the PMS. The PennDOT PMS pulls data from a variety of sources with most of the data coming from the PennDOT GIS. The Louisiana PMS pulls data from many different disparate systems in order to produce pavement management information. At this point in time, these systems rely on ETL (extract, transform, and load) functionality to take data from existing data sources and transform the data for use within the PMS. Sophisticated relationships are developed between different data sets for user permissions, roles and for workflows to facilitate the transfer of data.

In the future, pavement management systems must be flexible and sophisticated enough to use data in existing systems without the need for ETL technology. DOTs will adopt more of a load once philosophy where data is loaded and stored only in one system and all other systems that need access to that data must access the data through that one trusted source.

THE NEXT 30 YEARS
Much like the evolution of pavement management over the preceding 30 years, pavement management systems and integrated asset management systems will see many changes in the next 30 years due to increased demands put on these systems to aid in programming projects to achieve condition, mobility, economic, environmental and societal fiscally constrained goals and aspirational targets. COTS solutions as well as in house developed solutions will need to constantly evolve to meet these increasing demands with more open and flexible systems that include increasingly sophisticated optimization and prioritization methods. System operators, the pavement managers and asset managers, who are responsible for these systems will need to evolve as well to include more broad based training including economics, analytics and information sciences.

1 North American Pavement Management Conference, proceedings Volume 1 – 3, 1985
2 Tritsch, Steven L., “Iowa’s Pavement Management System”, North American Pavement Management Conference, proceedings Volume 1, 4.84, 1985
4 Deighton Associates Limited, Client Listing, on-line at www.deighton.com
5 Bennett, Christopher R., Success Factors for Computerized Road Management Systems, World Bank 2007
6 Richrath, Scott, Colorado DOT Tam and Financial Planning, 10th National Conference on Transportation Asset Management, Miami, Florida, April 2014
8 Hallin, John P., Pavement Design in the Post-AASHO Road Test Era, TRB Circular Number E-C118, July 2007
11 Ibid. Page 91
12 Ibid, Page 92