TECHBRIEF

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Next-Generation Pavement Performance Measures

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This TechBrief is part 1 of a two-part series (part 2 is *Next-Generation Transportation Asset Management Methodology* (FHWA-HRT-23-075)), and summarizes the Federal Highway Administration (FHWA) report *Development of Next Generation Pavement Performance Measures and Asset Management Methodologies To Support MAP-21 Performance Management Objectives* (FHWA-HRT-23-102).

INTRODUCTION

Since 2012, Federal legislation has promoted the use of performance-based decisions for managing the Nation's highway system. The Moving Ahead for Progress in the 21st Century (MAP-21) Act identified seven national goals and established requirements for pavement and bridge performance measures on the National Highway System (P.L. 112-141; 23 U.S. Code (U.S.C.) §115; 23 Code of Federal Regulations (CFR) Part 490). MAP-21 also established requirements for the development and implementation of risk-based Transportation Asset Management Plans (TAMPs) by State departments of transportation (DOTs) (23 CFR Part 515). These requirements promote the use of data-driven investment decisions to preserve the public's investment in the highway system and maintain the highway infrastructure assets in a state of good repair (SOGR).

Although the condition-based pavement performance metrics defined in 23 CFR 490.309 (e.g., cracking, rutting, faulting) meet the immediate needs under the legislation, FHWA initiated research to explore "next-generation" pavement performance measures (NGPPMs) that are more proactive in driving investment decisions that lead to enhanced long-term performance. FHWA also investigated the feasibility of a methodology to help agencies manage their highway infrastructure as a system rather than a network of individual asset classes.

The research was initiated in 2015 as a two-phased effort titled Identification of Effective Next-Generation Pavement Performance Measures and Asset Management Methodologies to Support MAP-21 Performance Management Requirements (FHWA n.d.). Phase I resulted in the identification of eight promising pavement performance measures (not currently required under any Federal legislation) capable of being used as leading indicators for long-term investment strategizing and decisionmaking (Bryce et al. 2016; Sadasivam and Mallela 2017). Two promising transportation asset management methodologies (TAMMs) were also identified through the research. In Phase II, after further development and analysis, seven of the promising performance measures and one of the proposed TAMMs were pilot

implemented at the State level to validate their use. The study also sought to validate the performance measures at the Federal level (Ram et al. 2023).

This TechBrief summarizes key findings from the research efforts to validate the NGPPMs and provides insights on how they can be used to support agencies' decisionmaking processes. A separate TechBrief documents the validation of the proposed TAMM as an approach to support cross-asset decisionmaking (Thompson et al. 2023).

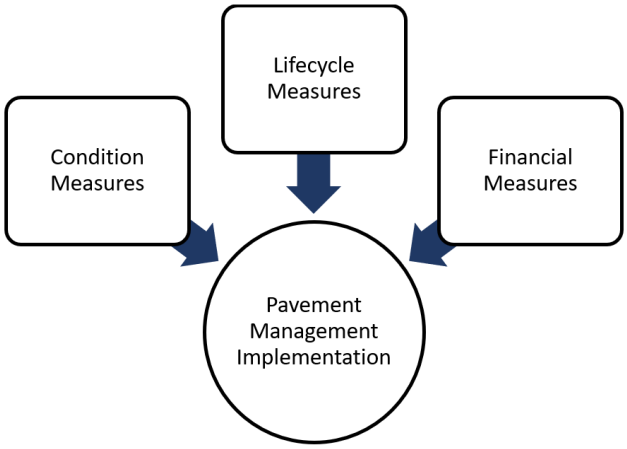
NGPPMs

Long-term investment decisions benefit from the use of performance measures that indicate expected pavement performance and investment needs. Performance measures that enable the implementation of a comprehensive asset management program may be grouped into the following three broad categories, as illustrated in figure 1.

- Condition measures that are specific to an asset class and agency (e.g., pavement roughness, rutting, and cracking, and an agency's rating scale of pavements in good/fair/poor conditions).
- Lifecycle measures that provide information on the lifecycle cost (LCC) of maintaining a pavement network.
- Financial measures that describe the financial sustainability of an agency's pavement management program.

Current and projected conditions are two common indicators of pavement performance. Condition is generally considered a measure that is physically observable through a standard rating protocol (e.g., cracking, rutting, roughness). These types of condition measures are currently used in pavement management systems (PMSs) and are predicted into future years using established deterioration models. Such models, combined with treatment application costs, enable agencies to estimate the cost effectiveness of applying treatments at different points in time. Applying this process to an entire network provides agencies with the information needed to evaluate different investment strategies. Most agencies already have procedures to rate asset conditions, and condition-based measures are well understood. However, these measures tend to lag behind investment decisions because they follow investments that have already been made. This study sought to look for additional leading measures that could be used proactively to drive investment decisionmaking in concert with existing condition measures.

Figure 1. Illustration. Performance measures to enable a comprehensive pavement management program implementation.



Source: FHWA.

The study focused on lifecycle and financial performance measures. Lifecycle performance measures characterize and monetize the long-term investment strategies (i.e., construction, maintenance, and rehabilitation treatments) associated with providing a desired level of service (LOS) for a highway asset. These measures proactively encourage activities that reduce the long-term cost of system preservation. Thus, the focus is on evaluating strategy cost effectiveness and achieving the highest overall system performance at the lowest practicable LCC. Table 1 provides an overview of the lifecycle performance measures selected by FHWA for evaluation during the second phase of the project.

Financial performance measures indicate if an adequate level of investment is being made to offset the rate of asset-value depreciation or to satisfy treatment needs (not just to meet condition targets but to sustain those targets into the future). Four different financial measures were evaluated in this study, each of them providing unique information on the financial sustainability of an agency's investment approach. Table 2 provides an overview of the financial performance measures selected by FHWA for evaluation during this phase of the study.

Each performance measure can help transportation agencies answer questions that are important to drive cost-effective investments, consider long-term pavement performance, and measure the overall effectiveness of the pavement management program.

Table 1. Lifecycle performance measure overview.

Measure	Description	Source
Remaining service interval (RSI)	• Identifies a structured sequence of the type and timing of various intensities of repair and replacement actions required to provide the desired LOS to users over the asset lifecycle at minimum practicable costs. • Provides a framework to incorporate a whole-life perspective in determining future repair and replacement actions (i.e., considering both current condition and past actions in determining future actions, performance risks, and investment needs).	Rada et al. (2016); Bryce et al. (2016)
Annualized unit cost ratio (AUCR)	• Establishes a ratio of the annualized cost of all planned expenditures over the pavement lifecycle to the annualized cost of expenditures under the optimized strategy. • Compares planned investments to the optimized lifecycle strategy.	Sadasivam and Mallela (2017)
Cost accrual ratio (CAR)	• Represents the ratio of net present value (NPV) of all programmed costs over a chosen period against the NPV of the agency's optimized lifecycle plan (LCP). • Compares the actual investments made against the optimized lifecycle strategy that requires the minimum practicable LCC.	Sadasivam and Mallela (2017)

Table 2. Financial performance measure overview.

Measure	Description	Source
Asset sustainability index (ASI)	• Represents the ratio of the amount of the budget allocated to the amount needed to address all current management system treatment selections. • Helps decisionmakers use ASI to determine the adequacy of investments to address needs identified by the management system. • Helps agencies determine a strategic investment plan using trends in the ASI.	Proctor, Varma, and Varnedoe (2012)
Asset sustainability ratio (ASR)	• Represents the ratio of asset maintenance, preservation, and replacement expenditure to asset depreciation for a given period. • Focuses on the process that is expected to drive pavement condition. • Helps decisionmakers determine if sufficient investments have been made in the current period.	Howard, Dixon, and Comrie (2011)
Asset consumption ratio (ACR)	• Represents the ratio of depreciated asset replacement cost to the current replacement value. • Establishes a metric that highlights the average proportion of as-new/as-built condition left. • Helps agencies use ACR trends to determine if adequate resources are being invested to maintain current life expectancy.	Howard, Dixon, and Comrie (2011)
Stewardship liability ratio (SLR)	• Represents the ratio of unfunded treatment needs to replacement cost of the network. • Helps agencies compare treatment strategies. Applies to multiple assets. The application capability exists to conduct tradeoff analysis and compare the impact of different funding levels across asset classes.	Zimmerman et al. (2016)

VALIDATION STUDIES

The NGPPMs were tested and validated at three selected State highway agencies—Idaho Transportation Department, South Dakota DOT, and Texas DOT (Ram et al. Forthcoming). In addition, the researchers attempted to validate the measures at the Federal level. The key findings from the validation efforts are summarized in the next section.

Key Findings From the State Validation Study

Table 3 summarizes the key takeaways and validation experiences associated with the lifecycle and financial performance measures evaluated in this study.

Table 3. Strengths and implementation challenges for each NGPPM evaluated.

Type	Approach/ Measure	Summary	Testing and Validation Experiences
Lifecycle measures	RSI	• Reduces the reliance on decision trees for treatment selection. • Identifies the lowest LCC strategy that meets established objectives and performance requirements under constrained and unconstrained budget situations.	• Difficult to develop optimized models if the pavement management practices at an agency are not currently considering LCCs. • Analysis runs are time- and resource-intensive. • Output dataset requires more storage space.
Lifecycle measures	AUCR	• Provides a relatively simple measure that compares the annualized costs of current strategies to the optimized strategy and is intuitive to decisionmakers. • Helps visualize the magnitude of the deviation from the optimized lifecycle strategy.	• Calculating the measure would require the identification of the lowest LCC strategy using either the RSI analysis or other methodologies. • Agencies would have to conduct additional work to determine the level of acceptable deviation from the optimized plan and its implications.
Lifecycle measures	CAR	• Helps in visualizing the deviation from the optimized LCP and the short- and long-term differences in spending when comparing multiple lifecycle strategies. • Aids in evaluating the financial sustainability of different lifecycle strategies assessed by the agency.	• Calculating the measure depends on the identification of the lowest LCC strategy using either the RSI analysis or other methodologies. • Agencies would have to conduct additional work to determine the level of acceptable deviation from the optimized plan and its implications.
Financial measures	ASI	• Assists in monitoring investment levels in different treatment categories (maintenance, preservation, etc.) and how they impact asset performance. • Applies across different asset classes. • Supports the establishment of short- and long-term investment targets at both the agency and district levels that will help the agency meet or exceed the desired SOGR.	• The measure requires calculation of the “need,” which can be challenging to apply consistently.
Financial measures	ASR	• Indicates if an agency is investing adequately to offset asset-value depreciation. • Applies across different asset classes. • Supports the establishment of targets that will help keep the asset-value depreciation rate in check.	• Calculating asset value depreciation can be challenging, and approaches can vary significantly across agencies. • Measures can help agencies communicate a story that can be different from what the condition trends may show.

Table 3. Strengths and implementation challenges for each NGPPM evaluated. (continued)

Type	Approach/ Measure	Summary	Testing and Validation Experiences
Financial measures	ACR	• Indicates the proportion of as-new condition left in an asset class. • Applies across different asset classes.	• Calculating asset value depreciation can be challenging, and approaches can vary significantly across agencies. • The measure does not communicate anything different than existing condition-based measures.
Financial measures	SLR	• Tracks time-series trends on the progression of backlog when compared to the replacement value of the pavement work. • The SLR was previously known as the backlog reduction ratio.	• If an agency's PMS does not report backlog, calculation of this measure can be difficult. • The measure can help determine whether a significant shift in treatment strategies may be necessary to help keep the rate of change of backlog in check.

Lifecycle Measures

From a whole-life perspective, the remaining service interval (RSI) framework is the most robust analysis approach that can help agencies establish long-term, cost-effective treatment strategies. However, the RSI approach is computationally intensive, and the analysis can be time consuming. Additionally, a learning curve is associated with implementing this approach within State DOTs. Computational resources will continue to improve over time, and the processing power of computers 5 to 10 yr from now could significantly reduce the time required to conduct the RSI analysis.

The RSI approach will help agencies:

- Evaluate the impact of all feasible treatment types and timing combinations without limitations imposed by decision trees.
- Make treatment recommendations based on lifecycle costs.
- Consider the short- and long-term impacts of deviating from the lowest LCC strategy (optimized strategy).
- Support pavement LCP activities required by 23 CFR Part 515.

FHWA has published a TechNote on the RSI approach that provides a simplified overview of the fundamental concepts associated with RSI (Ram et al. 2021). This TechNote provides suggestions on how agencies can start considering the RSI approach to support pavement LCP activities.

The other lifecycle measures evaluated in this study (CAR and AUCR) can be used in conjunction with the RSI analysis to help visualize how different lifecycle strategies compare against the optimized strategy.

Financial Measures

Asset sustainability index (ASI), asset sustainability ratio (ASR), and stewardship liability ratio (SLR) are the three most useful financial measures. When used together, these leading measures can help answer the following questions:

- How much needs to be invested to offset asset-value depreciation?
- Are the right types of investments (in terms of the right mix of treatment types that help offset depreciation effectively) being made rather than just focusing on the right investment level?
- When should a significant shift in the investment approach be considered to ensure acceptable long-term performance? (Ram et al. Forthcoming).

In the absence of network-level pavement structural condition information, the ASR can also serve as a surrogate measure for structural health if the asset value calculations are modeled based on predicted structural distresses (e.g., rutting and fatigue cracking).

The ACR measure provides some useful information from a communication standpoint (e.g., what fraction of the as-built condition is left). However, the story is no different from what conventional condition measures, such as the international roughness index (IRI) and composite indices, would help communicate (Ram et al. Forthcoming). Thus, agencies may not find the ACR measure very appealing.

One benefit of all the measures evaluated in this study is that they are asset generic and can be expanded to other asset classes besides pavements. This feature is beneficial for comparing investment options across asset classes.

NGPPM IMPLEMENTATION

Even without full implementation, State DOTs can start using the NGPPMs evaluated under this project with traditional condition-based measures to better understand their usefulness in the pavement management decisionmaking process. Some short- and long-term strategies for practical use are as follows:

- Short-term strategies (<5 yr).
    - Calculate the NGPPMs and compare the results to existing agency-based condition measures to see if the measures can help communicate a more informed story.
    - Use the measures to communicate differences between various treatment strategies and funding levels evaluated by the agency for a nontechnical audience.
    - Pilot the use of NGPPMs within a district/region or county to validate treatment decisions.
    - Conduct training for PMS practitioners on how the measures can be implemented today through the development of simple tools that can be used in conjunction with PMS results.
- Long-term strategies (5 to 10 yr).
    - Work with the PMS vendor to make necessary adjustments that enable the calculation of the measures within the PMS without other supplemental tools.
    - Use performance measures to validate pavement management decision trees. This process involves assessing whether the PMS is recommending the right type of treatment at the right time to offset asset-value depreciation over the long term.
    - Improve measure computation accuracy to make it more representative of actual values through refinements of PMS data and model inputs.

ENHANCEMENTS TO TOOLS AND PROCESSES

The following suggestions can help advance the implementation of the NGPPMs:

- **Ability to calculate the "need" within the PMS.** The calculation of the annual "need" to achieve or maintain the desired SOGR at the network level for each analysis run conducted using the PMS will greatly simplify the process of calculating the financial measures.
- **Ability to estimate asset value depreciation within the PMS.** If the analysis module within the PMS has tools to model asset valuation and asset-value depreciation using one or more approaches, it will significantly simplify the process of calculating financial measures, such as ASR and ACR.
- **Ability to calculate LCC within the PMS.** Typical PMS software tools do not calculate LCC suitable for use with the RSI approach. Considering the remaining value of treatments beyond the analysis period or the cost to restore the pavement network to the desired SOGR at the end of the analysis period will help in comparing the long-term impacts of different lifecycle strategies evaluated by the agency.
- **Ability to evaluate all feasible treatment strategies without relying exclusively on decision trees.** Many of the PMS tools generate multiple treatment strategies for each pavement segment in the network. However, the strategies developed rely heavily on the rules established using decision trees. Decision trees rely on predetermined thresholds for distresses, pavement condition, and/or other performance indicators (cracking, rutting, overall condition index, IRI, etc.). Using these somewhat subjective treatment trigger thresholds could potentially result in the true optimal solution being missed.
- **Use of structural health data to model asset valuation.** The assessment of the structural health of pavements using technologies like the traffic speed deflection device and using data from these technologies to develop asset valuation models that are tied to pavement structural health will improve the overall decisionmaking characteristics of the NGPPMs.
- **Use of robust pavement performance models.** The ability to develop performance models that not only consider the type of treatment and other associated parameters (e.g., traffic level, climate, functional class) but also the pretreatment structural and functional conditions will allow agencies to differentiate between viable treatment strategies and timings.
- **Staff dedicated to pavement management data analytics.** Staffing has always been a challenging issue for State DOTs. Agencies are already dealing with huge volumes of data, and the amount of data is only expected to increase in the future. A dedicated group of agency staff primarily focused on converting all the data collected (current and historical) into useful information that can be leveraged in the decisionmaking will be helpful in the future.

IMPLEMENTATION BENEFITS

The implementation of the NGPPMs will provide agencies with an enhanced ability to assess and compare pavement management strategies and make decisions that are not only cost effective in the short term but also provide the best return on investments over the lifecycle. The main uses from the implementation of the NGPPMs are summarized as follows:

- **Identify pavement treatment strategies that result in the lowest practicable LCC.** The lifecycle approaches and measures evaluated and validated in this project (RSI, CAR, and AUCR) will help agencies assess the effectiveness of the pavement management strategies selected by comparing the planned expenditures and performance outcomes to the optimized strategy. This approach will help agencies make necessary adjustments to the strategies being implemented to ensure that the deviation from the optimized strategy is minimized.
- **Convey a message that may not be possible using just condition-based performance measures.** The use of NGPPMs may help agencies communicate a story that may not be apparent from just condition-based indicators. Financial measures, such as ASI, ASR, and SLR, will help agencies not only evaluate the effectiveness of their investment approaches in meeting and sustaining the desired SOGR but also measure the impact of the treatment strategies in maintaining asset value and keeping the backlog growth rate in check. In addition, NGPPMs provide leading measures that can be used to drive investment decisions. The time-series trends exhibited by these measures can help identify when a significant shift in the pavement management approach may be needed.
- **Communicate performance outcomes using measures that resonate with decisionmakers.** The use of traditional performance measures, such as IRI, pavement distresses, and overall condition indexes, may not necessarily resonate with decisionmakers within agencies. The financial measures evaluated in this study communicate pavement network performance using simple, intuitive indicators that do not require specialized pavement management knowledge.
- **Use measures for cross-asset tradeoff analysis.** Because all the performance measures evaluated in this study are asset generic, one of the main benefits is the potential to use these measures for cross-asset tradeoff analysis to evaluate the long-term impacts of different treatment strategies and funding allocation approaches.

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