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Next-Generation Transportation Asset Management Methodology

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This TechBrief is part 2 of a two-part series (part 1 is *Next-Generation Pavement Performance Measures* (FHWA-HRT-23-076)), 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 the national performance measures for pavements and bridges 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). Requirements were also established for the development and implementation of risk-based Transportation Asset Management Plans 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.

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 transportation 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.a). Phase I of the project identified eight promising pavement performance measures (not currently required under any Federal legislation) highway agencies could use as leading indicators for long-term investment strategizing and decisionmaking, along with two promising transportation asset management methodologies (TAMMs). 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. Forthcoming).

This TechBrief summarizes key findings from the research efforts to validate the proposed TAMMs as an approach to support cross-asset decisionmaking. A separate TechBrief documents the validation and potential use of the NGPPMs (Ram et al. 2023).

TAMM DEVELOPMENT

Transportation agencies own, operate, and maintain a diverse infrastructure to support transportation services to the public. This infrastructure includes a variety of asset classes, such as pavements, bridges, tunnels, earthworks, drainage facilities, guardrails, traffic control devices, lighting, and buildings. These asset classes work together as an infrastructure network; however, each asset class has its own technologies and specialized maintenance requirements, and the performance of each asset class affects the public in its own way.

Because of the specialized technologies and professional disciplines required to construct and maintain the various classes of physical assets, transportation agencies have traditionally managed them separately. Over time, each asset class has evolved its own conceptual frameworks, research concerns, training requirements, technical jargon, and performance metrics. These issues make it challenging to develop practices and tools that leverage the great strengths of the separate technical disciplines while enabling the integrated management of the infrastructure network when viewed holistically (Maggiore et al. 2015).

PROPOSED TAMM

Agencies face decisions that relate current choices about work to be done (e.g., maintenance, preservation, rehabilitation, reconstruction, network expansion) to future expectations for network performance. Changes in the allocation of resources in the near term can be expected to lead (in a cause/effect fashion) to changes in performance later. If the agency allocates a greater share of funding to urban highways, for example, then urban network performance should be expected to improve relative to rural network performance. Similarly, focusing resources on safety in preference to other goals should result in greater safety improvement.

To adopt a results-oriented approach to decisionmaking, agencies need modeling tools that estimate future performance based on near-term actions. These tools use quantitative data about current asset inventory and performance, scientific and statistical understanding of deterioration processes, cost structure, project delivery capabilities, and treatment effectiveness. The tools then convert this information to network performance estimates at a future time.

Some of the needed tools already exist in the form of asset management systems like pavement management systems (PMSs) and bridge management systems (BMSs). What is missing is the ability to examine this tradeoff in an asset-generic way so that decisions that are not asset-specific (such as budgeting and programming) can be related to stakeholder-relevant measures of network performance while maintaining consistency with the technical analysis already provided by the management systems.

The researchers proposed TAMMs to support tradeoff analysis among multiple objectives and multiple asset classes that are traditionally managed separately, including at least pavements and bridges. The challenge in developing this methodology was to fairly reflect the diverse ways that different asset classes can affect road users and transportation system objectives.

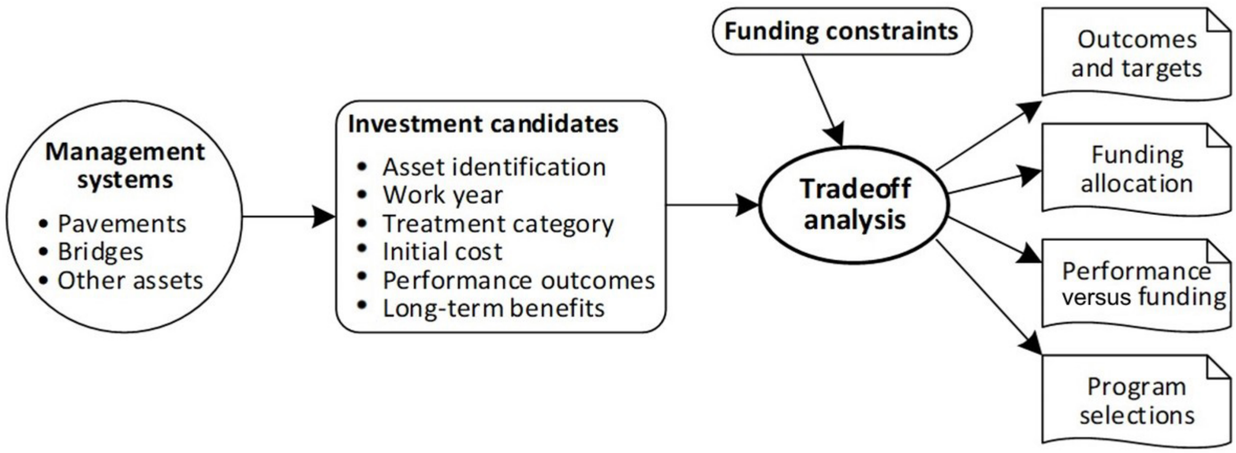
The methodology needed to be attainable using existing pavement and bridge management systems capabilities. The tradeoff analysis also needed to address common planning use cases in a familiar and implementable way for State DOTs and other transportation infrastructure owners.

Figure 1 illustrates how existing management system capabilities can be harnessed to support a cross-asset tradeoff analysis. Management systems produce sets of investment candidates, characterized by attributes that can be expressed in a sufficiently generic way to make them comparable. The tradeoff analysis can then use a prioritization scheme to provide decision support for common transportation asset management business processes.

TAMMs commonly integrate tradeoff analyses with priority setting because both functions demand compatible expressions of objectives and constraints. Thus, the TAMM was conceived as a prioritization approach that can be made sensitive to common performance goals, including condition, cost, safety, and mobility.

The proposed TAMM used social cost to evaluate tradeoffs, specifically, the savings in social cost if an investment is selected today rather than delaying it. Assuming the agency wishes to keep its network in

Figure 1. Illustration. Harnessing management systems to support cross-asset tradeoff analysis.



Source: FHWA.

service as a long-term social concern, the tradeoff analysis can be formulated as a problem of minimizing social cost. The analysis will include the consideration of long-term agency and user costs, either combined or independently depending on agency preferences, and can be constrained by funding availability and the desire to keep the network operating at the desired level of service. Designed in this way, an agency can use both agency and user cost components to evaluate tradeoffs or limit the analysis to consider only agency cost components if desired.

Existing models and research provide practical ways of computing the cost components. Ultimately, the proposed TAMM is used in the same way as any benefit-cost ratio (BCR) in a benefit-cost analysis and is compatible with common algorithms for priority setting and tradeoff analysis under fiscal constraints (World Bank 2022).

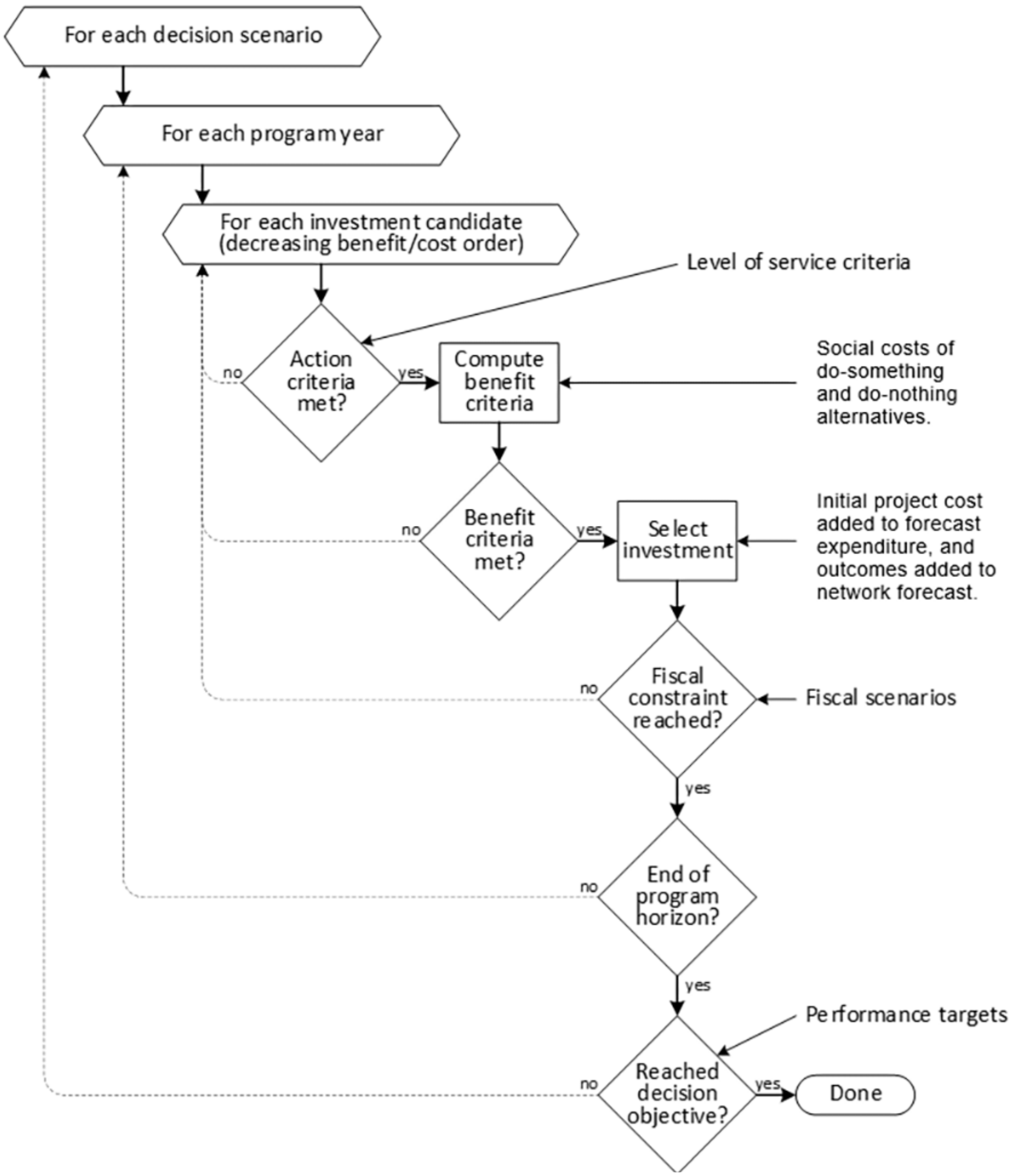
Investment candidates are prioritized by BCR each year. Top-ranked candidates are selected, subject to funding constraints. Candidates that cannot be selected are delayed, which may cause additional social costs. Performance outcomes for the network are the combined result of asset deterioration and the effects of all the investments that can be performed within the funding constraint.

New decision scenarios can be prepared by making changes in the policies that generate the investment candidates. A quicker method allows weighting factors to be applied to the components of social cost representing agency costs, safety-related user costs, and mobility-related user costs. This quicker method uses social cost in the same manner as a utility function. Initially, all types of costs may be given equal weight, but the agency may decide to increase the weight assigned to an objective (or to a portion of the network) to improve the performance of that portion of the program. The idea of shifting money to a part of the program that needs better performance is intuitive to program managers.

Using the outcome measures (based on asset condition, safety, mobility, and environmental sustainability) and the BCR, the researchers developed the methodology to forecast the results of any given decision scenario. A series of decision scenarios can then be developed that represent alternative fiscal scenarios, alternative allocations of resources, and/or alternative policies. A set of targets, expressed in the form of the outcome measures (percent good condition, percent poor condition, percent sufficient for safety, percent sufficient for mobility) can be used to assess whether a given scenario is likely to achieve its intended objectives. If the targets are not all satisfied, adjustments can be made in the decision scenario to find a more satisfactory solution. If no solution satisfies all the targets, then it may be necessary to adjust the targets.

Figure 2 represents a flow chart of this tradeoff analysis algorithm. The algorithm is a common feature of PMSs and BMSs and a feature of many homegrown spreadsheet programs that agencies have built to support capital-budgeting exercises. The main difference in this case is that the performance measures used in the algorithm are constructed to be as asset generic as possible to enable tradeoffs involving multiple classes of assets (especially pavements and bridges).

Figure 2. Illustration. Tradeoff analysis algorithm.



Source: FHWA.

To assist in the implementation of the proposed TAMM, the researchers developed and pilot tested a spreadsheet model at three State highway agencies—Idaho Transportation Department, South Dakota DOT, and Texas DOT. The findings from the implementation efforts are discussed later in this TechBrief.

FACTORS CONSIDERED IN DEVELOPING THE TAMM

This study focused on the development of a tradeoff analysis methodology that can serve the diversity of asset classes and cut across their boundaries to support business processes that manage the infrastructure network holistically. To enhance implementation feasibility, the methodology relied on existing management systems as far as possible and focused on a performance measure that can be used to prioritize investments and allocate resources fairly across all classes of assets. Such a measure could then be used in planning tools already familiar to transportation agencies to serve their business needs. The search for this measure produced the following findings:

- A focus on the network was facilitated by concentrating on existing Federal legislation and rules that agencies already observe that cut across asset class boundaries. For example, the focus included the statement of national transportation goals in the requirements of transportation performance measures and the requirements of management systems (23 U.S.C. §150(b); 23 CFR 490; 23 CFR 515).

- State DOTs often have legislation or strategic plans that closely follow the national goals, particularly condition, safety, mobility (for people and freight), and environmental sustainability. Some agencies also have additional objectives for factors such as customer satisfaction. Different asset classes affect these objectives in different ways. In some cases, the objectives are taken as constraints rather than variables to be optimized. For example, PMSs often do not attempt to quantify the mobility benefits of projects but merely apply constraints to limit mobility impacts due to deteriorated conditions.

- Federal transportation performance management rules give a precise definition for condition measures that are well established in current practice and support certain essential processes such as tracking of trends and management of targets (23 CFR Part 490). The pavement and bridge measures are superficially similar in that they both are weighted averages of the assets in good or poor condition. However, the definitions of good and poor fundamentally differ among asset classes, so these measures are not comparable across asset classes and cannot be used to compare dissimilar investments or to provide a basis for resource allocation. Further, these measures are only defined for pavement and bridge conditions, not for other asset classes or other performance concerns.

- Federal management system requirements reflect existing agency requirements and long-standing research, particularly the practice of lifecycle cost analysis (LCCA), risk management, and benefit-cost priority setting (23 CFR 515.17). However, many existing management systems, especially PMSs, are not configured by the agency for LCCA and risk.

- The research team, while reviewing the current state-of-the-art practice, observed that commonly used asset management systems were not using a performance measure that could be interpreted consistently across asset classes for tradeoff analysis. However, certain related software tools, such as FHWA's Highway Economic Requirements System (HERS), have some of the needed capabilities but lack others for lifecycle analysis and preservation planning (FHWA 2000). Moreover, existing management systems may have the necessary data and basic analysis capabilities to derive a usable performance measure.

- The representation of transportation goals or objectives as constraints in decision trees, rather than as variables to be optimized, limits the ability to readily perform a tradeoff analysis that investigates a range of alternative allocations of resources among asset classes or among performance concerns due to the iterative nature of the analysis. This inherent feature of many PMSs makes it difficult and time-consuming to develop a sufficient range of scenarios to support cross-asset tradeoff analysis. This issue is less of a concern with BMSs because they were designed from the start to work with highly diverse inventories, including nonbridge structures, and to model performance concerns other than condition.

DEVELOPMENTAL STRATEGIES TO SUPPORT TAMM IMPLEMENTATION

The barriers to improved management system capabilities to support cross-asset tradeoff analysis are found on both the supply and demand sides of the economic equation for developing and using management systems. On the supply side, no standard framework exists for the data needed to support cross-asset tradeoff analysis. As a result, developers lack a data model and analytical process that are sufficiently stable so that the cost of developing the system can be spread over multiple agencies.

On the demand side, the agency decisionmakers for selecting management systems are either pavement experts or bridge experts, but rarely both. Expertise in both areas, however, is beneficial. Cross-asset tradeoff analysis is a third area of expertise that is not often recognized. Additionally, most agency programming staff are not aware that cross-asset tradeoff analysis is feasible as an application that can be built on existing management systems.

Developers need to have expertise on appropriate features for cross-asset analysis. The most important areas to develop are as follows:

- Cross-disciplinary understanding and experience with multiple asset classes (including pavements and bridges) from a program management or research perspective.
- Lifecycle thinking, especially as practiced for network-level applications.
- User cost models and related methods of econometric analysis of public policy.
- Risk analysis encompassing the probability of extreme events, the effects of such events on transportation assets, and the resulting disruptions to transportation services.
- Software architecture and design expertise with large computational systems to optimize execution efficiency, including algorithm design and multithreaded programming.

Expertise in the above areas exist and are readily available, but companies developing management systems need sufficient assurance that an investment in these skills will satisfy their business needs. In the transportation industry, assurance could be provided by means of standard-setting processes or joint development projects.

TAMM VALIDATION FINDINGS

The next-generation TAMM was conceptualized as a means of integrating multiple asset classes within appropriate common business processes that might be implemented within the next 10 yr using data and tools likely to be available within that time frame. These cross-asset business processes include the determination of funding levels, network policy formation, resource allocation, project development, priority programming, and delivery. Implementation feasibility was a central concern, leading to decisions to keep the framework as simple as possible and relying on existing systems as much as possible.

If an agency's current process for budget allocation is simply the continuation of historical norms, the idea of using a tradeoff analysis may be new. Applying a tradeoff analysis requires stakeholders to consider changes in historical allocations, which may imply changes in staffing and other resources and may affect the workload of the contractor community. These changes make the impacts of such decisions much bigger than the scope of existing management systems. Part of the value of using an economic performance measure to evaluate tradeoffs is the ability to estimate the economic benefit of a change in historical norms, which can be weighed against the costs.

The complex part of implementing the proposed methodology is computing the required performance measures, including forecasts of outcomes and the benefit-cost priority measures. In the pilot studies, the benefit-cost calculation was generated exogenously in a manner considered temporary, using iterative processes for pavements and an open-source spreadsheet for bridges. These calculations did not work as well as expected (especially for pavements) due to the lack of necessary models (e.g., safety, mobility) within the PMS. A better approach is to enhance the PMS and BMS analyses and reporting capabilities to perform the necessary lifecycle and user cost analyses and then make the results available to outside programs for other purposes, including cross-asset tradeoff analysis. Such models are valuable for many purposes in pavement and bridge management because they fully reflect the economic benefits of infrastructure renewal work.

A working prototype of an investment candidate file was developed under this project that system developers can use to help them design an output format for the necessary data. In some cases, existing management systems may already perform the necessary calculations and merely need an appropriate format for exporting the results. Other cases may be more complex, especially in a PMS where safety and mobility are reflected only in constraints (such as "must levels") rather than as user costs. The biggest problem noted in the pilot studies was the challenge of using the PMS to fully account for the benefits of pavement work.

Developers are often concerned about the computational intensity of long-term economic analysis. Remarkably, this concern has been a constant for the more than 40 years that such tools have been in common use, even as the speed of computers has increased by many orders of magnitude. It may be that user expectations of such tools are increasing as fast as processor speed, leaving the widespread implementation constantly just beyond the horizon and allowing for further delays in adoption. Existing software tools such as HERS, the National Bridge Investment Analysis System, and StruPlan (an open-source, long-range renewal planning tool for transportation structures) show that execution times can be kept reasonable if system requirements are appropriately bounded and modern computational techniques and algorithms are used (FHWA 2000; Cambridge Systematics, Inc. 2011; Thompson 2021).

The researchers found few agencies having asset management systems for asset classes other than pavements and bridges capable of performing the necessary analysis. The main exceptions were agencies that incorporate nonbridge structures, such as tunnels, sign supports, and retaining walls, within their BMS. The proposed methodology is especially suitable for asset classes where preservation is a common action. Aside from nonbridge structures, assets could include unstable slopes, buildings (including rest areas), drainage facilities, intermodal facilities, signs, and barriers.

IMPLEMENTATION BENEFITS

The benefits of the proposed next-generation TAMM lie in the ability to manage an infrastructure network, maintaining an appropriate balance in resource allocations and performance among all the components of the network. This balanced approach helps to ensure that the desired level of service is provided at the lowest long-term cost, considering the differential levels of deterioration rates, cost, and risk that exist within the network. Elements of these benefits include the following:

- Existing management systems can continue to advance on their own lifecycles independently, taking advantage of the long-standing frameworks, expertise, training, tools, and research existing within each disciplinary area.
- Differences in performance among the parts of a network are evaluated objectively and equalized to the appropriate extent to best serve public needs.
- Differences in performance that remain within the network are justifiable based on objective analysis, helping the agency avoid unintended misallocation, especially among socioeconomic classes of users or geographic areas.
- Increments of transportation funding are allocated to the parts of the network that can most effectively use them to improve network performance.
- The long-term cost of keeping the network in service is minimized.
- Benefits of infrastructure renewal are estimated in a manner that is more consistent and complete and more easily communicated to stakeholders.
- Risk of extreme events, climate change, and advanced deterioration is allocated and balanced in a consistent way across all network components.

These benefits have always been part of the promise of asset management—a promise the proposed methodology will help to realize.

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