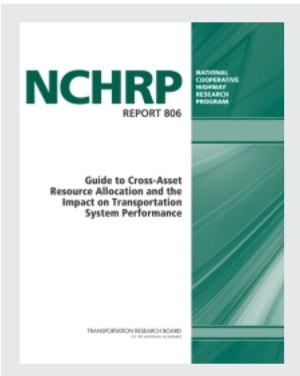

Guide to Cross-Asset Resource Allocation and the Impact on Transportation System Performance

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP REPORT 806

Guide to Cross-Asset Resource Allocation and the Impact on Transportation System Performance

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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FOREWORD

By Andrew C. Lemer
Staff Officer
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NCHRP Report 806: Guide to Cross-Asset Resource Allocation and the Impact on Transportation System Performance presents guidance for state transportation agencies on allocating limited resources among asset classes and organizational units to provide optimal system performance. The guidance includes discussion of analytical tools to support decision making and is supplemented by a prototypical spreadsheet-based implementation of the guide's analysis framework.

State departments of transportation (DOTs) and other local and regional agencies must invest public resources—funds, land, staffing, and others—to develop and operate a transportation system that will provide mobility—efficiently, safely, and with the least possible environmentally adverse impact—to support the economy and enhance quality of life. These investments are made to construct, maintain, preserve, enhance, rehabilitate, or replace a diverse portfolio of physical assets such as pavement, traffic signals, guardrails, bridges, signs, and drainage structures. Deciding how best to allocate inevitably limited resources across these various types of assets to provide acceptable transportation system performance poses a persistent and difficult challenge for agency managers, elected officials, and the public.

The objective of this research was to develop a guidebook to assist senior DOT managers who must analyze and communicate the likely system performance impact of investment decisions across multiple types of transportation assets. Such managers must consider (a) the several dimensions of system performance important to stakeholders (such as mobility, safety, and community livability); (b) the multiple measures an agency uses to describe condition and level of service of particular classes of transportation-system assets (such as pavements, signals, and drainage structures); and (c) the targets that an agency may set for the various dimensions of performance. This research was undertaken to develop a practical framework and analysis tools for dealing with this complex problem.

The research was conducted by a team led by CH2M Hill, Inc., of Chantilly, VA. The research team conducted a critical review of the state of knowledge and practices transportation agencies use to allocate resources among multiple classes of assets and to forecast and judge the impact of resource allocation decisions on system performance. Current practice was found to be based largely on allocation by organizational units (most commonly geographic districts or program areas) without mechanisms for considering agency- or system-wide implications of resource allocation decisions, a situation often termed “siloed” by practitioners. The research team then developed an analytical framework for addressing cross-asset resource allocation issues and the likely impacts of cross-asset resource allocation decisions on transportation system performance. The framework became the basis for an objective-weighting and mathematical optimization procedure for considering alternative allocations of resources across organizational units. A prototype spreadsheet-based tool was produced to implement the procedure and tested with several participating agencies. The team conducted additional testing in a workshop held in April 2014 in conjunction with the Transportation Research Board's 10th National Conference on Transportation Asset Management.

The team refined the framework and prototype tool based on the testing. The principal research product is the guidance presented in this document on cross-asset resource allocation. The guidance, meant to be used by DOT staff and others responsible for making programmatic resource allocation decisions in an agency, is designed to facilitate both strategic thinking about resource allocation and adoption of practical analysis methods. The prototypical spreadsheet tool, implemented using Microsoft Excel, is available as an ISO image that can be downloaded from the project web page at http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3398.

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CHAPTER 1

Research Summary

1.1 Problem Definition and Project Purpose

The objective of this research was to explore and provide guidance on how decision makers at transportation agencies can better analyze and communicate the likely impacts of system performance across multiple investment types to essentially make good on performance targets. By providing an analytical data-driven performance-based framework and tool prototype for cross-asset resource allocation, this research helps answer the question, "What investments should be programmed to best meet agency priorities?"

Transportation system performance measurement is not new; state departments of transportation (DOTs) and metropolitan planning organizations (MPOs) use performance information to manage state and regional systems, to evaluate project-level investment alternatives, to assess transportation land-use issues, and for many other purposes (Maggiore, 2013). However, performance-based planning and programming, where investments and strategies are evaluated, selected, and programmed to achieve goals and performance targets across multimodal transportation assets, is not as common as the use of performance measures themselves. States and MPOs are only beginning to develop performance-based plans that incorporate performance management concepts for all modes, for operations, and for achieving broad economic, environmental, and community development goals.

Under NCHRP Project 08-91, asset and performance management principles were fully researched and applied in an effort to establish a link between data-driven performance estimates and resource allocation decisions in support of performance-based investment strategies. The research builds upon performance management best practices by developing a methodology and accompanying tool prototype to evaluate the impact of resource allocation decisions across asset types. A user guide for the tool prototype is also provided, as well as specific implementation use cases (see Section 4.4). (The tool prototype and user guide can be downloaded from the project web page at http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3398.) By providing an implementation framework and tool prototype that can be applied to help decision makers develop the best mix of performance outcomes that can be achieved under various funding levels, the common hurdles that transportation agencies may face when integrating an "un-siloed" investment approach into decision-making practices are directly addressed. Whether comparing physical assets or operational performance, the framework was designed to be flexible and can support decision making across any investment category.

With a focus on implementation, this research guide summarizes the most essential outcomes and lessons learned in researching the problem of cross-asset resource allocation. In order to arrive at the final framework, the research team conducted a comprehensive domestic and international literature review focusing on the transportation and financial sectors, interviewed state

DOTs on implementation challenges, and field tested the framework and tool prototype across the country through workshops with transportation practitioners and decision makers.

This guidebook of findings is presented with a playbook (Chapter 4) of implementation strategies. This is in an effort to document the state-of-the-art technical theory while remaining relevant and meaningful to practitioners given current allocation decisions in practice and the need to make the transportation investment decision-making process more transparent and accountable, particularly in light of the Moving Ahead for Progress in the 21st Century Act (MAP-21).

1.2 Framework Summary and Tool Overview

A framework and tool prototype were developed under NCHRP Project 08-91 to reflect both technical best practices and transportation agency organizational and institutional needs.

Blending planning principles with readily collected data and available predictive management tools, the NCHRP Project 08-91 cross-asset allocation framework (Figure 1) integrates:

1. Goals and objectives that serve as an expression of agency priorities and vision,
2. Performance measures that demonstrate progress toward agency goals and objectives,
3. Predictive models to forecast likely project impacts on system performance,
4. Decision science techniques to score projects on a level playing field and optimize their selection for programming based on their anticipated benefits and the relative importance of those benefits to the decision maker, and
5. Trade-off analysis to reinforce scenario planning and to compare priorities with fiscal constraints.

The framework allows for a blank canvas of agency goals, objectives, and performance measures, where any measure from the planning process can be selected given agency needs and regional, state, and federal requirements. Its application can facilitate an inclusive goal development process and better planning/programming linkages by bringing various stakeholders to the table.

While a cross-asset investment approach is preferred, the framework is flexible, and the tool prototype allows transportation agencies to consider both cross-asset optimization and siloed project prioritization given agency constraints. The framework and tool prototype accommodate mandated projects and required buckets of program expenditures as well as dedicated or project-specific funding sources.

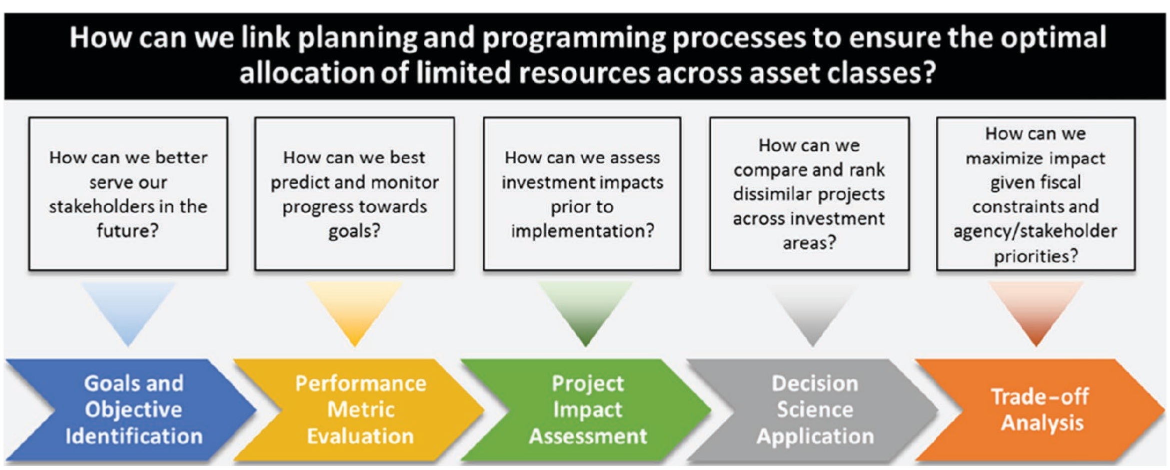


Figure 1. Cross-asset resource allocation framework.

By directing agency resources toward the most cost-beneficial investments, performance-based planning principles are reinforced. The framework is consistent with guidance provided in the *AASHTO Transportation Asset Management Guide*: "An agency must be able to demonstrate that they are making progress on established goals and objectives and set goals and objectives tied to measurable metrics; make resource allocation decisions based on these goals and objectives and the funding available using the metrics to guide the decision making; and then demonstrate to its customers the results of the investments" (AASHTO, 2011).

Critical to the framework is the use of performance modeling to predict project impacts with respect to a holistic set of performance metrics *within* investment types. The focus of the tool prototype is on assessing and communicating the network performance impacts of investment trade-offs *among* investment types. The tool prototype focuses largely on framework steps four and five, and applies:

- Decision science techniques to score projects or on a level playing field based on their anticipated benefits and the relative importance of those benefits to the decision maker(s);
- Prioritization to screen feasible projects and apply rankings based on the expected value of a project per dollar spent;
- Optimization to select projects from the ranked list in accordance with performance and budget constraints, where the sum of selected projects within each investment category as a ratio of the total available budget determines the optimal cross-asset resource allocation; and
- Trade-off analysis to support what-if analyses by conducting optimizations under varying constraints.

The tool prototype applies these decision science techniques so as to create a transparent, structured, and repeatable method for project selection and communicating performance outcomes under varying constraints. This is done by facilitating the weighting of all performance measures with respect to priorities by creating a value matrix,[1] converting project benefits with respect to various performance metrics into dimensionless units that can be readily compared, expressing project benefits in terms of their relative importance, and prioritizing/optimizing the project set to select the most cost-beneficial projects with respect to budget and performance constraints. The tool prototype was developed in Microsoft Excel for ease of use and to implement the framework's proof of concept.

1.3 Framework Benefits and Challenges

Transportation officials face a myriad of projects, alternatives, and strategies when it comes to prioritizing investments and allocating resources. The main challenges in implementing such an informative approach have been the availability of trade-off tools and the lack of consensus building around performance outcomes. The capabilities of any tool implemented should allow for the opportunity to collaborate around a technically sophisticated starting point that can be readily replicated based on a transparent methodology. Expert opinion is critical for taking the results and iterating possible solutions with a focus on validating and updating decision points as data become available.

To help decision makers sort through the noise of project development and selection, the tool prototype developed in the research applies trade-off analysis to better understand and communicate what performance can be obtained given various investment scenarios and funding levels. Additionally, the framework and tool can be used to inform decision makers and stakeholders

[1] The pairwise comparisons and weighting of all performance measures form the value matrix and are applied for project and program prioritization in the tool prototype.

of exactly what is gained and lost by allocating resources in a specific way, thus allowing them to consider the benefits and implications of investment decisions. In this way, the framework and tool prototype can be used to facilitate meaningful discussions around what truly matters to executives, practitioners, stakeholders, and users of the transportation system given the complexity involved in applying limited resources to achieve comprehensive performance goals. Ultimately, the preferences gathered from discussions around the tool can be used to adjust performance targets to arrive at the most beneficial cross-asset resource allocation in light of fiscal constraints. This satisfies MAP-21 performance-based planning requirements and can support agencies in the development of transportation asset management plans (TAMPs).

The research from NCHRP Project 08-91 supports direct linkages between planning and project prioritization and programming. While this is considered a best practice even outside of this research, it should be noted that the ability of transportation agencies to implement a fully flexible, discretionary approach to resource allocation varies across the country due to unique institutional, organizational, and political situations. Moreover, transportation planning and programming are not always well linked, and in certain cases, transportation agencies may not have the ability to alter program structures.

This is a particular challenge for states that have resource allocations based on legislative mandates. A siloed mentality, where investment trade-offs are essentially considered only within asset classes, is also prevalent at state agencies, making a comprehensive performance approach more difficult to coordinate. Decision science applications in these contexts may be to optimize performance within an asset management system as opposed to across asset classes.

The agency practice review conducted as part of this research identified these and other implementation challenges that need to be addressed in order to make the framework more relevant and meaningful to practitioners. While many of the implementation challenges are institutional and organizational in nature, the siloed project development and subsequent decision making of agencies is likely the largest barrier to overcome for implementation. Comparisons of transportation system performance under a mandated resource allocation structure versus a flexible, cross-asset approach may be beneficial for agencies in such situations; however, the framework and tool prototype were designed to be flexible to agency constraints, allowing transportation agencies to consider both cross-asset and siloed project prioritization while encouraging an inclusive goal development process and better planning/programming linkages. The framework also accommodates mandated projects and program expenditures as well as dedicated or project-specific funding sources. The tool prototype communicates the results of the framework using dashboards to communicate with stakeholders, the public, and elected officials to show the minimum budgets need to meet performance targets, among other critical trade-offs.

1.4 Research Components

The NCHRP Project 08-91 research was developed over an 18-month time frame through a series of reports, webinars, interactive workshops, and tool prototype testing.

- A baseline framework was developed by the research team in the project proposal and was expanded on throughout the research development process.
- An extensive review of theoretical and practical approaches to cross-asset resource allocation was conducted. While the theoretical best practices reviewed confirmed the technical approach provided in the baseline framework, the state-of-the-practice review revealed that there are significant implementation challenges that must be addressed in order to successfully apply the theory amidst operational, political, and organizational considerations. These were addressed by revising the framework and yielding a tool prototype better suited for practical use.

- The tool prototype was designed to be a proof of concept and shows that a performance-based cross-asset resource allocation framework can be implemented using data and information currently available to transportation agencies. The tool prototype directly employs the framework but is flexible to allow for agency-specific implementation and reinforces scenario planning, using what-if scenario development via optimization algorithms that consider budgeting and target-setting constraints.
- Workshops and tool testing (summarized in Chapter 3) allowed for the panel and other transportation agency practitioners and decision makers to see the power of the framework as programmed into the tool prototype.

1.4.1 Literature Review

A comprehensive literature review was conducted to supplement the baseline framework, with the idea that modifications would be integrated based on current domestic and international literature in the areas of performance-based planning, asset management, financial investments, decision science, risk analysis, and multi-objective optimization. Each step of the baseline framework was researched and analyzed to ensure the development of a cutting-edge framework and tool prototype. Many of the sources considered in the literature review were used to develop the decision science and optimization methodologies detailed in Chapter 2. A summary of findings and sources for each step of the framework is provided in the following.

1.4.1.1 Goals and Objectives Identification

State DOTs typically develop goals that align with national planning regulations (John A. Volpe National Transportation Systems Center, 2012) in addition to others that address more specific priorities for their state's multimodal transportation system. Visioning is commonly used by state DOTs to identify these priorities by asking the public and stakeholders how the transportation system can be improved in the future to better meet their needs. These priorities are typically grouped to form a more manageable set of goal areas for which goals and objectives are developed. Ultimately, the resulting set of goals needs to be comprehensive and succinct regardless of how they are developed; they need to fully encapsulate the transportation priorities for the state and the agency while providing clear direction for investments in the transportation system.

State DOTs typically establish goals through the development of statewide long-range transportation plans (SLRTPs) and select projects from the statewide transportation improvement program (STIP) based on agency-specific prioritization criteria. Allocations in the STIP in many cases are based on historical precedent and funding restrictions rather than the achievement of performance goals. This is changing following MAP-21 implementation and is reinforced by the framework since the framework suggests the use of performance-based planning concepts and tools to support decision making with a focus on plans and programs that are directly linked.

While these examples provide common practices for the development of agency goals and objectives, it is important to note that the successful application of the framework is not dependent on which goals are ultimately selected for use as long as they are measurable, nor is it dependent on the scale of implementation (i.e., statewide versus regional). Rather, the focus is placed on creating an inclusive goal and objective development process that achieves widespread recognition and buy-in among all stakeholders.

1.4.1.2 Performance Metric Evaluation

The literature review provided a detailed description of tools and methods that are commonly used to predict transportation system performance with respect to infrastructure condition, safety, mobility, economic development, and other performance areas. Transportation agencies collect substantial amounts of data, and many states and MPOs apply these data to better understand system condition and performance.

NCHRP Report 660: Transportation Performance Management: Insight from Practitioners underscores the importance of performance measures as they relate to performance management: "In the last several years, there has been a shift from performance measurement to performance management as well as from reporting whatever data are on hand to carefully and strategically selecting measures, setting targets, reporting measures, and using this information to shape decisions" (Cambridge Systematics, Inc., and High Street Consulting Group, 2010). In this way, performance measures directly link to national, regional, and agency goals and objectives. What makes a "good" measure, however, is often subjective among agencies.

The application of measures was also highlighted in the literature. Implementation of measures needs to be integrated holistically (both vertically and horizontally) across business processes: policy formulation, data collection/analysis, long-range and short-term planning, programming/budgeting/resource allocation (of prime consideration herein), program/project delivery, and system monitoring/feedback (Cambridge Systematics, Inc., et al., 2010). More recently, The Task Force on Performance Measure Development, Coordination, and Reporting, as part of the AASHTO Standing Committee on Performance Management (SCOPM), has established six overarching principles to guide the development and implementation of national performance measures (AASHTO Standing Committee on Performance Management, 2012).

Similar to the flexibility of agency goals in the framework, specific performance measures are not mandated; however, performance models need to be applied (if available) to forecast future baseline performance with respect to various metrics. These models are generally developed using historical data to predict how a particular measure will respond to changes in relevant explanatory factors. To the extent practicable, the literature supports that these models should be calibrated to reflect current data and validated based on a comparison of actual to predicted performance outcomes.

1.4.1.3 Project Impact Assessment

To evaluate the impacts of implementing—or not implementing—a proposed project, a variety of analytical techniques were explored in the literature review that encompassed a wide range of complexity levels. To navigate this field, selection of a modeling technique ultimately comes down to the level of comfort of the modeling staff, available data, and nature of the prediction.

Various methodologies and tools are available to support agencies in evaluating performance impacts. These are most established when it comes to preservation with predictive techniques described in *NCHRP Report 713: Estimating Life Expectancies of Highway Assets* (Thompson et al., 2012) and implemented in various off-the-shelf management systems (e.g., software developed by Deighton, AgileAssets, and Cambridge Systematics). The Federal Highway Administration (FHWA) provides national models, the National Bridge Investment Analysis System (NBIAS) and the Highway Economic Requirements System State version (HERS-ST) to help practitioners predict performance for bridges and pavements, respectively. AASHTO provides a combination of tools, including network bridge, pavement, and safety applications. Safety countermeasure impacts can additionally be quantified using the *Highway Safety Manual*, as described in *NCHRP Report 715: Highway Safety Manual Training Materials* (Dixon et al., 2012). For mobility impacts, statewide and regional travel demand models and techniques can be processed to assess congestion relief impacts; INRIX is also commonly used for assessing traffic speeds. The FHWA provides the Motor Vehicle Emissions Simulator (MOVES) software for air quality and emissions analysis and the Traffic Noise Model (TNM) for traffic noise. IMPLAN economic data along with models from Regional Economic Models, Inc. (REMI) can be used for economic impacts, if desired. *NCHRP Report 456: Guidebook for Assessing the Social and Economic Effects of Transportation Projects* details an approach for property value. Techniques for evaluating energy, ecological, hydrological, visual, and socio-cultural impacts, in addition to those mentioned, have been effectively summarized in Sinha and Labi (2007). Yet, despite the abundance of technical resources, agencies often struggle to collect the right performance data to support quantitative analysis. The benefits of the framework is that, if the data are not available, professional judgment can be used to qualitatively assess the impact.

Most generally, projects can be viewed as having an immediate performance impact (a jump) or having a lagging change in the rate of the performance measure. For instance, in Figure 2 a resurfacing project could be evaluated with regard to ride quality, where a lower value is preferred. The change in performance (delta) with and without implementation is critical for using the framework; however, a higher-level network relationship between performance and investment level can also be used.

1.4.1.4 Decision Science Application

In the literature, multi-objective decision analysis (MODA) has widely been recommended to address cross-asset resource allocation problems. This decision science approach consists of using preferences to guide project selection through weighting, scaling, scoring, prioritization, and optimization techniques.

In order to assign the relative importance of a performance measure or area, weighting is often used to help develop a prioritization score. Given the sensitivity of the ultimate transportation program to the indicated weights, care should be taken in selecting a representative methodology. These methods have included direct and swing weighting, the Delphi method, regression, and most popularly, the analytic hierarchy process (AHP) (Dalkey and Helmer, 1963; Hammond et al., 1975; Saaty, 1977; Goicoechea et al., 1982). The latter technique is built into the tool prototype and further discussed in Chapter 2. If users input qualitative pairwise ratings capturing the general preference between two areas, mathematical techniques can be applied to arrive at the intended weights.

Scaling is a leveling technique that can be used to convert metrics with different dimensions or units of measurement into a normalized form by which they can be compared. The three most common techniques in the literature have been cardinal/ordinal linear scaling, monetization, and value/utility preference-based scaling. Cardinal scaling is used to convert metrics to a 0 (worst) to 1 (best) scale based on the raw performance relative to the maximum and minimum cases (Bai and Labi, 2012). Alternatively, ordinal scaling can be simplified by converting raw performance values to discrete levels of service, as detailed in *NCHRP Report 677: Development of Levels of Service for*

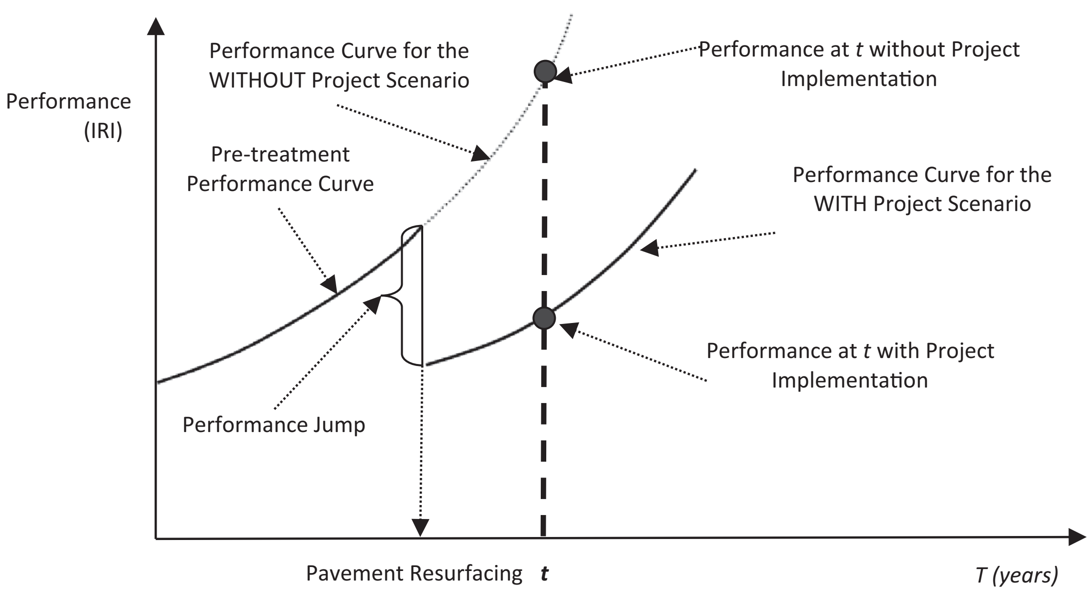


Figure 2. Example preservation performance impact modeling (Bai and Labi, 2012). Note: IRI = International Roughness Index.

the Interstate Highway System (Dye Management Group et al., 2010). Monetization methods have generally been divided between the value of "avoiding losses" or of an "improvement over alternative" (Weisbrod et al., 2009). More predominant in the literature, and programmed in the tool prototype along with linear scaling, is that of preference-based scaling, which takes into account the level of satisfaction gained by an improvement based on where one started in terms of performance (Ford, 2011). Value scaling consists of direct rating, mid-value splitting, and regression techniques; utility scaling typically consists of direct questioning using a gambling approach and a certainty equivalent approach (Patidar et al., 2007; Spy Pond Partners et al., 2012; and Keeney et al., 1993).

In order to compare projects either within or across asset management systems, a representative score can be assigned that combines agency weighting and scaling preferences. Higher scores indicate the relative importance of pursuing a project and can be used to support prioritization efforts. Various methods for scoring projects have been recommended in the literature, including the weighted-sum method, the multiplicative utility function, the benefit/cost ratio method, and the goal programming method (Bai, 2012). The weighted sum method is most commonly used by agencies in developing overall pavement condition indices; it is applied in the tool prototype.

The optimal solution for an agency is then the set of projects that maximize the program score subject to financial constraints and performance targets. This is referred to as an integer programming problem, where algorithms must be used in order to quickly arrive at a solution, recognizing that testing all combinations of projects and alternatives would be infeasible. Preference-based optimization, similar to that shown in Li and Sinha (2004), is used in the tool prototype using the advanced algorithms detailed in Bai et al. (2011).

1.4.1.5 Trade-off Analysis

Intrinsically related to multi-objective optimization, trade-offs refer to the balancing of competing objectives that by definition involve the sacrifice of one objective for the sake of another. Trade-off analysis can be used in transportation asset management to inform the decision-making process by evaluating the impacts of various investment levels and allocation strategies on overall system performance, as well as the extent to which one performance measure can be exchanged for another. Technically speaking, when linked to multi-objective optimization, trade-off analyses inform decision makers of the consequences (i.e., what is gained and what is lost) of moving from one feasible Pareto-optimal solution to the next (Figure 3).

Most trade-off research to date has focused on pavement and bridge asset performance. In pavement management, the following trade-offs have been evaluated for Pareto-optimal solutions derived from various multi-objective optimization formulations and algorithms: pavement network performance versus cost (Pilson et al., 1999), maintenance cost versus work product

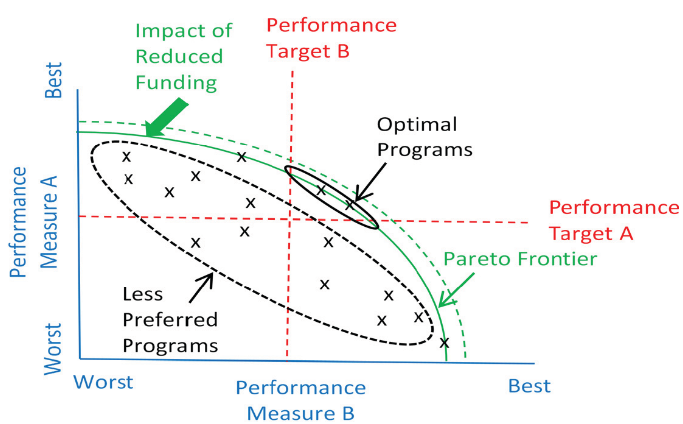


Figure 3. Example trade-off analysis.

for pavement maintenance programming (Fwa et al., 2000), maintenance cost versus reliability (Deshpande et al., 2010), pavement maintenance and rehabilitation (M&R) cost versus average pavement network condition (Wu and Flintsch, 2009), and average annual M&R cost versus average proportion of network in the "very good" condition state (Gao et al., 2012).

In bridge management, Liu et al. (1997) and Liu (2005) adopted the genetic algorithm to examine the relationship between the rehabilitation cost and the deterioration degree for network bridge deck rehabilitation programming. Similarly, Liu and Frangopol (2005) used a genetic algorithm to perform trade-off analyses between maintenance cost, failure cost, and user cost for bridge management.

In addition to studies on highway asset trade-offs, studies such as NCHRP Project 08-36, Task 7, have focused on multimodal trade-offs. The suggested analysis procedure in this study was to establish current levels of performance, identify alternative future funding levels, analyze individual programs under alternative funding levels, and analyze inter-program effects under alternative funding levels (Cambridge Systematics, Inc., 2004).

While state agencies have become proficient in managing bridge and pavement assets independently, findings from *NCHRP Report 545: Analytical Tools for Asset Management* indicate that agencies struggle with comparing "apples to oranges" trade-offs across asset classes (such as mobility versus preservation and maintenance versus expansion) (Cambridge Systematics, Inc., et al., 2005). This becomes particularly challenging when recognizing the fact that projects may have a positive impact on one performance measure but a negative impact on another.

1.4.1.6 Literature Review Findings

In general, the literature review conducted for this project supported the baseline framework but revealed that advances can be applied to link performance-based planning to make resource allocation decisions, largely by way of the following two approaches:

- **Target-based allocation:** allocations can be determined by a qualitative review of applying optimization techniques within asset silos to systematically varied budgets, and
- **Preference-based allocation:** allocations can be determined using quantitative optimization techniques to select cross-asset projects on the basis of performance preferences.

The latter approach is applied in the framework and tool prototype to support the ability of agencies to identify both performance-based cross-asset resource allocations and a baseline set of performance targets based on agency preferences. The literature review underscored that trade-off analysis can be further applied to inform the decision-making process by evaluating the impacts of various investment levels and allocation strategies on overall system performance, as well as the extent to which one performance measure can be exchanged for another. Agencies can then assess potential programs for both performance and considerations of risk.

1.4.2 Practice Review

In order to help state DOTs better analyze and communicate the likely impacts of system performance across multiple investment types, the starting point for implementing a cross-asset resource allocation framework was analyzed in a case study–style practice review. Specifically, an understanding regarding how state DOTs currently make decisions about the allocation of their limited resources to different types of major investment categories—such as preservation, modernization, expansion, operations, safety, and alternatives modes—was investigated by the research team. To develop this understanding and ensure that the framework can be implemented in practice, the following key questions were addressed:

- What is the historical context for state DOT resource allocation?
- What are the key elements of resource allocation decision making?

- What are the major differences in the approaches state DOTs use to make resource allocation decisions?
- What institutional barriers and other constraints exist that could limit the ability of state DOTs to adapt their resource allocation decision-making practices?

To answer these questions, the research team developed case studies of five states—New Jersey, North Carolina, South Carolina, Utah, and Virginia[2]—and documented how decision makers in these states make high-level resource allocation decisions. Reviews of Pennsylvania, Ohio, and Texas were also incorporated based on recent experiences of the research team in developing long-range transportation plans (LRTPs) in these states. This is important since resource allocation decisions can and should begin in LRTP development.

Practice review findings revealed that state DOTs vary in the level of sophistication and analytics used to inform their resource allocation decisions. The associated approaches generally fall into the following four categories, although some states have hybrid methodologies that may straddle or combine these categories:

- **Legacy driven:** For many states where the research team has performed recent planning work, including Louisiana, Kansas, and Mississippi, the approach to resource allocation is largely legacy driven, meaning that the amount of funding that goes toward addressing a given goal or objective is largely determined by the existing program structure and either the amount or share of funding that has historically gone to each program. Changes may be made at the margins to accommodate inflation or emerging priorities.
- **Fix it first:** Several states, such as Georgia, Colorado, Virginia, and South Carolina, have allocation processes driven largely by asset management systems that determine needs for preservation investments. Due to financial constraints in these states, this tends to leave very little funding left to be allocated for other purposes. Remaining allocations are thus typically a reflection of desired projects rather than goal-level priorities.
- **Soft optimization:** To varying degrees, some states use approaches that may start from a legacy or fix-it-first approach but then adjust allocations to better align spending with the relative priorities of the agency. This is called "soft optimization" because decisions are mostly or partly driven by professional discretion and other nontechnical inputs. Example states are Arizona, Ohio, North Carolina, and Michigan, where these decisions are made by DOT leadership.
- **Performance based:** The states that come closest to performance-based cross-asset resource allocation are those that have heavily integrated performance measurement into their resource allocation decision-making approaches. The main difference between this category and soft optimization is that decisions are more data- and analysis-driven through the use of models and tools that help the state forecast likely outcomes across different goal areas; ultimately, allocation decisions still require leadership to make professional judgments about the right balance of trade-offs. Examples of states that have used performance-based allocation approaches, or are at least moving in that direction, are Washington, Utah, Virginia, Florida, and Oregon.

Another critical finding from the research on current state approaches to resource allocation decisions is that several barriers exist when it comes to the potential and implementation of cross-asset resource allocation optimization approaches. While the type and nature of the barriers vary by state and tend to be influenced by which of the allocation approach categories a state fits into, several common potential hurdles are evident across states:

- **Weak strategic direction:** While every state DOT has identified system-level goals (as has the federal government through the MAP-21 national goal areas), they typically steer clear of

[2] Listed states were approached and reviewed prior to development of the final framework and tool prototype so as to build an understanding of current practices.

establishing overt relative priorities between different goals and objectives. Moreover, DOTs often share resource allocation decision-making authority with MPOs, regional planning organizations, or local governments, but the goals, objectives, and relative priorities of these partner agencies may be poorly aligned (e.g., an MPO may be focused on mobility while a DOT is more concerned with preservation). Together, these issues may make it difficult to determine what relative priorities should drive cross-asset allocation.

- **Tools and data:** The transportation community has made great strides in recent years to improve data collection and expand tools that can inform decision making. This is particularly true for the asset management and safety goal areas, but there are also areas where performance forecasting capabilities remain weak or are limited. For example, data on congestion are now readily available and accurate for the Interstate system but are less available and reliable for lower network classifications.
- **Institutional constraints:** As exemplified by the number of states that continue to base allocations on legacy considerations, agencies will likely face significant institutional hurdles in trying to change their resource allocation approaches. Examples of this are statutory requirements for how funds are distributed either geographically or by investment categories, existing program structures that have entrenched advocacy groups that will resist change, antiquated laws and policies that limit flexibility, and legacy commitments that agencies need to honor for political reasons.
- **Organizational considerations:** Factors such as reporting relationships, span of control, and agency culture may influence the ability of a DOT to make changes in its allocation process. For example, agencies that have been highly decentralized and have effectively allowed districts to decide how funds are spent may find it difficult to rein in this authority.
- **Public/stakeholder issues:** Stakeholders (and to a lesser degree, the public) typically have a strong understanding of a state's existing allocation processes and have learned to work within it. Changing allocation approaches may be viewed as threatening, particularly if the new process is highly technical and difficult for laypeople to understand.
- **Political resistance:** As was clearly exemplified by the resistance to the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) management system mandates, efforts to increase the level of analytics and modeling to influence projects can threaten decision makers. Any new resource allocation approach will need to balance the role of analysis and political influence in decision making.

These challenges are addressed in the framework and tool prototype, both in technical application (see Section 2.4) and in possible agency applications based on the state's maturity in linking planning-level goals with project selection (see Sections 4.1 and 4.2).

1.4.3 Workshops and Tool Testing

The development of a detailed review of the state of the practice was used to create an accessible framework and implementable tool prototype. While the practice review uncovered potential challenges for implementation, workshops and one-one-one agency testing allowed for a review of the framework and tool prototype by the project panel and an additional 25+ transportation agencies. All workshops and the tool prototype testing are described in more detail in Chapter 3. Documentation regarding the workshops is provided in the Technical Memorandum: Cross-Asset Resource Allocation Workshops.

CHAPTER 2

Research Guidebook

2.1 The NCHRP Project 08-91 Framework

The NCHRP Project 08-91 framework was developed following an extensive review of theoretical and practical approaches to cross-asset resource allocation. As previously noted, the theoretical best practices confirmed the technical approach provided in the baseline framework; however, the state-of-the-practice review revealed that there are significant implementation challenges that must be addressed in order to successfully apply the theory amidst operational, political, and organizational considerations. Many of these were directly addressed in the final framework and tool prototype; others may be addressed in future research (Chapter 5).

The following sections describe the final framework. The framework reinforces performance-based planning and decision-making principles by directing agency resources toward the most cost-beneficial investments with an eye toward meeting agency goals and objectives. The framework has five steps that are consistent with performance-based planning and management principles:

1. Goals and objectives identification,
2. Performance metric evaluation,
3. Project impact assessment,
4. Decision science application, and
5. Trade-off analysis.

2.1.1 Goals and Objectives

Step 1 of the framework suggests the development of agency goals that are clearly articulated through objectives that encompass internal agency priorities as well as those of the transportation network. As stated in the *AASHTO Transportation Asset Management Guide*, goals provide "a sense of purpose, direction, and a high-level picture of what an organization wishes to achieve" (AASHTO, 2011). In performance-based planning, goals are used to translate the future vision for the transportation system into something that can be measured and tracked. The establishment of meaningful goals that achieve widespread organizational, partner, stakeholder, and public recognition and support is critical to ensuring that investments made at all levels of the state are directed at common outcomes and aligned with the desired future vision for the transportation system.

To achieve broader acceptance and understanding of statewide goals, the framework underscores the importance of an inclusive goal and objective development process that considers the perspectives of all transportation system users and providers. The final framework aligns investments with goals using a performance-based approach. The framework accommodates any goals for which the benefits of investments can be quantitatively or qualitatively assessed. Of course, agency goals that include the national goals created under MAP-21 (Table 1) will be required and are accommodated in the framework.

Table 1. MAP-21 national goals.

MAP-21 Goals	
Safety	To achieve a significant reduction in traffic fatalities and serious injuries on all public roads
Infrastructure condition	To maintain the highway infrastructure asset system in a state of good repair
Congestion reduction	To achieve a significant reduction in congestion on the National Highway System
System reliability	To improve the efficiency of the surface transportation system
Freight movement and economic vitality	To improve the national freight network, strengthen the ability of rural communities to access national and international trade markets, and support regional economic development
Environmental sustainability	To enhance the performance of the transportation system while protecting and enhancing the natural environment
Reduced project delivery delays	To reduce project costs, promote jobs and the economy, and expedite the movement of people and goods by accelerating project completion through eliminating delays in the project development and delivery process, including reducing regulatory burdens and improving agencies' work practices

2.1.2 Performance Measures

The framework incorporates performance measures (Step 2) as a means to track progress toward goal fulfillment with respect to system operations and asset conditions. In the framework, any performance measure can be selected and compared as long as users provide the corresponding impact assessments. The framework requires comparisons of performance data but does allow for the integration of data and information that are qualitative in nature. For instance, professional judgment can be applied to quantify impacts on a commensurate scale (e.g., low = 1, medium = 2, high = 3).

Performance data can be obtained or calculated from agency management systems to forecast the future condition of the system across multiple performance areas and to understand likely project impacts. In this way, performance measures can be applied to understand which investments are likely to contribute the most toward the achievement of broad performance outcomes. Selecting the right measures is dependent on the goals and objectives identified and on whether they are applied for performance forecasting or monitoring. In general, good measures are useful for short- or longer-term decision making, meaningful to the public and stakeholders, and supported by quality data that are regularly maintained. As defined in the *AASHTO Transportation Asset Management Guide*, quality data are accurate, precise, appropriate in context and in level of detail, timely, accessible, and well defined (AASHTO, 2011).

Performance targets can be developed from selected measures to define the state-of-good-repair thresholds (for physical assets) and level-of-service (LOS) thresholds (for system operations). Targets have typically been set by edict or based on past performance or expert opinion and are adjusted over time to reflect more reasonable performance expectations in light of budget constraints. Data management systems can be used to track system performance against set targets, streamline internal and external communications, and develop predictive tools based on historical inspection and treatment data.

The selection of projects in the framework provides the basis for the cross-resource allocation approach and is directed at achieving network-level performance targets while allowing for project-level constraints. The framework then allows the agency to understand the costs associated with achieving mandated performance targets but can also allow for the agency to set targets based directly on agency goals and preferences.

2.1.3 Project Impact Assessment

The application of performance models to forecast future performance with respect to various metrics is an essential component of the framework. Step 3 requires a project list with before-and-after predictions.

Predictive models are generally developed by agencies using historical data to show how a particular project will influence network performance. To the extent practicable, these models need to be calibrated to reflect current data and validated based on a comparison of actual to predicted performance outcomes.

Performance-based modeling is used in the framework to predict project impacts prior to implementation or before projects are built. Project impacts are incorporated through changes to the expected future baseline of a particular measure via performance jumps (i.e., instantaneous improvements) or delayed onsets of benefits (i.e., reduced rates of performance deterioration) depending on the measure being predicted and the project being evaluated (Figure 4). In particular, impacts can be inferred across performance areas as the forecasted change in a representative performance metric with and without implementation of a candidate project.

Project impacts determined by this process are expressed in the same measurement units as the forecasted performance metrics. When these impacts are normalized to allow for a comparison between dissimilar metrics, the most beneficial projects with respect to agency goals and preferences can be predicted prior to implementation. In this way, the framework is consistent with guidance provided in the *AASHTO Transportation Asset Management Guide*, which suggests that "through the use of management systems, engineering and economic analysis, and other tools, transportation agencies can evaluate collected data before making decisions on how specific resources should be deployed" (AASHTO, 2011).

Agencies commonly apply performance modeling within individual management systems to predict project impacts with respect to a particular performance area; for example, the effect of repaving on pavement condition. Such siloed analysis is limited in its ability to assess impacts across all performance areas, focusing instead on what can be readily predicted using the individual data management system. This approach can preclude consideration of other significant or adverse consequences that are important to understand when making decisions and considering trade-offs. To avoid this potential pitfall, the final framework combines projects from all management systems into a single pooled set in order to evaluate project impacts across all performance areas in a systematic way (Figure 5). This allows for agencies to take credit for

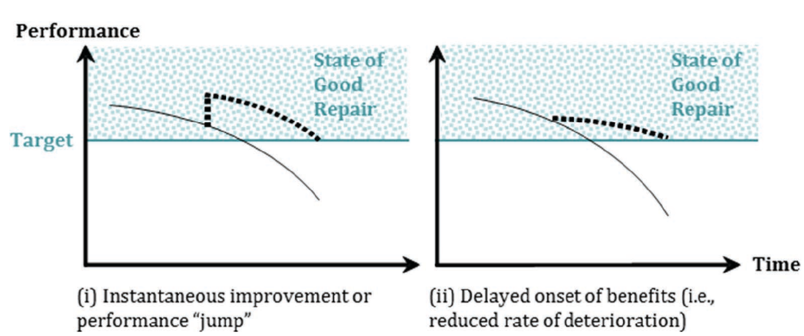
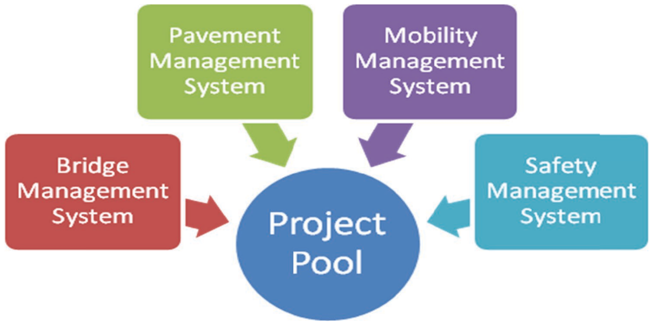


Figure 4. Project benefits can be realized (i) immediately or (ii) over time.



Source: Adapted from Mamlouk and Zaniewski, 1998; Labi, 2001.

Figure 5. Combining all projects across management systems into pooled set.

overlapping performance impacts not traditionally assessed within a silo (e.g., pavement resurfacing can lead to a safety benefit).

It is important to note that many state DOTs apply predictive tools in the areas of bridge and pavement asset management but lack similar tools and methods for predicting performance and project impacts across other performance areas. Further, calibrating predictive models by comparing observed with predicted outcomes can be challenging in practice when the relative contribution of a project to overall system performance is unknown; as stated in the *Performance-Based Planning and Programming Guidebook*, "a time lag exists between the implementation of many transportation improvements and the resulting changes to performance indicators, making the connection between decision making and results unclear" (ICF International, 2013). Some project benefits are not immediate but are realized over time, so their effect on system performance may not be directly apparent; for these cases, it is especially important to maintain historical performance and treatment data and to calibrate predictive models over time to match observed data.

Several tools and methods are available to quantitatively predict future baseline performance and project impacts with respect to infrastructure condition, safety, and mobility metrics. However, for many other performance areas, including livability and sustainability, predictive tools and methods are not well developed. Expert opinion can be used to qualitatively assess project impacts across performance areas for which there are no predictive tools or methods available. As explained in an FHWA case study of the Minnesota DOT, it is "difficult to balance goals with less rigorous measures, such as economic competitiveness or livability, with goals such as system preservation, mobility, and safety" (John A. Volpe National Transportation Systems Center, 2011).

In order to develop a comprehensive understanding of project impacts across all performance areas, the framework incorporates both quantitative and qualitative measures. While performance modeling can be used in many cases to quantify the expected project impacts, the use of predictive tools and methods is not always appropriate or reasonable given available data.

Additionally, breaking down silos to select the most beneficial projects overall and allocating resources accordingly will require a fundamental change in the way these decisions have historically been made. In practice, project selection often occurs within asset silos—that is, projects are chosen within individual management systems given a predetermined budget allocation that is typically set based on historical proportions or by legislative edict rather than in accordance with performance goals. Arbitrarily allocating resources across siloed management systems in such a way limits the ability of agencies to select and implement projects that are most beneficial with respect to performance goals. The framework overturns this paradigm by basing cross-asset resource allocation on the selection of projects that are expected to achieve the greatest performance outcomes across all investment categories. This is also considered an improvement on the needs-based allocation that

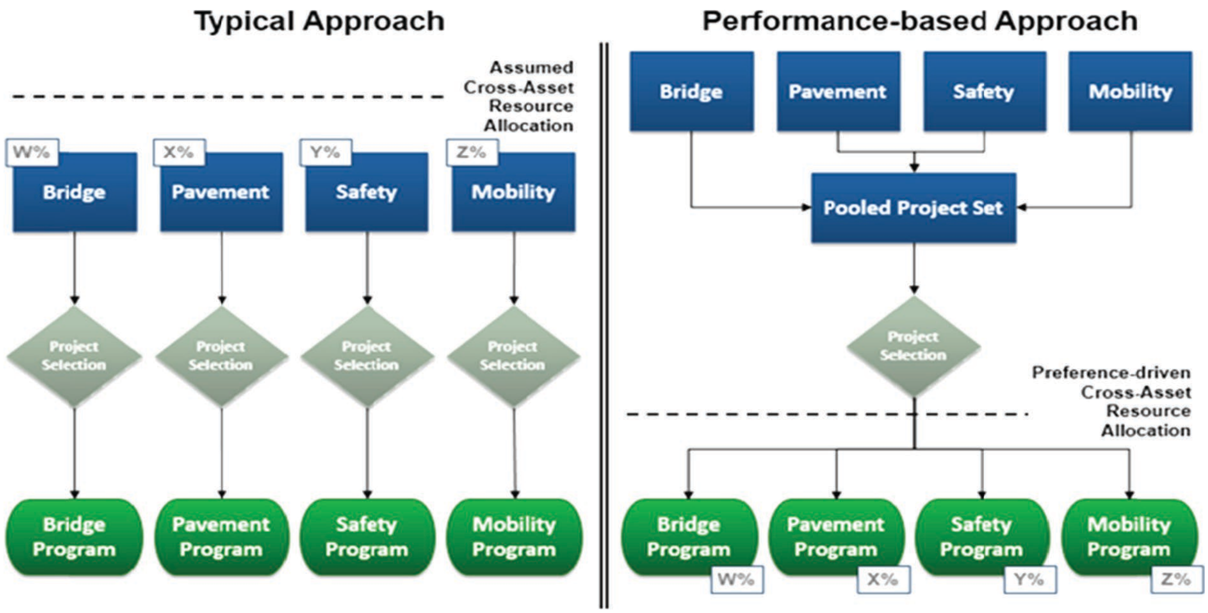


Figure 6. Typical siloed investment planning versus a performance-based approach.

is increasingly being applied at state DOTs. The challenge with this approach is that the allocation is reliant upon varying definitions of "need" and still takes a siloed focus instead of a system focus.

The framework advances siloed decision making by moving away from viewing resource allocation as the input to the programming process and instead considers the allocation to be the output corresponding to the optimal set of achievable performance outcomes (Figure 6).

Agencies often organize departments around silos that receive set allocations, thus requiring the individual departments to do the best with what they have. While a more integrated approach is strongly encouraged, the framework does allow for semi-siloed decision making. Two optimization techniques are used in the framework, depending on agency preferences and data availability. Of these two, a bottom-up approach that fully integrates linkages to management systems is preferred; however, a top-down approach can be conducted that incorporates the use of asset management systems within the silos.

2.1.4 Decision Science Application

Project performance benefits can be predicted across performance areas using a variety of methods by calculating the change in a performance measure with or without implementation of a candidate project. The resulting project impacts are expressed in the same units as the measures being predicted; thus, impacts across performance areas cannot be readily compared. Further manipulation is required to achieve a true apples-to-apples comparison between performance metrics across investment categories. The *AASHTO Transportation Asset Management Guide* similarly recognizes this "need to combine dissimilar performance measures . . . in order to develop a scale that can be used for comparing and prioritizing alternative investments."

Decision science techniques are applied in the framework to create a transparent, structured, and repeatable method for normalizing and comparing project benefits across investment categories on a level playing field based on the following process:

- **Weight:** Determine which project benefits are most important to the decision maker using a value matrix to evaluate priorities,

- **Scale:** Convert project benefits with respect to various performance metrics into dimensionless units that can be readily compared,
- **Score:** Express project benefits in terms of their relative importance to the decision maker,
- **Prioritize:** Divide project benefits by costs to determine feasibility and rank eligible projects, and
- **Optimize:** Select the most cost-beneficial projects with respect to budget and performance constraints.

The optimal cross-asset resource allocation is then equal to the ratio of the total selected project costs within each asset class divided by the total budget. While this seems straightforward, the ability of transportation agencies to implement a fully flexible, discretionary approach to resource allocation varies across the country due to unique institutional, organizational, and political situations. The framework accommodates the technical challenges of these nuances, as detailed in Section 2.4. As previously noted, the framework provides two optimization techniques for project selection.

- **Bottom-up (project-level):** The framework's bottom-up analysis is preferred and is applied in the tool prototype. This technique provides comprehensive impacts (e.g., benefit and disbenefit assessments) and cost estimates to evaluate and justify project-level selections. In this approach, performance values that would occur with and without implementation of the project for all metrics relating to agency goals are evaluated and compared.

  Using the previously described decision science techniques, optimized project sets are generated under varying constraints and compared. The objective of the bottom-up optimization is to maximize the program score, subject to constraints, by changing which projects are selected, as shown in Figure 7.

- **Top-down (network-level):** The objective of the top-down optimization is a slightly different formulation than the bottom-up, as shown in Figure 8. This is more common in the industry in practice, and is based on the development of network-level performance versus investment-level curves that are built by running siloed management systems under varying financial constraints. Decision makers then have the ability to examine allocations until a suitable performance outcome is reached.

If a top-down approach is used, the framework suggests a hybrid application (Figure 9), which applies decision science principles to identify the optimal mixture of performance levels across the asset types; this can also be applied in the tool prototype. Once the optimal point on each of the performance curves is decided based on user preferences, the associated project sets can be generated and compared. The main challenge of this approach is the reliance on management

Maximize: Program Score
Subject to: Financial Constraints and/or Performance Targets
By changing: Projects Selected

By changing ↓

Silo	Project ID	Project Score	Project Cost	Program?
Bridge	1	**80**	$2.5 M	**Yes**
Pavement	2	85	$4.0 M	No
Mobility	3	**75**	$2.0 M	**Yes**
Safety	4	50	$0.1 M	No
Total	Maximize →	**155**	**$4.5 M** ←	Subject to budget

Figure 7. Example bottom-up project selection.

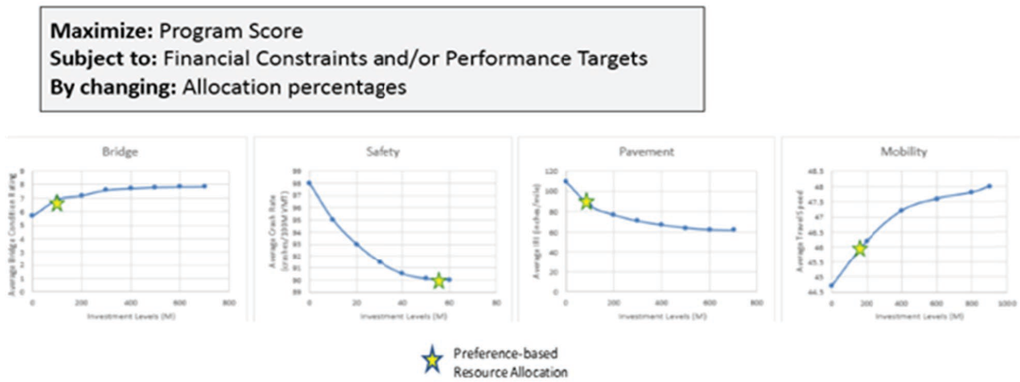


Figure 8. Example top-down performance versus investment level trade-offs.

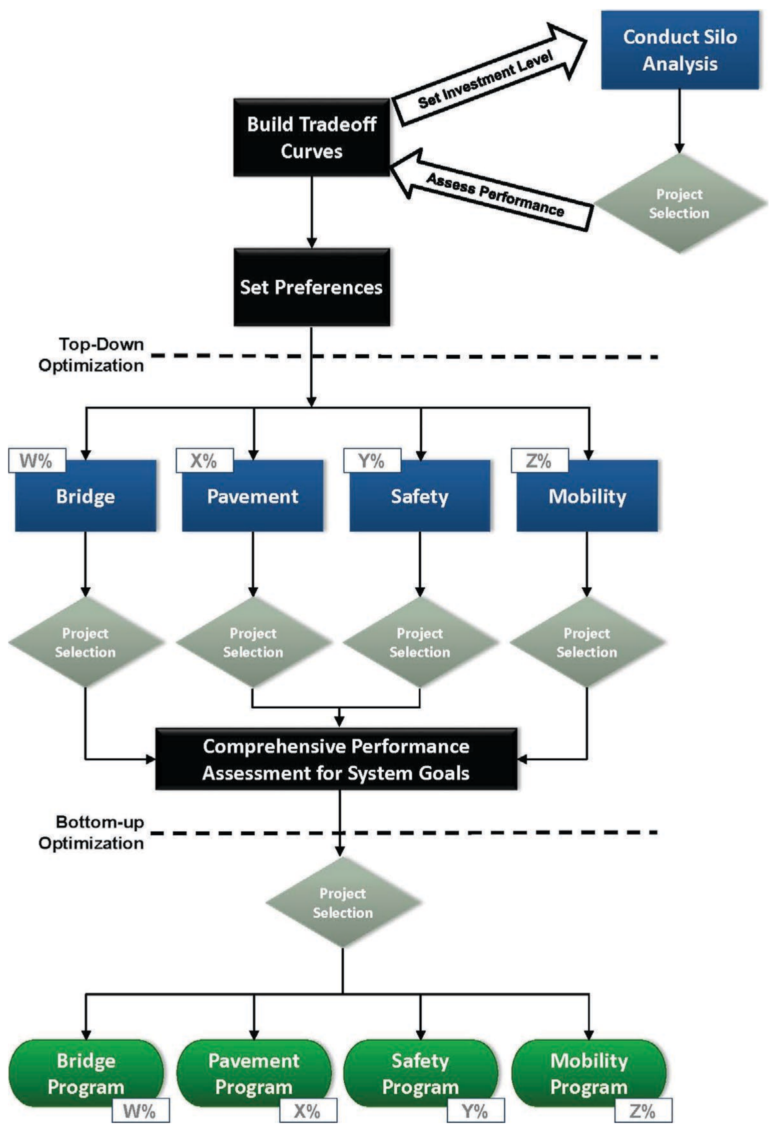


Figure 9. Hybrid approach blending top-down and bottom-up approaches to resource allocation.

systems since each system typically considers different performance measures without consideration of cross-asset impacts.

2.1.5 Trade-off Analysis

Trade-off analysis is applied in the framework to determine what performance can be bought given various investment scenarios and funding levels. Additionally, it is used to inform decision makers and stakeholders of exactly what is gained and lost by allocating resources in a specific way, thus allowing them to consider the benefits and implications of policies and strategies associated with making investment decisions. In this way, trade-off analysis can be used to facilitate meaningful discussions around what truly matters most to stakeholders and users of the transportation system given the complexity involved in applying limited resources to achieve comprehensive performance goals. Ultimately, the preferences gathered from this discussion can be used to adjust performance targets to arrive at the most beneficial cross-asset resource allocation in light of fiscal constraints.

Example trade-off analyses that can be explored using the framework include comparing project alternatives and programs; identifying the minimum investment level to achieve targets; and assessing the sensitivity of outcomes to varying investment levels, allocation percentages, political initiatives, and agency preferences (e.g., Figure 10).

2.2 Incorporating Risk

MAP-21 legislation calls for state transportation agencies to develop risk-based transportation asset management plans for highway infrastructure on the enhanced National Highway System. While "risk" is a term with multiple connotations, it is considered in this context to deal

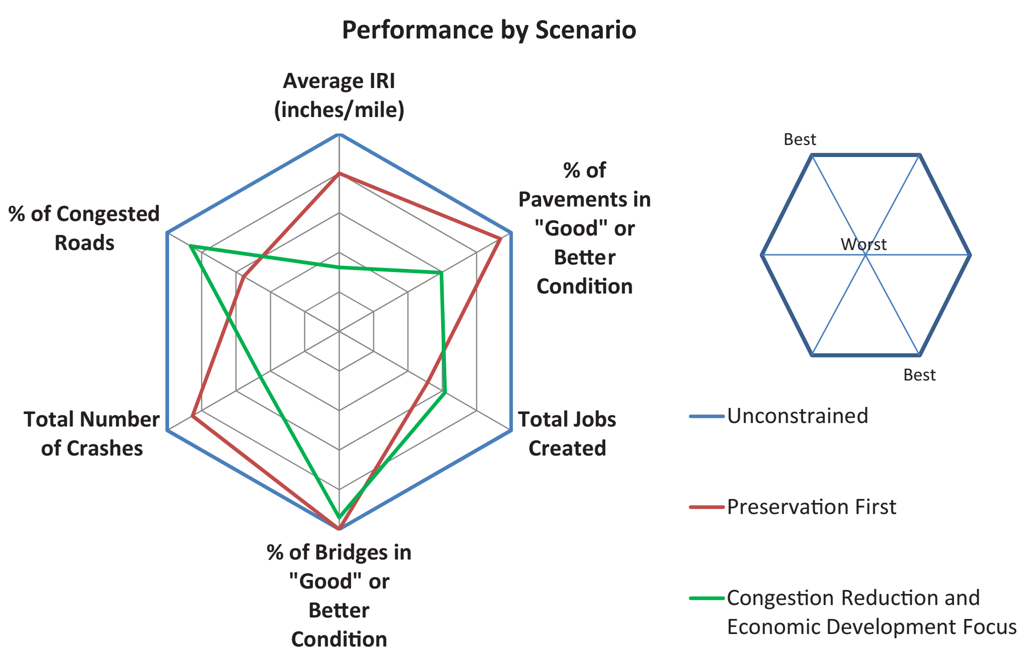


Figure 10. Example comparison of performance outcomes by strategic direction. Note: By assessing the impact of agency decisions with a focus on constraints in particular, the data-driven framework can be used to bolster a case for more flexibility in allocating resources.

with various hazard, financial, operational, and strategic threats and opportunities (Proctor and Varma, 2012).

- **Hazard risks** can be classified as uncertain structural performance due to an aging infrastructure or vulnerability to extreme events. Uncertain performance due to typical aging and climate processes has been evaluated in research, such as that in *NCHRP Report 713: Estimating Life Expectancies of Highway Assets*, with an emphasis on identifying contingency funding levels; uncertain performance due to extreme weather events has been an area of emphasis in research such as that of Croope (2010), with a focus on reducing vulnerability through improved infrastructure resilience.
- **Financial risks** can be classified as having insufficient funding available due to either uncertain revenue or project costs.
- **Operational risks** can be classified as ineffectual maintenance programs or inaccurate forecasting models.
- **Strategic risks** can be classified as weak program management and data collection processes.

In the context of cross-asset resource allocation, a comprehensive consideration of risk is beneficial. Figure 11 details how such risk considerations are integrated into the framework.

As highlighted in Figure 11:

- **Hazard risks** are integrated into the framework via the project development process by identifying candidate projects to reach and maintain a state of good repair (SGR), simulating deterioration probabilities, as a performance measure/target in the prioritization/optimization process, and constraining the selection of critical projects to be "must do."
- **Financial risks** are incorporated through simulating revenue sources and assessing performance trade-offs for various levels of investments.
- **Operational risks** are incorporated through simulating performance impacts.
- **Strategic risks** are incorporated by testing the sensitivity of varying performance preferences, targets, and resource allocations strategies (e.g., silo versus integrated management, fixed versus flexible budget allocation, and worst first versus proactive preservation).

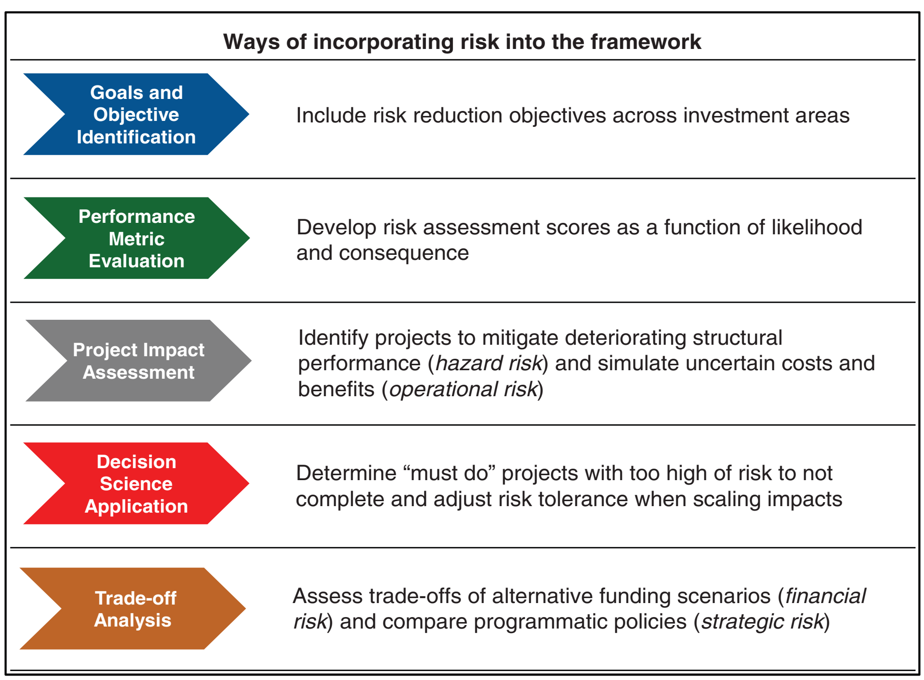


Figure 11. Incorporating risk into the framework.

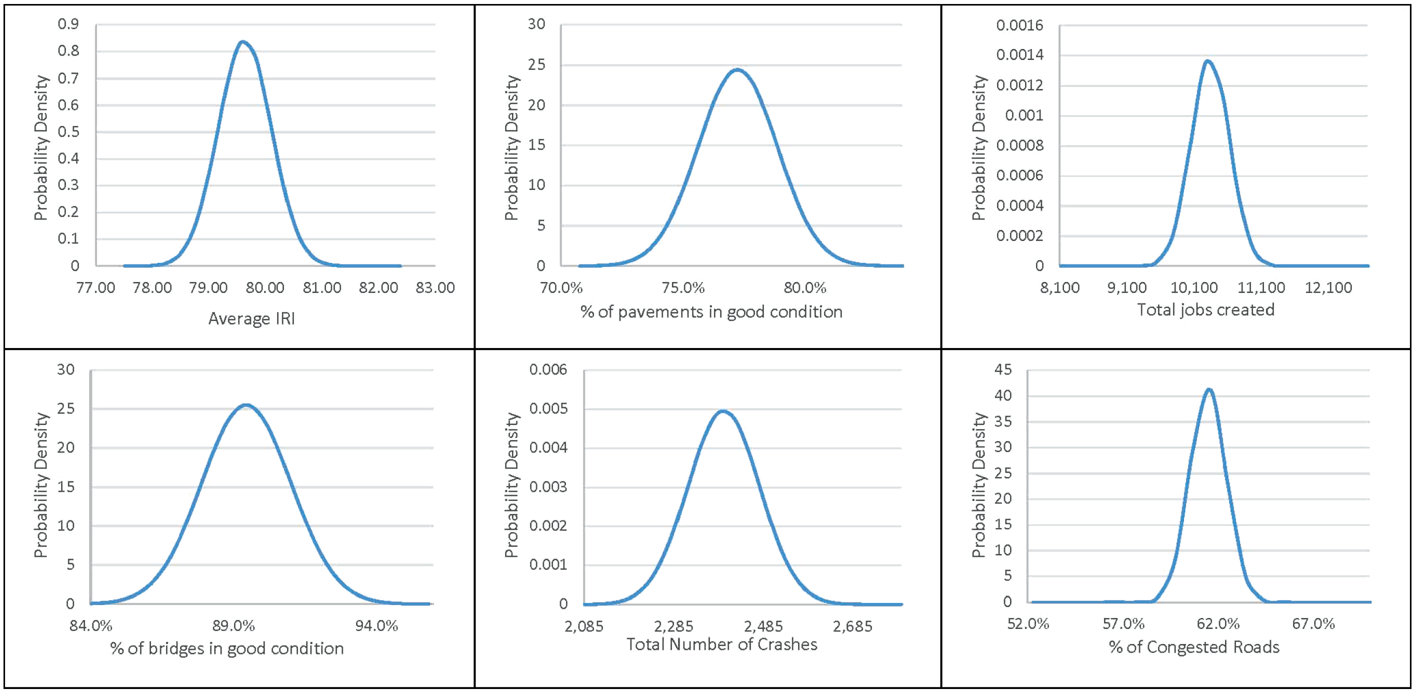


Figure 12. Assessing confidence in performance outcomes.

By simulating distributions describing the likelihood of performance outcomes, practitioners identify the level of confidence in achieving performance goals. For instance, if the standard deviation for each project impact was known, the probability of various system performance measures could be determined (Figure 12). A similar exercise could be completed for an uncertain budget or other factors.

In all cases, it is suggested to identify, assess, manage, and monitor the effectiveness of risk strategies as determined via agency tolerance. Whether qualitatively or quantitatively determined, risk likelihood and consequence can be registered in a log that can be used to evaluate strategies and can be updated over time in order to improve future decision making.

2.3 Tool Prototype

2.3.1 Technical Components

The tool prototype focuses largely on the decision science application (framework Step 4), which includes weighting, scaling, scoring, prioritizing, and optimizing investments in the project pool. A description of the automated functions are described in the following; however, it should be noted that user overrides are provided in the tool prototype for all results.

- **Weight:** In the tool prototype, the AHP is applied to weigh each of the selected performance measures. The relative importance of each criterion is based on qualitative ratings assigned by the user for each pairwise comparison. Matrix algebra is then applied to identify the intended weights, which are technically represented by the eigenvector of the value matrix. To validate, consistency checks are built into the tool prototype to preserve the preference order of ratings (e.g., if measure A is preferred to measure B and measure B is preferred to measure C, then measure A should be preferred to measure C). The setting of ratings may be conducted in a collaborative group setting or through a Delphi process (anonymous rounds of setting and revising ratings per aggregated group results), the latter of which can mitigate biases from dominant personalities.

- **Scale:** Utility-based and linear scaling methods are programmed into the tool prototype. The utility method is preferred because it allows agencies to assign relative importance to varying levels of performance. By removing the assumption of linearity, preferences can be used to ensure that projects with higher performance outcomes can be scored on a sliding scale relative to lower performance levels. For example, a pavement project that results in an improvement from poor to fair condition may produce greater utility (e.g., "satisfaction" represented on a dimensionless scale of 0–least to 1–most) than a project with an improvement from fair to good condition. If all improvements are valued the same, then linear scaling may be applied. These techniques mitigate potential pitfalls associated with monetization efforts. By letting perfection stand in the way of progress, agencies often hesitate to include softer metrics such as livability in benefit–cost analyses. This exclusion can disaffect stakeholders that do not feel that they are heard. Additionally, even dollar-to-dollar comparisons can be subjective when considering the value associated with saving one dollar for the agency versus one dollar for the user. Therefore, utility scaling can be applied to more accurately align preferences for the comparison of dissimilar metrics.
- **Score:** A representative score for each project is assigned to each candidate in the tool's project list. The score combines agency weighting and scaling preferences using the weighted-sum product method ($\text{Score} = \text{Weight}_1 \times \text{Scaled Value}_1 + \text{Weight}_2 \times \text{Scaled Value}_2 + \ldots$). Higher scores indicate the relative magnitude of benefits realized by implementing a project. This scoring process is similar to the overall pavement condition index commonly applied by state DOTs, where the index is a function of varying distresses (e.g., rutting, raveling, and cracking) rated by inspectors on a simplified scale.
- **Prioritize:** Critical to a financially constrained program, the tool prototype develops a prioritized list of projects for screening based on their score-to-cost ratio (similar to a benefit-to-cost ratio). This essentially allows the best, most cost-effective projects to be programmed.
- **Optimize:** The optimal allocation of resources is automated in the tool prototype using three general techniques:
  - **Bottom-up optimization:** The selection of projects from a prioritized list is determined by solving the integer programming problem by way of a branch-and-bound algorithm. This algorithm works by systematically navigating along different possible combinations of projects (branches) and moving toward a solution that maximizes performance, while meeting all constraints, by dropping subsets of suboptimal paths (cutting branches). This technique is most commonly known for being able to approximate a solution to what is known as the travelling salesman problem, where travel time must be minimized subject to making all required stops by changing discrete pathways selected.
  - **Top-down optimization:** The selection of allocations from preferences of performance outcomes is determined by solving the nonlinear optimization problem using the generalized reduced gradient algorithm. This algorithm analyzes derivatives (or rates of change) in the overall score by changing allocations so as to quickly arrive at a solution by maximizing the program score.
  - **Trade-off optimization:** In order to reduce computing time without a significant loss in precision when producing trade-off curves (i.e., the Pareto frontier of optimal solutions), a heuristic algorithm was constructed in the tool prototype by blending the greedy algorithm (sort prioritized list by score-to-cost ratio in descending order and program down the list until funds are exhausted) with a genetic algorithm (a machine-learning technique, similar to the Watson computer of Jeopardy fame, that mimics the human mind through artificial intelligence to quickly find patterns in the data through nonlinear mutation functions) to enhance the solution.

2.3.2 User Benefits

Given the complexity of the technical components behind optimizing resource allocation decisions, results need to be communicated in an understandable way. In the tool prototype, various summary graphics and dashboards are used to quickly view what performance can be achieved given user inputs. Additionally, as part of the MAP-21 legislation, state officials are asked to define various performance measures using system performance LOS and asset SGR. The tool prototype allows decision makers to define either performance categorization on a red-yellow-green color scale for each measure and to report outcomes of optimization and trade-off analyses in these terms. Performance dials showing these scales by measure are built into the tool to provide a real-time predictive performance report card suitable for executive decision making.

Using the tool prototype provides a number of benefits, including transparency and accountability in decision making as well as opening the door to discussions of agency leadership and practitioner priorities and preferences. These benefits are described in more detail in Chapter 4, which highlights the potential uses of the tool in agency planning, project selection, and program development.

2.4 Technical Challenges and Success Factors

In order for any decision-support tool to be of practical use to transportation agencies, flexibility is critical such that a variety of planning processes and measures can be accommodated. Recognizing that performance and asset management programs vary in maturity across the country, adoption of the tool prototype will be dependent on the ease of use, ability to automate complex calculations, clear communication of outputs, and ability to iterate alternative decision strategies.

The following specific technical challenges were identified in the research and tool prototype workshops and testing. Each was considered and overcome by modifications to the framework and/or tool prototype:

- Setting a planning horizon,
- Identifying and selecting must-do projects,
- Providing the ability to analyze user-specified performance measures (including qualitative metrics),
- Identifying performance measures by functional class,
- Handling of alternative funding structures,
- Integrating data from existing management systems,
- Allowing for geographic constraints, and
- Providing clear reporting of performance outcomes in a simple user interface.

A discussion of each of these considerations is provided in the following subsections, as are the modifications made to the framework and tool prototype.

2.4.1 Setting a Planning Horizon

One limitation of a stand-alone decision tool is the inability to communicate with agency-specific asset management systems. As such, any stand-alone tool would not have the benefit of linkages to agency databases, performance prediction models, or life-cycle-cost analytical tools to evaluate project alternatives. This poses a challenge for supporting longer-term analysis associated with cross-asset resource allocation.

For the bottom-up analysis, the tool prototype developed is currently suitable to support a shorter-term planning cycle of no more than 4 to 5 years (e.g., a typical horizon for STIPs). For periods exceeding 5 years, a linkage to asset management systems would be required to dynamically update project bundle recommendations based on what has or has not been able to be programmed under a financially constrained scenario as well as to link investment levels to long-range performance.

What could be done as a next step in the research would be to include the incorporation of windows of opportunity into the optimization for a long-range multiyear analysis period. For instance, if a bridge rehabilitation is not completed within sufficient time, then a bridge replacement might become the more prudent project. Pavement projects have similar concerns: if preventive maintenance measures are not applied on-cycle, then far more costly repair projects may be required.

When using the framework for LRTP development, project alternatives (preferably a more limited number to reduce computational time) can be defined for every year within the planning horizon as determined by the management system and what is or is not programmed within the specified window. The optimization would then be modified to have a constraint that only one alternative activity profile can be completed for each structure. The objective would then be to maximize the performance at the end of the planning horizon while keeping assets at a tolerable level of performance throughout, or to maximize performance each year in the planning horizon by dynamically updating projects throughout.

For the top-down analysis, the tool prototype was designed to maximize performance at the end of a short-range planning horizon assuming constant annual funding. This is based on user inputs for performance over time at various annual investment levels. To build on this research, the next steps would include considering the impact of optimizing a variable annual funding amount over the planning horizon among the asset classes and programming this optimization into an updated tool.

2.4.2 Identifying Must-Do Projects

While the flexibility to choose any set of projects based on agency discretion is attractive, there often exists a subset of projects considered as "must do" or "earmarked"—meaning that they should be programmed above all others. Examples are policies that require an agency to dedicate preservation dollars to critical assets prior to consideration of all other transportation assets, policies that require an agency to select projects based on risk tolerance, and policies that dedicate funding to a signature project with remaining funds available for other investments. The tool prototype accommodates such cases and others through the optimization process: if the user specifies a must-do project, the available discretionary funding can be appropriately adjusted and applied using the aforementioned decision science techniques. If the selected must-do projects exceed available funding, then the standard approach of using agency preferences to select projects still applies.

2.4.3 Ability to Analyze User-Specified Performance Measures

Successful framework implementation will depend on the ability of the tool prototype to accommodate user-specified performance measures. As developed, the tool prototype is not limited to a subset of measures. Instead, users may specify the performance measure and respective performance value with and without implementation of each candidate project. When combined with the decision science process of weighting and scaling the measures, the tool prototype allows for the comparison of any set of quantitative or qualitative measures. The only resulting limitation of this approach is the type of network-level trade-off curves that can be generated. To support any specified performance measure, the trade-off curves generated by the tool prototype will be limited to (a) a network average of the specified performance measure, (b) a percentage of the network beyond a specified performance threshold associated with the user-identified measure, or (c) the network total of the specified performance value. This excludes network statistics with a more complex linkage to the specified performance measures.

2.4.4 Identifying Performance Measures by Functional Class

In recognizing the varying traffic volumes and economic activity among different roadways, it is often prudent to distinguish between functional classes when setting performance targets. Per the MAP-21 legislation, agencies are specifically tasked with keeping the National Highway System

(NHS) within an acceptable state of repair. In order to reflect varying performance by functional class, the tool prototype was designed to accommodate user-defined investment areas and performance measures. For instance, users may wish to create unique performance measures to reflect NHS and non-NHS structurally deficient bridge deck area and the International Roughness Index (IRI). Likewise, the user can create two investment areas representing the NHS and non-NHS pots of money from which to improve the corresponding metrics. Along with the distinction of functional class performance, the tool prototype allows the user to define varying states of repair by metric.

2.4.5 Handling Alternative Funding Structures

In recognition of projects being eligible for certain programs, the tool prototype was designed to allow for multiple funding sources or investment areas. For each pot of money, users can specify budget floors or ceilings while identifying which funding source corresponds to which project. However, due to the complexity of funding structures across the country, the tool prototype is limited to the ability of an agency to consider internal processes (such as matching or partial funding from multiple programs) when setting budget totals by program.

2.4.6 Integrating Data from Existing Management Systems

Manual collation and processing of data can be time consuming and inhibit agencies from pursuing more analytical resource allocation techniques. While an application and interface to pull and clean data sources could not be designed within the scope of the tool prototype, the framework was designed to accommodate commonly collected information.

Data requirements will vary by the optimization approach being applied. From a bottom-up perspective, agencies are expected to have a list of candidate projects with a total cost estimate, project performance values with and without implementation, identification of primary funding source, and a unit of measure (e.g., project length) that could be used to develop a weighted network average (e.g., percent miles in good condition). From a top-down perspective, agencies are expected to input trade-off curve information: network performance values at various investment levels. Conclusions and Next Steps (Chapter 5) suggests a full test deployment to allow for a streamlined enterprise solution for more automated data integration.

2.4.7 Allowing for Geographic Constraints

As with environmental justice analyses, it is the responsibility of the agency to ensure the fair distribution of system performance benefits among its stakeholders. This is particularly acute at agencies with a more decentralized structure. To ensure the equity among districts/regions or urban/rural populations, the tool prototype can be used to define unique funding sources for each sub-area and then to set minimal performance targets or budget floors/ceilings for each area.

2.4.8 Clear Reporting of Performance Outcomes in a Simplified User Interface

The interface of the tool prototype provides user comfort in navigating among the complex analyses by guiding users to essential inputs at the front end while reserving all complex mathematical calculations for automated back-end processes. Additionally, the tool prototype allows for exploratory what-if analyses through quick and easy iterations among possible performance outcomes and strategic policies.

Given the technical complexity behind the tool prototype, there is also a need to effectively tailor messages for audiences ranging from analysts to executives. The tool prototype uses infographics for communicating performance outcomes, which can be compared in a summary tab.

Such a dashboard (e.g., Figure 13) can be customized per agency definitions of LOS and SGR. Additional summaries can be generated for agencies wishing to see more detail within a specific management system.

Many participants in the workshops and tool testing noted the desire to have additional functionality and screens in the tool prototype (Section 3.3) that were outside the scope of the proof-of-concept tool prototype. These modifications are suggested by the research team in Chapter 5.

Optimization - Project Selection and Resource Allocation Home

Input Budget Information

Program Areas	Pavement	Bridge	Safety	Mobility
Budget Floor ($M)	100	20		
Budget Ceiling ($M)				
Total Budget ($M)		330		

Input Program Performance Targets

	Average IRI (inches/mile)	% of Pavements in "Good" or Better Condition	Total Jobs Created	% of Bridges in "Good" or Better Condition	Total Number of Crashes	% of Congested Roads
Program Target		80%				

Program Outputs

Allocated Budget

	Pavement	Bridge	Safety	Mobility	Total
Allocated Budget ($M)	100.38	28.27	0.59	200.75	329.97

Performance of resulting allocations

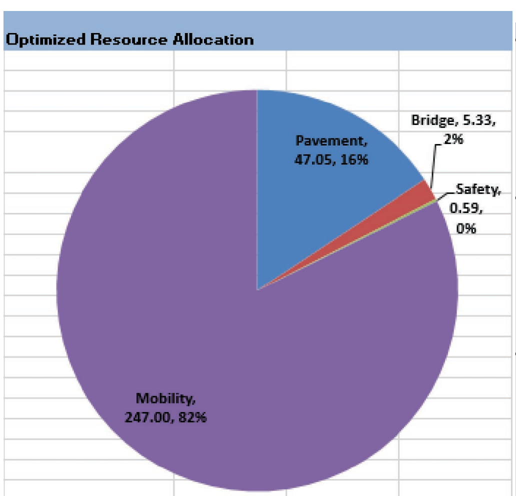
	Average IRI (inches/mile)	% of Pavements in "Good" or Better	Total Jobs Created	% of Bridges in "Good" or Better Condition	Total Number of Crashes	% of Congested Roads
Program Performance	85.58	80.3%	12,900	86.1%	2,529	30.9%

Input Network Performance (excluding Program)

	Average IRI (inches/mile)	% of Pavements in "Good" or Better	Total Jobs Created	% of Bridges in "Good" or Better Condition	Total Number of Crashes	% of Congested Roads
Performance Values	90.00	85.0%	50,000	85.0%	3,500	25.0%
Weight of rest of the system (vs. program)	0.75	0.85	0.5	0.75	0.6	0.7
System Performance	88.90	84.3%	62,900	85.3%	6,029	26.8%

Selected Projects for Implementation

Project ID	Must-Do Projects	Selected Projects	Project Score	Project Cost ($Thousands)	Score/Cost Ratio	Project Ranking
1		1	0.119	$ 22,285	0.005	258
2		1	0.012	$ 126	0.097	60
3		1	0.028	$ 45	0.637	5
4		1	0.015	$ 45	0.339	15



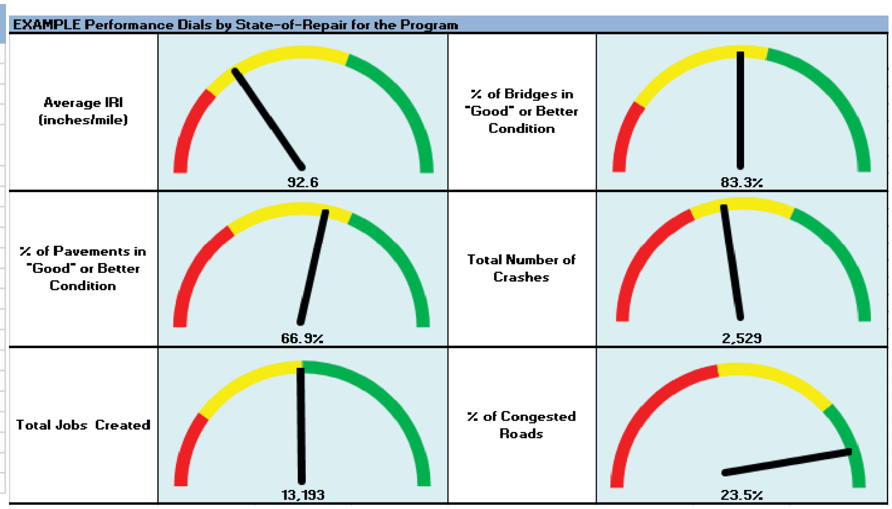


Figure 13. Tool prototype graphics of expected performance outcomes based on allocation strategy.

CHAPTER 3

Testing the Tool Prototype

3.1 Summary of Testing Opportunities

In order to develop an implementable framework that advances the state of the practice for performance-based cross-asset resource allocation, the tool prototype was developed and tested across multiple audiences at workshops across the country. Feedback gathered from participants has assisted the research team in understanding the ways the framework and tool prototype could be used by practitioners (detailed in Section 3.3).

3.1.1 Pre-Workshop Activities

Prior to the workshops, the research team conducted a short electronic survey of planned attendees to help understand participants' experience with, and interest in, cross-asset resource allocation. Results indicated that while transportation officials have considerable interest in an analytical tool, workshop attendees had little experience in applying a comprehensive, data-driven approach. Most agencies noted that they struggle with the technical challenge of comparing data, hesitate to use a program that operates without a clearly defined mathematic framework, and are not quite sure how to overcome siloed (or stove-piped) decision making. Additionally, respondents expressed concern with the industry's current ability to develop meaningful performance measures, compare measurement results/projections, and quantify the trade-offs between different resource allocation strategies. Yet at the same time, there was not a high level of comfort with participants' agencies current allocation process. After the tool was explained, a high level of interest was expressed in using the tool to communicate the consequences of different policies and strategies.

3.1.2 Workshops and Content

From April through September 2014, workshops and presentations were given in Florida, Arizona, New Jersey, Utah, New Mexico, and Indiana to present the framework and test the tool prototype. The Miami (FL), Scottsdale (AZ), Albuquerque (NM), and Indianapolis (IN) workshop meetings were held in conjunction with Transportation Research Board and AASHTO conferences. This allowed for the opportunity of a broad cross-section of DOTs and other transportation professionals to test the tool and comment on the framework. Tests were also conducted for several state DOTs, including those of New Jersey, Utah, North Dakota, Illinois, California, Kansas, and Missouri.

All workshops were focused on cross-asset investment planning and were designed to implement the project framework. Asset classes, performance measures, and general investment categories were developed based on a sample data set provided by a member of the project panel. Participants were encouraged to explore the cross-asset resource allocation framework and tool prototype and were invited to provide feedback on the usefulness of the tool in understanding and communicating the impacts of investment decisions on transportation system performance. The agenda for the workshops included the following:

- **Presentation of NCHRP Project 08-91 framework and tool prototype,** including a briefing on the research findings and the math behind the tool.
- **Value matrix exercise:** Participants used role-play and scenarios to weigh goals and priorities. Breakout group activities were designed as table exercises, where each table worked together as an "agency" to fulfill goals and objectives through the development of a capital program. Each agency reported its final recommended program to all workshop participants.
- **Real-time program optimization:** Based on the weighting exercise and budgetary constraints, the tool's trade-off analysis capabilities were showcased.

Scenario role-play was used to guide tool performance measures weighting and the program optimization and budgeting exercise. Scenarios used to showcase the tool included:

1. A preservation scenario, where teams were encouraged to prioritize bridge and pavement preservation projects while still meeting moderate mobility goals;
2. An economic growth scenario, where teams were asked to meet political priorities for congestion reduction and job creation; and
3. A "confused legislature" scenario, where politicians provided conflicting direction to the teams on where to spend money (congestion relief) while mandating performance targets for bridges.

In all scenarios, teams were given approximately half of the needed budget to meet all performance goals, so trade-offs were critical for final program recommendations, and not all targets could be achieved.

3.2 Audience

Participants at the workshops and on-site tool prototype testing included NCHRP Project 08-91 Panel members, senior leaders and practitioners from DOTs, FHWA staff, representatives from MPOs, and consultants and other private-sector representatives (Table 2).

Table 2. Tool workshops and testing attendees.

Attendees Summary	
Workshop at 10th Annual Asset Management Conference Miami, Florida April 28, 2014	Participants included the NCHRP Project 08-91 Panel as well as agency decision makers, data analysts, programmers, and external communications professionals and consultants; state DOTs, MPOs, and transit agencies were represented.
Utah DOT Tool Testing Salt Lake City, Utah June 16, 2014	Three workshops were conducted with the following attendees (25 in total): • Executive leadership, including the Utah DOT Executive Director and directors of program development, project development, transportation, operations, asset management, program finance, central preconstruction, and Utah DOT regional directors; • Engineers in areas including traffic operations, traffic management, traffic and safety, pavement management, pavement modeling, bridge modeling, bridge planning, and bridge design; and • The six-member Asset Advisory Committee, including pavement, bridge, and finance directors as well as technical staff.

Table 2. (Continued).

Attendees Summary	
Workshop at AASHTO SCOP/SCOPM Conference Scottsdale, Arizona June 20, 2014	Participants included agency decision makers and data analysts with levels of expertise in some or all of the following areas: pavement, bridge, safety, mobility, transit, programming, construction, and operations; FHWA staff also attended to provide a national perspective with regard to MAP-21.
New Jersey Tool Testing Trenton, New Jersey June 25, 2014	A workshop was conducted with the following attendees (seven in total): • Executive leadership including directors of statewide planning, statewide strategies, capital investment planning and development and the assistant commissioner for capital investment planning and grant administration; and • Engineers in areas including pavement and drainage management, project planning, and project management.
Meeting at Western Association of State Highway and Transportation Officials (WASHTO) Conference Albuquerque, New Mexico July 15, 2014	Participants included agency decision makers and data analysts from the Western state DOTs and MPOs; FHWA staff also attended to provide a national perspective with regard to TAMP development, where a refocus on starting with bridges and pavements first was recommended.
Meeting at Mid-America Association of State Transportation Officials (MAASTO) Conference Indianapolis, Indiana July 30, 2014	Participants included agency decision makers and data analysts from the Midwestern state DOTs and MPOs. Participants had expertise in operations and maintenance, pavement, bridge, financial planning, and programming.
North Dakota Tool Testing Bismarck, North Dakota August 18, 2014	Participants included division directors; planning, programming, and asset management leaders; and bridge specialists. District engineers participated via webinar conferencing.
Illinois Tool Testing Springfield, Illinois August 26, 2014	A broad range of department leaders and specialists participated in the workshop, including directors, section chiefs, program development managers, bureau chiefs, unit chiefs, squad leaders, and planning analysts. Disciplines represented included bridges, cost estimating, land acquisition, location studies, operations, pavement management, planning, performance and cost support, and programming.
Kansas Tool Testing Topeka, Kansas September 8, 2014	Program managers, bureau chiefs, analysts, and engineers representing the following organizational units participated in the workshop: bridge, budget, construction and materials, pavement, performance measures, program and project management, and safety and technology.
Missouri Tool Testing Jefferson City, Missouri September 9, 2014	A small group of directors, administrators, specialists, and engineers participated in the workshop. Their areas of expertise included organizational performance, planning, and system analysis.

3.3 Findings

Both the cross-asset resource allocation framework and the tool prototype were well received by workshop and testing participants. Workshop attendees were active in their breakout group exercises, and the discussion was both lively and informative. Overall, participants indicated that there was significant value in the technical analysis capabilities of the tool prototype as well as the ability to apply it toward supporting and informing decision-maker and stakeholder discussions regarding performance targets, measures, and investment strategies.

The following are highlights of the suggested or possible uses of the tool prototype based on comments received from the participants. These are further explored in Section 4.2.

- **Identifying appropriate performance measures:** Most participants focused on the performance metrics established by MAP-21 as the baseline for all measures nationwide. However, individual states may want to layer on their own set of metrics. With multiple metrics layered on top of one another, finding a common system for evaluation poses challenges. Participants had concerns that such a common set of standards could realistically be agreed on, giving several examples of metrics that could be at odds across states and systems. For instance, some technical experts struggled with the use of overall condition indices since these ratings could mask the true nature of disaggregated condition metrics. The tool prototype can help frame these discussions by building a consensus among stakeholders.
- **Establishing investment program areas:** Participants indicated that it may be helpful to categorize investment programs into subclasses. Programs that focused on asset management were identified as different when compared to those that focused on operations or capital projects. Additionally, specific regional differences in investment programs were acknowledged. Topography, population, and primary road types can differ by region, and participants suggested that investment programs may need to be aligned in regional categories.
- **Evaluating data availability and management systems:** Workshop participants noted several practical concerns related to data collection. The ability to generate, gather, store, and analyze data varied greatly across jurisdictions and agencies. While most collect some data metrics, the format of each differed, making both intra-agency and inter-agency cross-asset comparisons difficult. A paradigm shift toward collecting post-implementation performance data, not normally collected, is additionally important to collect so as to improve future impact assessments. There were practical technical issues identified as barriers to linking such data systems. Interest was high in a system to automate linkages among management systems and the tool prototype.
- **Facilitating values discussions through weighting:** While deriving weights, participants noted that agency goals and objectives are sufficiently publicized and instilled across all levels of the organization, yet there is still wide latitude when it comes to interpreting how those values translate to a program. By sitting down together and talking through the importance of one measure over another, revealing conversations occurred on more closely defining performance preferences (e.g., what is more important, the structural health of the pavement or the ride quality that the users experience? Are pavements more important than bridges because of the sheer magnitude of investment or does the larger risk with bridges dominate?). Some participants feared that these conversations could favor larger personalities getting their way but still appreciated the opportunity to think beyond their silo and make a case for their performance areas. In practice, such weighting discussions could be incorporated via a Delphi method to protect against internal biases.
- **Prioritizing projects from a system perspective:** Many workshop participants noted that their agency does have siloed asset management systems in place, particularly for pavements and bridges. They pointed out that these systems could be integrated by using the tool prototype, and decision making could likely be improved through a more holistic approach. Additionally, because various groups within the agency would be required to participate in broader prioritization processes, it is likely that a better organizational understanding would be developed. In this way, agency management systems would generate lists of projects, and the tool prototype would be used to select the best projects across all management systems, which could then be integrated into the STIP or midterm capital program (for example, a 10-year program). Having both top-down and bottom-up approaches was encouraging to participants so as to more directly link common management system outputs.

- **Analyzing investment trade-offs:** Participants suggested that this tool is not so much a "cross-asset" tool as a "cross-investment" tool. The tool could be expanded to look across modes and has the ability to consider performance with regard to operations (e.g., congestion) instead of just physical infrastructure. The ability to quickly evaluate the trade-offs among investment areas was found to be powerful in supporting decision makers in finding the right mix of investments.
- **Making a case for increased flexibility:** By reflecting real-world constraints, participants appreciated having the ability to run the tool prototype with and without different policies so as to make a case for additional discretion in decision making (e.g., if the governor says I must do Project X, what are the impacts on system performance? If we could reallocate dedicated funds, what performance benefits could be realized?).

While many saw the usefulness, there was also genuine concern about implementation. Having now developed and tested the tool prototype with audiences across the country, the following are possible refinements, based on participant feedback, which would help ensure that the tool prototype best meets agency needs. It is important to note that the tool prototype as developed cannot accommodate all of these refinements, but that any add-on or future deployment might consider the following:

- **Simplified interface:** A few refinements were suggested regarding making the mechanics of using the tool prototype more user-friendly. For example, the user currently weights performance measures against each other using a numerical, nine-point comparative scale. Attendees suggested that a sliding bar or scale between measures might be easier to use for this task to avoid confusion about how to value relative priorities. Participants mentioned this refinement several times.
- **Performance measures/outcomes:** The tool prototype's output currently provides the value of performance measures as a result of implementing certain projects or portfolios of projects. Some attendees expressed a desire to show trend lines, not just points in time, commenting that it would be useful to see if asset conditions are improving or worsening. It was also noted that the tool should be able to adapt to varying performance targets by functional class. This has been incorporated into the framework but is not reflected in the sample data set provided in the tool.
- **Scenario comparison:** Participants noted a desire to save each scenario/run within the tool so that subsequent runs can be compared between one another. This accommodation has been built into the tool prototype.

Additional discussions at the workshop meetings focused on risk-based planning, the ability to incorporate economic impacts, longer-term analyses, and data needs. One participant asked what capacity the tool prototype would have to support risk and sensitivity analysis, particularly since MAP-21 includes requirements for agencies to factor uncertainty into planning and decision-making processes on the NHS. Risk has been incorporated into the tool by including standard deviations around the budget and performance impacts, which allows users to make decisions with confidence given the likelihood of various outcomes (Figure 12).

After the tool prototype was demonstrated with a preloaded measure for number of jobs created, participants pointed out that economic models (e.g., IMPLAN and REMI) already exist that could supplement traditional silo analysis. Related to economic value was a discussion point a participant raised on how the tool prototype could be used to show the impact of the delay of a project (i.e., missing the window of opportunity) with regard to both cost and performance. This can be accommodated in the tool by defining lagging performance measures such as a life-cycle cost metric. If fully integrated with a management system, the tool prototype could be linked to compare the diminishing value between project alternatives (e.g., rehabilitation versus patch-fix) at any point in time. Sensitivity testing could then be conducted by iterating the project timing or activity type and evaluating the corresponding impacts on performance.

In anticipation of implementing the framework with long-range transportation plans, several participants asked how the tool prototype could be adapted to predict performance over time. While this was outside the scope of the project, the tool can be analyzed from the top down or repeatedly run on a year-by-year basis with manual updating based on what projects were selected each year. To automate this process, a linkage to management systems is suggested. With access to deterioration predictions, life-cycle cost evaluations, and project alternatives, the tool could be enhanced to support long-range optimization, including the ability to set minimum performance levels throughout the planning horizon.

Discussion at workshops and testing also included questions on what performance measures/allocation areas should be included in the tool prototype and the availability of data to support these measures. The sample data set used in the workshops included safety data, for example, which not all DOTs consider to be a stand-alone allocation area. The flexibility of the tool allows for customization so that states/agencies can use whichever areas/performance measures work best for their unique circumstances and decision-making support needs. It was also noted that the tool prototype depends on data being entered for each project, including the impact of the project on various performance measures. Concern was expressed that this type of information does not exist in many agencies, and the tool is only as good as the data that are entered into it. The research team acknowledged that executive leadership will have to be convinced of the value of such data collection and of its reliability and further noted that as states/MPOs continue to expand their data sets, many mandated by MAP-21, information will be more readily available for use within the tool.

Of course, the application of the framework and tool prototype depends on the agency's organizational structure and performance management maturity. New Jersey, for example, is unique in that it has more flexibility with state and toll dollars, so agency leadership is supportive of the concept of allocating funds that are not pre-dedicated to a specific silo. Utah has expressed interest in an enterprise solution that can accommodate strategic planning, long-range planning, and STIP development. Many states expressed interest in using the top-down tool functionality as a first step toward implementation while they work to understand the benefits of a project across performance types; for example, pavement projects may have safety benefits that are not captured in current data collection processes.

CHAPTER 4

Tool Implementation Playbook

4.1 Applying the Tool for Agency Decision Making

State DOTs and MPOs can apply the framework and use the tool prototype in a variety of ways. This can be summarized as conducting analyses and producing critical inputs for at least four key agency activities:

- **Planning:** Providing analytical support for development of SLRTPs, metropolitan transportation plans (MTPs), comprehensive freight plans, TAMPs, and other planning activities (e.g., medium-range plans and alternatives analyses);
- **Programming:** Evaluating and prioritizing projects to support development of STIPs, MPO transportation improvement programs (TIPs), and other budgeting and project evaluation/selection activities;
- **Strategic activities:** Providing analysis, information, and documentation to support strategic efforts such as the development of revenue initiatives or a special program of projects; and
- **Communications and public involvement:** In conjunction with the previous activities or as stand-alone efforts, the tool prototype can be used as a tool to engage stakeholders and the public in policy development and investment analysis and to provide documentation and transparency for agency decision making.

The following section provides an overview of how the various tool prototype functionalities can be applied to support agencies in addressing one or more of these activities; it includes a road map agencies can use to pursue these applications.

4.2 Example Applications and Use Cases

Agency application of framework can be customized based on the unique interests and needs of individual agencies with respect to the four activities previously listed and used to support the following agency planning and policy development functions:

1. Overarching project prioritization,
2. Program-level analysis,
3. Project-level analysis,
4. Performance analysis and target setting,
5. Scenario analysis,
6. Establishing of relative priorities, and
7. Risk analysis.

4.2.1 Overarching Project Prioritization

At the most basic level, the prototype is a project prioritization tool that enables agencies to comprehensively rank projects and optimize their selection given unique program areas, performance measures/targets, priorities (i.e., weighting of performance measures), needs (i.e., candidate projects), resources, and policies. This application can be applied by agencies in a wide range of functions, including:

- Prioritizing projects for inclusion in SLRTPs (if project-specific) and MTPs;
- Prioritizing projects for inclusion in STIPs and TIPs; and
- Providing a tool to educate stakeholders and the public about project selection processes (or even engage them in the process).

Example Application: A state DOT that wants to develop a project-specific long-range plan can use the framework and tool prototype to conduct analysis and policy development at the front end of its planning process to identify a long list of candidate projects; define/revise goals, program categories, and performance measures; and evaluate minimal investment levels corresponding to system performance targets, establish achievable system performance targets, and set relative priorities. The tool prototype could then be employed to evaluate and rank projects to inform development of a final list of selected projects to be included in the plan. The tool could also be used for a top-down analysis, where trade-off curves are established by management systems to develop budgets for inputs into the initial project development phase.

4.2.2 Program-Level Analysis

In a more targeted application than the one described previously, agencies could use the tool prototype to evaluate and rank projects within specific program areas such as mobility, pavement, bridge, safety, operations, and economic development. Associated uses may include:

- Prioritizing projects in program areas where management systems are weak or do not exist,
- Developing a list of preferred projects to be funded through a targeted revenue initiative,
- Assessing the performance trade-offs associated with different sets of priorities (i.e., changing criteria weighting) or program funding levels, and
- Providing documentation and transparency for how a given set of projects was selected.

Example Application: An agency has good pavement and bridge management systems that support prioritization of preservation projects but lacks a meaningful and defensible approach for selected mobility projects that are funded through a dedicated funding source. The tool prototype can be used to provide a defensible mechanism for informing the selection of mobility projects and to enable the agency to respond to inquiries about what projects would get funded at different program spending levels. Data to be analyzed may include qualitative data to support regional development or identify a project by location; for example, an expansion project on the primary freight network.

4.2.3 Project-Level Analysis

The tool prototype can be applied to conduct analyses of individual projects and programs of projects to support decisions about investing in them. The following are some of the associated analyses an agency could use the tool to perform:

- Assess the system performance trade-offs between two individual projects,
- Assess the system performance trade-offs between two portfolios of projects, and
- Assess the merits of a specific project or a portfolio of projects relative to all other candidate projects and evaluate the implications of advancing or deferring the project or projects.

These analyses can better inform stakeholders and the public by comparing the merits of preferred projects to other candidate projects and to showing the impacts advancing these projects would have on overall system performance.

Example Application: An agency receives a politically based request (e.g., from the governor) to advance at least one of two projects not currently programmed. The tool prototype could be applied to evaluate how each project ranks relative to projects in the program and other candidate projects that have not yet been selected for implementation. The tool prototype could also be used to quantify the system performance implications of implementing a predetermined project or set of projects in lieu of one selected purely based on investment optimization. Based on the results of the analysis, the findings could be used to (1) support one project over the other, (2) justify advancing the project(s) (e.g., if the project is not that far out of the money or if reprioritization would have minor performance impacts), or (3) provide documentation to support opposing the request (e.g., if the desired projects have relative little merit or advancing them would have significant performance implications).

4.2.4 Performance Analysis and Target Setting

The prototype can also serve as a tool to conduct performance analyses across multiple investment categories. Potential applications include:

- Forecasting the overall system performance and other consequences that would occur at different investment levels (e.g., baseline, high, and low), for either planning or programming horizons;
- Assessing the overall system performance trade-offs associated with achieving different performance standards for individual goal areas;
- Helping stakeholders understand what performance targets are attainable, both individually and in concert with system-wide performance for other goal areas; and
- Providing performance-based documentation and justification for plan and program decisions.

Example Application: A state legislature is considering a statewide transportation funding initiative and has created a blue-ribbon panel to develop recommendations for the size of the revenue package and how the new money should be used. To help inform the panel's recommendations, the state DOT and the state's MPOs could use the tool prototype to forecast the system performance that could be achieved at different funding levels. Similarly, the tool prototype could be used to quantify and articulate the impacts of a proposed funding cut to legislators, other stakeholders, and the public.

4.2.5 Scenario Analysis

The tool prototype can be used to conduct scenario analyses in support of performance-based planning and programming. Potential applications include:

- Assessment of system performance and resource allocation at different investment levels,
- Determining the minimum investment/resource allocation required to achieve specific performance targets,
- Development and analysis of scenarios based on specific constraints (e.g., proscribed resource allocations), and
- Enabling stakeholders to develop and evaluate different investment strategies.

Example Application: As a state develops a long-range transportation plan, it becomes apparent that senior management and stakeholders have widely divergent views about what the state's future highway investment priorities should be. Moreover, these views tend to be based on narrow perspectives of what is important and how investment decisions can affect other performance areas. The tool prototype could be employed to develop scenarios that emphasize different program areas to help inform stakeholders about the need for balanced investment.

Similarly, a state could use the tool prototype to support top-down development of its TAMP by helping officials look across asset classes to determine where they want them to fall on cost versus performance curves and allocate resources accordingly. These allocations could then serve as inputs to agency management systems.

4.2.6 Establishing Relative Priorities

The AHP contained in the tool's weighting module provides a means to help agency officials and stakeholders understand how their views of relative priorities translate into program area weights and ultimately the corresponding resource allocations. Potential applications of this capability include:

- Generating inputs to resource allocation decisions/guidance for statewide and metropolitan long-range plans, STIPs/TIPs, and other budgeting activities,
- Identifying parameters for developing alternative investment strategies, and
- Providing a tool to engage the public in discussions about how agencies can balance competing priorities.

Example Application: A state DOT wishes to actively engage its stakeholders in development of its long-range plan's resource allocation guidance. To do so, the agency conducts a series of stakeholder workshops that use the tool prototype's AHP weighting module to help participants gain consensus on relative priorities and associated resource allocation options. These findings are then used to inform the development and analysis of alternative investment scenarios.

4.2.7 Risk Analysis

Uncertainty surrounds transportation decision making. Whether pertaining to cost estimates, budgets, asset deterioration, or project performance impacts, agencies are at risk of delivering programs with outcomes that differ from original estimates. This realization has inspired MAP-21 legislation to call for risk-based transportation asset management plans. The tool prototype provides an example of how uncertainty could be accommodated in a decision-making framework by:

- Evaluating performance impacts for plus–minus changes in available budget,
- Building probability distributions around performance outcomes given the estimated standard deviation of a project's impact, and
- Supporting exploratory sensitivity testing around outcomes under varying inputs.

Example Application: A state DOT is asked how confident it is in being able to achieve MAP-21 targets for bridge conditions in light of possible budget cuts over the next 10 years. To answer this, the agency first assesses bridges that are on the bubble, which, while not expected to become deficient, are at least questionable within the time horizon. Second, the agency assesses the uncertainty surrounding the efficacy of selected activities to correct/prevent structural deficiency. By simulating the likelihood of unplanned-for bridges to become deficient and the likelihood of successfully getting the planned-for bridges out of the deficient state, the agency runs an optimization process multiple times at the reduced funding level. The findings of these analyses are used to provide the stakeholder with a percentage statistical level of confidence based on the number of times the target was reached despite the uncertainties.

4.3 Getting Started—Self-Assessment

Agencies interested in exploring application of the framework and tool prototype may wish to begin by considering the questions and issues identified in Table 3. The table content builds on the findings of the initial project literature review on resource allocation practices and is meant to

Table 3. Tool prototype self-assessment questions, issues, and considerations.

Questions and Issues	Considerations
Intended Applications – What planning processes do you wish to support and what decisions do you want to inform through use of the tool prototype?	• Intended applications will drive both the data needed to support the tool prototype and the processes that can be used to apply it. • To the extent possible, agencies will want to integrate the use of the framework and tool prototype at the beginning of planning and decision-making processes. • Applications will benefit from well-thought out development of analytical scenarios (e.g., baseline, high, and low funding).
Time Horizon – What is the time frame for applications?	• Running the tool prototype over different planning horizons will likely lead to different results. • Ability to apply different planning horizons will be influenced by specificity of project data. • Optimizing projects over an LRTP horizon should incorporate windows of opportunity into the optimization for a long-range multiyear analysis period.
Strategic Frameworks – Has your agency established adequate system goals, objectives, and performance measures needed to drive the cross-asset allocation analysis?	• Goals and objectives drive configuration of tool prototype program areas and are essential to the NCHRP Project 08-91 framework. • Efforts to establish relative priorities among goals and objectives can help influence tool weightings. • MAP-21 goals and performance measures can/should also be integrated into the tool.
Program Structure – How well do program areas (i.e., funding categories) align with goals and objectives?	• The better the alignment, the more the tool prototype will be able to show the relationship between recommended resource allocations and achievement of agency goals.
Performance Targets – Have performance targets been established for key goal areas?	• Agencies will need to enter performance targets into the tool, or • Agencies can use the decision science processes to identify preference-driven targets, as long as they meet MAP-21 and state criteria.
Candidate Projects – Is there an existing list of candidate projects to be evaluated? If not, are there plans for developing the lists or systems and processes in place to support development of a list?	• The level of candidate project information will influence tool prototype analytical capabilities. • A top-down analysis can be implemented as a first step to performance-based budgeting and cross-asset resource allocation.
Stakeholder Roles – Do you intend to use the tool prototype as a stakeholder or public engagement tool?	• Agencies will need to determine if they are using the tool to educate stakeholders/the public or to bring them into decision making; the latter will require

(continued on next page)

Table 3. (Continued).

Questions and Issues	Considerations
	more work to bring people up to speed on how the tool prototype works. • The application of the tool prototype as an engagement tool will need to be designed around the transportation literacy of those that will be involved, and some modifications will be needed.
Clear Institutional Constraints – What institutional barriers could limit the use or effectiveness of the tool prototype? Does the agency's organizational structure create barriers to implementation of the tool prototype?	• In instances where there is a well-established process or set of planning tools, agencies may need to clearly articulate the benefits of using the tool prototype (particularly if it is replacing rather than complementing an entrenched process/methodology). • Outreach may be needed to help planning partners (e.g., MPOs) understand the tool prototype and its implications for decision making. • Agencies with highly decentralized decision making may find application of the tool prototype more challenging (at least on a statewide basis).
Resource Allocation Parameters – What statutory, administrative, or other factors influence resource allocation decisions?	• Parameters such as statutory requirements for certain program allocations can be accommodated in the tool prototype. • The tool prototype can be used to show the performance implications of greater or reduced funding flexibility.

serve as a guide to help agencies (1) determine the highest value uses for the tool given an agency's unique circumstances, (2) assess its level of readiness, and (3) identify the need to develop any resources or conduct preliminary research and analysis to support application of the tool.

4.4 Using the Tool

The tool's user guide has been developed showing the hands-on use of the tool prototype. Starting with the home page (Figure 14), the user guide walks through each tab of the Microsoft Excel–based spreadsheet, following the framework of NCHRP Project 08-91.

Once project data are entered and performance measures are selected, weighting, scaling, and scoring are performed. Various trade-offs and optimization options may then be chosen.

Within the spreadsheet interface, different colors indicate different functions of the cells. This method allows the user to quickly identify where input is required or where there is the potential for override.

The screenshots in the user guide are for demonstrative purposes only, and all data inputs are merely examples. Any performance measure may be used based on the goals and objectives developed by the user agency.

The following sections define how each tab within the tool prototype is used for the preferred bottom-up approach. As previously mentioned, a top-down approach may also be used, so the user guide addresses that, as well.

Figure 14. Tool prototype home page.

4.4.1 Data Integration and Performance Measures

- **Projects tab:** Input candidate projects and attributes into the tab. Required attributes are a unique project ID, project cost and sponsoring program area, and variables to convert between project- and network-level performance [e.g., annual average daily traffic (AADT), project length]. Geographic identifiers may also be inputted for user reference.
- **Settings tab:** Users can specify program areas to allocate resources between and measures to weigh performance preferences against. For each program area, project-level and corresponding network-level performance measures should be chosen. The tool is prepopulated with common program areas and performance measures, but any area or measure may be entered.
- **Performance tab:** Projects and performance measures are populated from previous input. The user enters the estimated value of each performance measure in the cases of with and without project implementation.

4.4.2 Weighting, Scaling, and Scoring

- **Weighting tab:** A rating scale compares the relative importance of performance measures (Figure 15). The weights are calculated and stored as the AHP weights. There is a consistency check for the selected pairwise comparisons. Expert overrides/fixed weights may be entered, as well.

Weighting via the Analytic Hierarchy Process			Next
Rating Scale			
1	Criterion X	is equally important to	Criterion Y
2	Criterion X	is equally to slightly more important than	Criterion Y
3	Criterion X	is slightly more important than	Criterion Y
4	Criterion X	is slightly to moderately more important than	Criterion Y
5	Criterion X	is moderately more important than	Criterion Y
6	Criterion X	is moderately to strongly more important than	Criterion Y
7	Criterion X	is strongly more important than	Criterion Y
8	Criterion X	is strongly to extremely more important than	Criterion Y
9	Criterion X	is extremely more important than	Criterion Y
**Take Reciprocal if Y is deemed more important to X*			

Figure 15. Rating scale for pairwise comparison.

- **Scaling tab:** All performance measures are normalized to a level playing field. If linear scaling is chosen, users must specify minimum/maximum possible values for each performance measure. For utility scaling, users must enter in the coefficients of the calibrated function.
- **Scoring tab:** Scores, representing the importance of the project, are calculated by combining the weighting and scaling results. Users can iteratively override any result. Satisfactory scores are then sent to optimization/trade-off analysis.

4.4.3 Trade-off Analysis and Optimization

- **Optimization tab:** Input budget and performance constraints. The analysis will show the recommended resource allocation for each program area, as well as a list of selected projects. State-of-repair dials are displayed based on user definitions of good, fair, and poor for each performance measure.
- **Trade-off tab(s):** For the bottom-up mode, six different trade-off analyses are available:
  - **TF1: Trade-off between two individual projects**—Any two projects may be compared by entering the unique project IDs;
  - **TF2: Trade-off between two project portfolios**—Projects are chosen for each portfolio (project selection may be copied from previous optimization runs) and relative preferences are compared;
  - **TF3: Trade-off between performance and investment level**—Any performance measure and objective (minimize or maximize) may be selected; result shows general linkage between performance measure and investment level;
  - **TF4: Minimum investment level to achieve performance targets**—The user enters a performance target for all network-level performance measures; analysis will approximate the minimum investment budget necessary to reach each target;
  - **TF5: Resource allocation scenario analysis**—The user inputs various resource allocations for each program area; results show the final performance levels associated with each scenario;
  - **TF6: Weighting scenario analysis**—Weight of performance measures may be varied for each scenario; results show the allocated budget and performance for each scenario.
- **Example scenario comparison tab:** Different scenarios can be conducted and compared, presenting the outputs in a variety of formats.

4.4.4 Top-Down Analysis

The top-down approach allows decision makers to observe the impact of different resource allocations across assets at a strategic level. It is also helpful in identifying the optimal resource allocation across assets, given budget limitations, objectives, and performance targets. Users need to input the following data for performance measures (such as IRI, bridge condition, and travel speed) and program areas (such as pavement, bridge, and mobility) in order to run top-down analysis:

- Performance measure bounds (minimum and maximum values),
- Performance measure targets,
- Weight of each performance measure,
- Investment level versus performance data,
- Budget floor and ceiling for each program area, and
- Total available budget.

The investment versus performance data are used to develop trade-off curves in order to interpolate the resulting performance for any resource allocation. The tool will then determine the optimal resource allocation across program areas that maximizes system performance per agency preferences.

4.4.5 Risk Analysis

The tool considers the uncertainties in expected budget and predicted performance measures and provides a range of possible performance outcomes by simulating different budget scenarios.

- **Risk tab:** The user will input how much the performance measure may vary from its expected value for both with and without cases for each project.
- **Risk summary tab:** Using the expected budget, how much the budget may vary from the expected budget (standard deviation), and the confidence interval as defined by the user, the tool will provide a range for the performance measures given budget and performance uncertainties. The tool also produces a graphical spectrum of expected performance values.

CHAPTER 5

Conclusions and Next Steps

The NCHRP Project 08-91 framework and tool prototype demonstrate that a cross-allocation approach to analyze and communicate the likely system performance impact of investment decisions across multiple types of transportation assets can be developed and applied. The project products were well received by agency decision makers and technical practitioners participating in the project as part of the research panel or tool workshops and testing.

The tool prototype provides an implementable framework that can be used to directly link planning, resource allocation, and programming to achieve agency performance goals. While example applications for the framework and tool prototype are documented in Chapter 4, it is important to note the following summary considerations, which link directly to the suggestions and next steps for implementing the NCHRP Project 08-91 research. The idea is that these considerations are challenges that must be addressed in a real-life deployment setting.

- **Data development and integration:** The framework suggests a bottom-up approach to program development, where all possible projects are pooled and prioritized prior to capital budgeting. The challenge for many agencies is the overall lack of a suitable list of candidate projects with adequate information on project details and anticipated performance impacts. More work is needed at the agency level to better understand how and where data must be aggregated to feed the tool. Additionally, identification is needed of how/where qualitative information (e.g., equity and quality-of-life considerations) can support the framework to better integrate priorities outside of those traditionally measured.
- **Integration with existing management and analysis systems:** The use of siloed asset management systems is widely applied in many state DOTs, and with MAP-21's focus on asset condition and performance, most states will likely rely on management systems at some level in their decision-making processes in the near future. The NCHRP Project 08-91 framework shows that management systems can be applied to identify performance information for both the project-level (bottom-up) and the network-level (top-down) optimization approaches; however, the tool prototype would need to be expanded to directly integrate these data in an automated or agency-wide enterprise solution. This means that the management systems would develop candidate project lists for incorporation directly into the tool prototype.

  Additionally, the integration of other models into the tool could be researched. This would include an assessment of how national models [e.g., HERS-ST, NBIAS, AASHTOWare Bridge (aka PONTIS)] can be used to feed the before-and-after performance information needed to run the tool.

- **Development of a more streamlined user interface:** Suggested refinements to the tool prototype include making the mechanics of using the tool more user-friendly and providing a web-based solution. For example, changing the nine-point comparative scale to a sliding bar or scale to compare measures as well as development of trend lines for performance measures. Additionally, allowing for each user to be assigned different weights within the weighting process could be integrated to allow for the relative importance of a group to influence performance weights (e.g., stakeholders, practitioners, technical experts).

- **Testing the framework and tool in planning and programming:** Chapter 4 highlights the intended applications of the framework and tool for agency long-range, strategic, and TAMP planning; project prioritization and capital programming; and communications and public involvement. Clearly, the ability to apply the framework and tool prototype depends on an agency's organizational structure and maturity with respect to performance-based planning, asset management, needs identification, and performance management. For example, many states expressed interest in using the top-down tool functionality as a first step toward its broader implementation. In addition, these or other agencies could use the framework and tool to analyze data to better understand the benefits of projects across performance types (e.g., pavement projects may have safety benefits that are not quantified in current data collection and analytical processes).
- **Establishing weighting and performance targets:** The project testing workshops focused on applying the framework and tool functionality; thus it was assumed that the process of establishing program area weightings and setting performance was linear. In reality, setting these parameters will likely require a significant and iterative policy development effort that will need to be integrated with an agency's broader decision-making processes.
- **Scope of performance considerations:** The tool testing workshops incorporated a fairly basic set of performance considerations—preservation, mobility, economic impacts, and safety. Many agencies use a broader set of metrics to drive decision making that include considerations such as environmental benefits and livability/sustainability. These could be incorporated, as well as other modes or geographic subregions, to provide a more comprehensive and inclusive set of performance considerations.
- **Programmatic alignment:** During testing of the framework and tool it was generally assumed that all agency funding was fungible (note that some testing scenarios did look at earmarking specific funding levels for certain program areas, but only as a sample project-specific exercise). In reality, agencies tend to have complex program funding structures, and effort will be required to translate the outputs of the tool and framework to an agency's actual funding categories and associated requirements. The tool prototype has been developed to overcome these requirements but has not yet been tested in this way.

While NCHRP Project 08-91 provides an implementable methodology that was tested for the research, it does not include a full deployment of cross-asset resource allocation approach within a transportation agency. A full test deployment would include:

- **An assessment of data and suggestions for data sets and tools that are available to support comprehensive performance management:** This includes the ability to predict future performance, whether based on objective or subjective information. Both quantitative and qualitative post-processing and predictive modeling of available information are suggested to support and validate predictive models.
- **Modifications to the framework and tool to accommodate an agency-wide enterprise solution:** A full deployment would be used to implement the project research at an agency enterprise level, where the tool would accommodate data automation and updated interface considerations.
- **Real application to agency planning and programming:** The framework could be applied to the development of an LRTP update, for example, or to the development of a capital program. The exact application would depend on the agency's timing in the planning and programming process, but would largely follow the applications in the self-assessment in Section 4.3.

- **Improved outputs and visualization:** While the tool prototype provides dashboard indicators and other graphical inputs, development of better visualization capabilities and exploration of how the tool could be linked to other graphic and communication platforms could greatly enhance the benefit of the tool to agencies.

The main contributions of the research have been in advancing data-driven techniques to support performance-based project prioritization, program development, scenario analysis, and target setting while still accommodating various opportunities for expert judgment.

While the research team has accomplished the goal of delivering an implementable framework that decision makers may use to better understand the outcomes of investing across asset classes and investment types, a full pilot deployment was advised by participants at project workshops and testing to overcome the implementation challenges noted and to better understand how the framework and tool prototype could be applied in practice. This is also suggested by the research team, since many of the modifications needed to make the tool implementable at an enterprise scale are outside the scope of the current research project.

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ATTACHMENT

Technical Memorandum: Cross-Asset Resource Allocation Workshops

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Section 1. Overview

NCHRP Project 08-91, "Cross-Asset Resource Allocation and the Impact on System Performance," sought to address a common performance-based planning challenge for transportation agencies. While there is considerable interest in assessing the anticipated performance outcomes from different ways of allocating resources across asset classes and investment types, a lack of tools and methods exists to enable agencies to conduct these analyses through optimization-based approaches. As a result, current agency processes for defining performance measures and setting targets are often separated from efforts to select projects or optimize the allocation of limited transportation resources.

The research team conducted research to develop an implementable framework and tool prototype that advances the state of the practice in cross-asset resource allocation and program optimization.

From April through July of 2014, the team conducted multiple workshops and presentations to present the proposed framework and test the tool prototype. Workshops were held in Miami (FL), Scottsdale (AZ), Albuquerque (NM), and Indianapolis (IN) in conjunction with TRB and AASHTO conferences. These workshops provided and allowed for the opportunity to test the tool with a broad cross-section of state DOTs and other transportation professionals and enabled participants to comment on the framework. Tests were also conducted for several state DOTs, including those of New Jersey, Utah, North Dakota, Illinois, California, Kansas, and Missouri, through state-specific, on-site workshops (see Figures 1.1 and 1.2).

Top Takeaways from the Workshops

Key issues, considerations, and observations that emerged from the various testing workshops included the following:

1. Participants representing a range of agencies: The FHWA, state DOTs, and MPOs generally expressed a strong interest in and curiosity about the concept of cross-asset

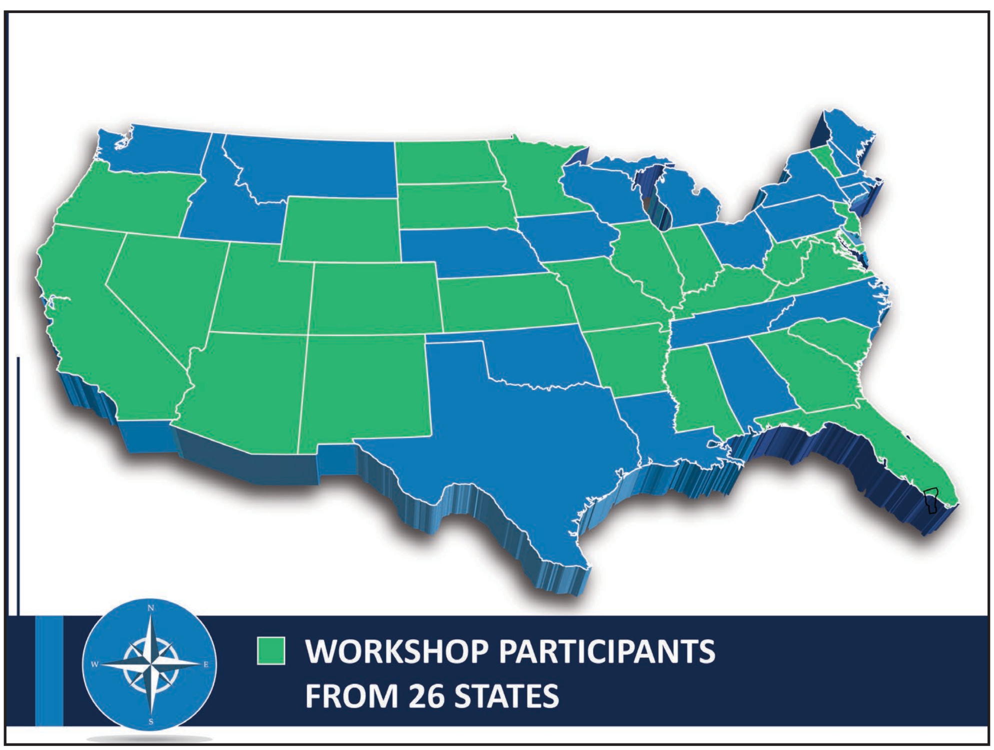


Figure 1.1. States where the framework and tool were presented for testing.

Figure 1.2. Conducted conferences in a variety of states.

allocation and the development of an associated analytical framework tool to support its application/implementation.

2. Users had mixed reactions to the AHP approach to developing goal weighting; some found the approach uncomfortable (e.g., I can't provide a relative preference for preservation versus safety), while others felt the weighting exercise provided a meaningful starting point for determining an agency's relative priority for competing goals.

3. Through the workshop exercises, participants appeared to gain a strong appreciation for the framework's/tool's capacity to support decision-maker and stakeholder discussions regarding goal weighting, performance targets, investment strategies, and impacts of one-off decisions.

4. Participants expressed concern about their agencies' abilities to gather enough project data across asset classes to run the tool prototype analysis. Although researchers pointed out that an expert panel approach could be used to estimate project benefits or other needed tool inputs, participants expressed reservations about the amount or resources that would be required to do so.

5. The prototype is seen as a powerful scenario analysis tool that could help agencies evaluate alternative futures based on different assumptions about available revenues.

Section 2. Workshop and On-Site Testing Participants

Workshop and on-site tool prototype testing participants included NCHRP Project 08-91 Panel members, senior leaders and practitioners from DOTs, FHWA staff, representatives from MPOs, and consultants and other private-sector representatives. Table 2.1 summarizes participants' roles and expertise from the various workshops.

Table 2.1. Tool workshops and testing attendees.

Location Date	Participants	Expertise	Estimated No. of Participants
Workshop at 10th Annual Asset Management Conference **Miami, FL** **April 28, 2014**	• NCHRP Project 08-91 Panel • Agency decision makers • Data analysts • Programmers • External communications professionals • Consultants • State DOTs, MPOs, and transit agencies were represented.	• Analytics • Asset management • Bridge • Construction • Finance • ITS • Mobility • Modes • Non-pavement assets • Operations • Pavement • Programming • Safety • System-level cross-asset allocation	20 registrants
Utah DOT Tool Testing **Salt Lake City, UT** **June 16, 2014**	• Bridge directors • Consultants • Contract administrators • Directors • Engineers • Engineers Asset Advisory Committee • Executive leadership including the Utah DOT executive director • Finance directors • Regional directors • Technical staff	• Asset management • Bridge design • Bridge modeling • Bridge planning • Central preconstruction • Operations • Pavement management Pavement modeling • Program development • Program finance • Project development • Traffic and safety • Traffic management • Traffic operations • Transportation	25
Workshop at AASHTO SCOP/SCOPM Conference **Scottsdale, AZ** **June 20, 2014**	• Agency decision makers • Data analysts • FHWA staff also attended to provide a national perspective with regard to MAP-21.	• Bridge • Construction • Mobility • Modes • Operations • Pavement • Programming • Safety • Transit	21
New Jersey Tool Testing **Trenton, NJ** **June 25, 2014**	• Assistant commissioner for Capital Investment Planning and Grant Administration • Directors • Engineers	• Capital investment planning and development • Pavement and drainage management • Project management • Project planning • Statewide planning • Statewide strategies	7

Table 2.1. (Continued).

Location Date	Participants	Expertise	Estimated No. of Participants
WASHTO Conference **Albuquerque, NM** **July 15, 2014**	• Agency decision makers • Data analysts • FHWA staff also attended to provide a national perspective with regard to TAMP development, where a refocus on starting with bridges and pavements first was recommended.	• Bridge • Construction • Mobility • Modes • Operations • Pavement • Programming • Safety • Transit	–
Meeting at MAASTO Conference **Indianapolis, IN** **July 30, 2014**	• Agency decision makers • Data analysts	• Bridge • Financial planning • Operations and maintenance • Pavement • Programming	–
North Dakota DOT Tool Testing **Bismarck, ND** **August 18, 2014**	• Division directors • Engineers • Planning specialists • Bridge specialists • Business support executives	• Asset management • Bridge • Construction • Design • Operations • Pavement • Planning • Programming • Transportation programs	10
Illinois DOT Tool Testing **Springfield, IL** **August 26, 2014**	• Engineers • Section chiefs • Program development managers • Bureau chiefs • Directors • Planning specialists • Unit chiefs • Squad leaders • Planning analysts	• Bridges and structures • Cost and estimates • Highways • Land acquisition • Location studies • Operations • Pavement management • Planning • Performance and cost support • Programming • Project and environmental studies • Structural services • Systems planning and services • Transportation planning • Urban planning	34

(continued on next page)

Table 2.1. (Continued).

Location Date	Participants	Expertise	Estimated No. of Participants
Kansas DOT Tool Testing **Topeka, KS** **September 8, 2014**	• Assistant directors • Program managers • Chiefs • Engineers	• Bridge • Budget • Construction and materials • Management engineering • Pavement • Performance measures • Planning • Program and project management • Transportation safety and technology	12
Missouri DOT Tool Testing **Jefferson City, MO** **September 9, 2014**	• Specialists • Engineers • Directors • Administrators	• Organization performance • Planning • Transportation system analysis	6

Section 3. Pre-workshop Surveys

Prior to the Asset Management Conference and the AASHTO SCOP/SCOPM Conference workshops, the research team conducted a short electronic survey of planned attendees to help understand participants' experience with, and interest in, cross-asset allocation analysis. Survey questions included:

- What role do you play in asset allocation/programming?
- In what areas do you have specific knowledge or expertise?
- Within your agency or client base, to what extent is there demand for cross-asset allocation?
- If there is little to no demand for cross-asset allocation, why do you think that is the case?
- What challenges or hurdles has your agency faced (or do you imagine it might face) when it comes to cross-asset allocation?

In the case of the Asset Management Conference held in Miami, results from respondents indicated that while transportation officials have considerable interest in cross-asset allocation analysis, workshop attendees have little experience in the field. No respondents indicated a high level of comfort with their agencies' current allocation process. Moreover, respondents expressed concern with the industry's current ability to develop meaningful performance measures, compare measurement results/projections, and quantify the trade-offs between different resource allocation strategies.

At the AASHTO SCOP/SCOPM Conference in Scottsdale, Arizona, seven respondents indicated that there is definite interest in cross-asset allocation analysis. However, all respondents answered that the agency is technically challenged when it comes to cross-asset allocation. In addition, more than half of the people surveyed said that a lack of industry-accepted tools, funding mandates, and stove-piped decision making have been challenges faced when it comes to cross-asset allocation.

Appendix A contains survey results.

Section 4. Workshop Objectives and Structure

The research team identified four key objectives for the workshops and on-site tests:

1. Focus on the decision-making framework developed as a part of the project research;
2. Introduce the tool prototype to aid implementation and understanding of the framework, and guide participants through performance measure selection, weighting, budgeting, and scenario planning case studies to simulate real-world decision-making needs and challenges;
3. Demonstrate tool functionality to support both top-down analysis where a recommended program of projects is developed based on pre-established investment budgets, and bottom-up analysis where program budgets are driven by project prioritization based on project-specific performance; and
4. Keep participants engaged through an interactive workshop that enables them to test drive the tool prototype.

Throughout the workshops, groups were reminded of their scenario and were asked to make decisions based upon that scenario.

Based on these objectives, highly interactive workshops were developed by the research team. The workshop format and materials were prepared for each workshop based on the number of participants and whether the workshop was conducted as part of a national conference or for a state department of transportation with specific concerns.

Representative materials, including a workshop agenda, presentation, and scenario handouts, are provided in Appendix C. Key components of each workshop included:

- An overview presentation to introduce participants to the cross-asset resource allocation framework and prototype tool, including the methodology (and math) behind the tool.
- One or more activities that were conducted with breakout groups (and in some cases, a single group) so that participants could experience firsthand how the tool works and identify ways in which the tool might be improved. Generally, participants decided on the weights for each performance measure, the desired target(s) for each performance measure, and the amount of funding required to meet some or all of the performance targets. Funding was constrained to simulate real-life situations.
- A discussion, at the conclusion of the workshop, of the functionality and practicality of the tool, refinements that could be made, and the best use of the tool in practice.

Section 5. Findings

Both the cross-asset resource allocation framework and the tool prototype were well received by workshop and testing participants. Workshop attendees were active in their breakout group exercises, and the discussion helped identify several potential refinements for follow-on initiatives. To review specific suggestions for refinement, opportunities to use the prototype tool, and additional observations or concerns from each workshop and state department of transportation meeting, please see Appendix D.

Overall, participants indicated that there was significant value in the technical analysis capabilities of the tool prototype as well as the ability to apply it toward supporting and informing decision-maker and stakeholder discussions regarding performance targets, measures, and investment strategies.

Following are highlights of the suggested or possible uses of the tool prototype based on comments received from the participants.

- **Identifying appropriate performance measures:** Most participants focused on the performance metrics established by MAP-21 as the baseline for all measures nationwide. However, individual states may want to layer on their own set of metrics. With multiple metrics layered on top of one another, finding a common system for evaluation poses many challenges. Participants had concerns that such a common set of standards could realistically be agreed upon, giving several examples of metrics that could be at odds across states and systems. For instance, some technical experts struggled with the use of overall condition indices since these ratings could mask the true nature of disaggregated condition metrics. The tool prototype can help frame these discussions by building a consensus among stakeholders.

- **Establishing investment program areas:** Participants indicated that it may be helpful to categorize investment programs in subclasses. Programs that focused on asset management were identified as different when compared to those that focused on operations or capital projects. Additionally, specific regional differences in investment programs were acknowledged. Topography, population, and primary road types can differ by region, and participants suggested that investment programs may need to be aligned in regional categories.
- **Evaluating data availability and management systems:** Workshop participants noted several practical concerns related to data collection. The ability to generate, gather, store, and analyze data varied greatly across jurisdictions and agencies. While most currently collect some data metrics, the format of each differed, making both intra-agency and inter-agency cross-asset comparisons difficult. A paradigm shift toward collecting post-implementation performance data, not normally collected, is additionally important so as to improve future impact assessments. There were practical technical issues identified as barriers to linking such data systems. Interest was high in a system to automate linkages among management systems and the tool prototype.
- **Facilitating values discussions through weighting:** While deriving weights, participants noted that agency goals and objectives are sufficiently publicized and instilled across all levels of the organization, yet there is still wide latitude when it comes to interpreting how those values translate to a program. By sitting down together and talking through the importance of one measure over another, revealing conversations were had on more closely defining performance preferences (e.g., what is more important, the structural health of the pavement or the ride quality that the users experience? Are pavements more important than bridges because of the sheer magnitude of investment, or does the larger risk with bridges dominate?). Some participants feared that these conversations could favor larger personalities getting their way but still appreciated the opportunity to think beyond their silo and make a case for their performance areas. In practice, such weighting discussions could be incorporated via a Delphi method to protect against internal biases.
- **Prioritizing projects from a system perspective:** Many workshop participants noted that their agency does have siloed asset management systems in place, particularly for pavements and bridges. They pointed out that these systems could be integrated by using the tool prototype and decision making could likely be improved through a more holistic approach. Additionally, because various groups within the agency would be required to participate in broader prioritization processes, it is likely that a better organizational understanding would be developed. In this way, agency management systems would generate lists of projects, and the tool prototype would be used to select the best projects across all management systems, which could then be integrated into the STIP or midterm capital program (for example, a 10-year program). Having both top-down and bottom-up approaches was encouraging to participants so as to more directly link common management system outputs.
- **Analyzing investment trade-offs:** Participants suggested that this tool is not so much a "cross-asset" tool as a "cross-investment" tool. The tool could be expanded to look across modes and has the ability to consider performance with regard to operations (e.g., congestion) instead of just physical infrastructure. The ability to quickly evaluate the trade-offs among investment areas was found to be powerful in supporting decision makers in finding the right mix of investments.

- **Making a case for increased flexibility:** By reflecting real-world constraints, participants appreciated having the ability to run the tool prototype with and without different policies so as to make a case for additional discretion in decision making (e.g., if the governor says I must do Project X, what are the impacts on system performance? If we could reallocate dedicated funds, what performance benefits could be realized?).

While many saw the usefulness, there was also genuine concern about implementation. Now that the tool prototype has been developed and tested with audiences across the country, the following are possible refinements, based on participant feedback, that could help ensure that the tool prototype best meets agency needs. It is important to note that the tool prototype as developed cannot accommodate all of these refinements but that any add-on or future deployment might have the following:

- **Simplified interface:** A few refinements were suggested regarding making the mechanics of using the tool prototype more user-friendly. For example, the user currently weights performance measures against each other using a numerical, nine-point comparative scale. Attendees suggested that a sliding bar or scale between measures might be easier to use for this task to avoid confusion about how to value relative priorities. Participants mentioned this refinement several times.
- **Performance measures/outcomes:** The tool prototype's output currently provides the value of performance measures as a result of implementing certain projects or portfolios of projects. Some attendees expressed a desire to show trend lines, not just points in time, commenting that it would be useful to see if asset conditions are improving or worsening. It was also noted that the tool should be able to adapt to varying performance targets by functional class. This has been incorporated into the framework but is not reflected in the sample data set provided in the tool.
- **Scenario comparison:** Participants noted a desire to save each scenario/run within the tool so that subsequent runs can be compared. This accommodation has been built in to the tool prototype.

Additional discussions at the workshop meetings focused on risk-based planning, the ability to incorporate economic impacts, longer-term analyses, and data needs. One participant asked what capacity the tool prototype would have to support risk and sensitivity analysis, particularly since MAP-21 includes requirements for agencies to factor uncertainty into planning and decision-making processes on the NHS. Risk has been incorporated into the tool by including standard deviations around the budget and performance impacts, which allows users to make decisions with confidence given the likelihood of various outcomes.

After the tool prototype was demonstrated with a preloaded measure for number of jobs created, participants pointed out that economic models (e.g., IMPLAN and REMI) already exist that could supplement traditional silo analysis. Related to economic value was a discussion point a participant raised on how the tool prototype could be used to show the impact of the delay of a project (i.e., missing the window of opportunity) with regard to both cost and performance. This can be accommodated in the tool by defining lagging performance measures such as a life-cycle cost metric. If fully integrated with a management system, the tool prototype could be linked to compare the diminishing value between project alternatives (e.g., rehabilitation vs. patch-fix) at any point in time. Sensitivity testing could then be conducted by iterating the project timing or activity type and evaluating the corresponding impacts on performance.

In anticipation of the framework being implemented with long-range transportation plans, several participants asked how the tool prototype could be adapted to predict performance over time. While this was outside the scope of the project, the tool can be analyzed from the top down or repeatedly run on a year-by-year basis with manual updating based on what projects were selected each year. To automate this process, a linkage to management systems is suggested. With access to deterioration predictions, life-cycle cost evaluations, and project alternatives, the tool could be enhanced to support long-range optimization, including the ability to set minimum performance levels throughout the planning horizon.

Discussion at workshops and testing also included questions on what performance measures/allocation areas should be included in the tool prototype and on the availability of data to support these measures. The sample data set used in the workshops included safety data, for example, which not all DOTs consider to be a stand-alone allocation area. The flexibility of the tool allows for customization so that states/agencies can use whichever areas/performance measures work best for their unique circumstances and decision-making support needs. It was also noted that the prototype tool depends on data being entered for each project, including the impact of the project on various performance measures. Concern was expressed that this type of information does not exist at many agencies, and the tool is only as good as the data that are entered into it. The research team acknowledged that executive leadership will have to be convinced of the value of such data collection and of its reliability and further noted that, as states/MPOs continue to expand their data sets, many mandated by MAP-21, information will be more readily available for use within the tool.

Of course, the application of the framework and tool prototype depends on the agency's organizational structure and performance management maturity. New Jersey, for example, is unique in that it has more flexibility with state and toll dollars, so agency leadership is supportive of the concept of allocating funds that are not pre-dedicated to a specific silo. Utah has expressed interest in an enterprise solution that can accommodate strategic planning, long-range planning, and STIP development. Many states expressed interest in using the top-down tool functionality as a first step toward implementation while they work to understand the benefits of a project across performance types; for example, pavement projects may have safety benefits that are not captured in current data collection processes.

APPENDIX A

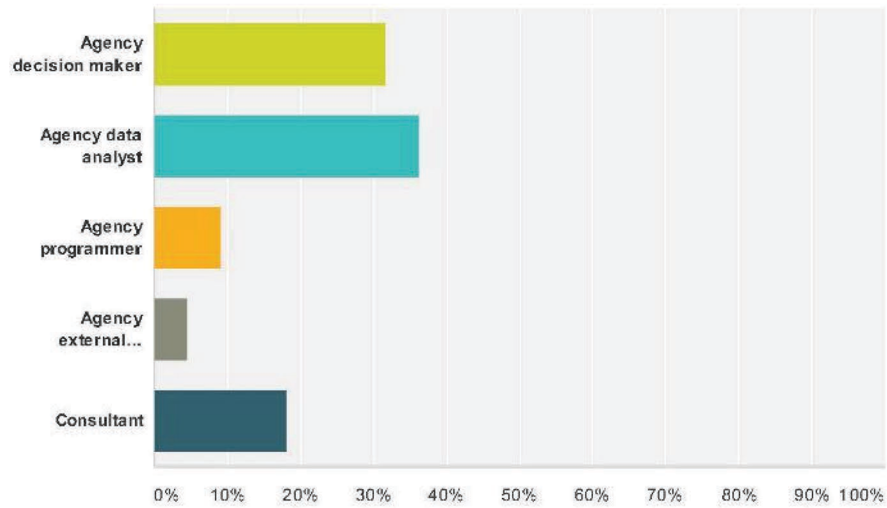
Survey Results

Asset Management Conference Workshop

Workshop 017: Cross-Asset Allocation

Q1 What role do you play in asset allocation/programming?

Answered: 22 Skipped: 0

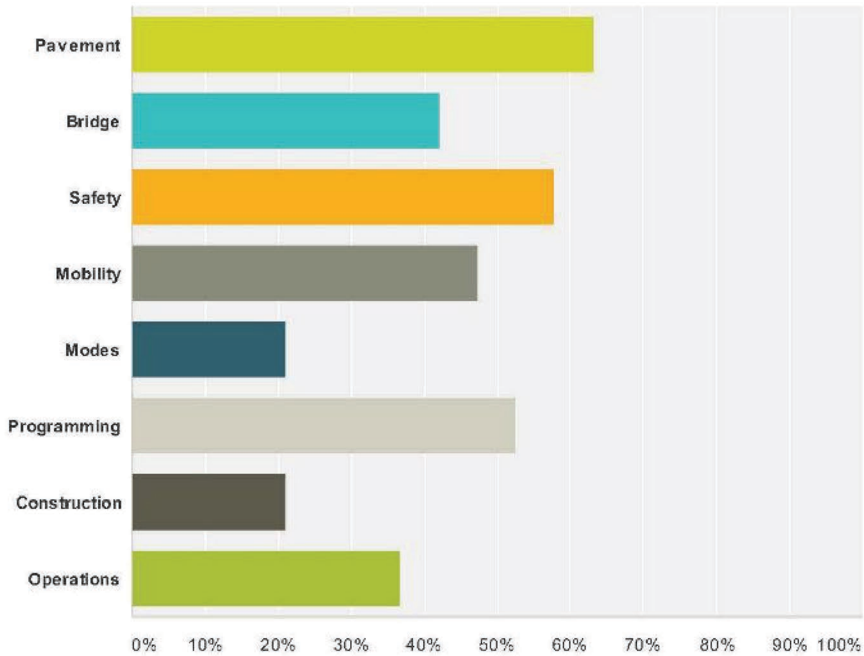


Answer Choices	Responses	
Agency decision maker	31.82%	7
Agency data analyst	36.36%	8
Agency programmer	9.09%	2
Agency external communications	4.55%	1
Consultant	18.18%	4
Total		22

Workshop 017: Cross-Asset Allocation

Q2 In what areas do you have specific knowledge or expertise? (check all that apply)

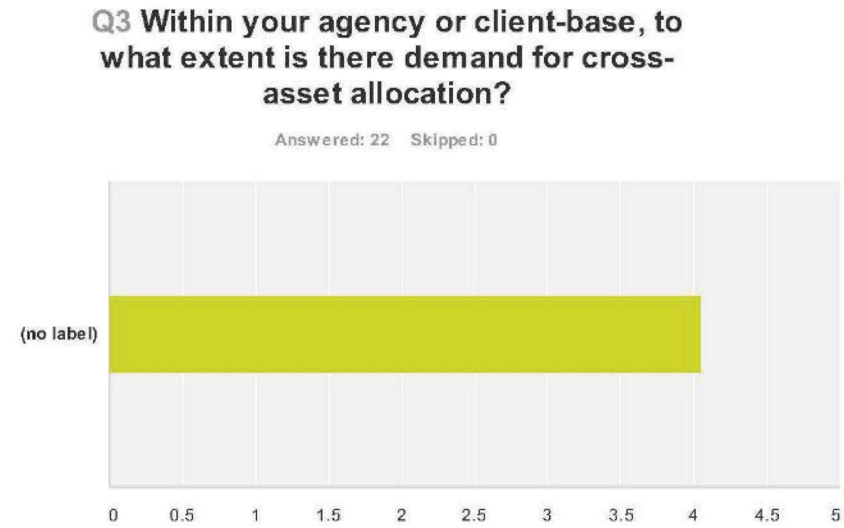
Answered: 19 Skipped: 3



Answer Choices	Responses	
Pavement	63.16%	12
Bridge	42.11%	8
Safety	57.89%	11
Mobility	47.37%	9
Modes	21.05%	4
Programming	52.63%	10
Construction	21.05%	4
Operations	36.84%	7
Total Respondents: 19		

#	Other (please specify)	Date
1	maintenance	4/23/2014 7:22 AM
2	I have knowledge of all categories at a high level	4/21/2014 3:57 PM
3	Finance	4/21/2014 3:23 PM

Workshop 017: Cross-Asset Allocation

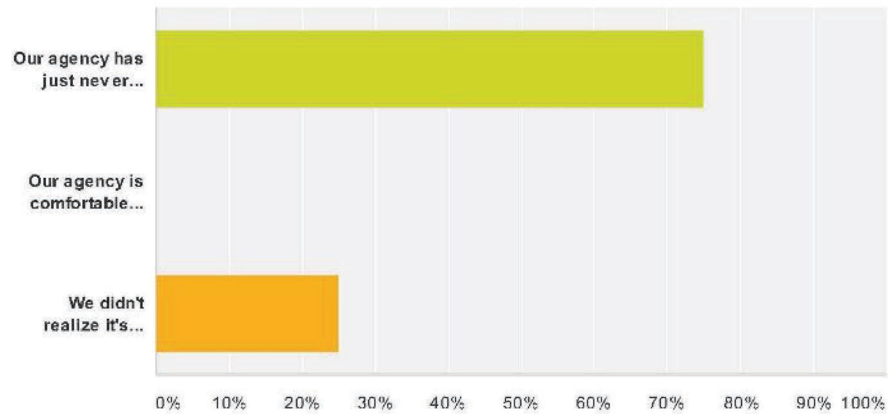


	None 1	2	Somewhat 3	4	Considerable 5	Total	Average Rating
(no label)	0.00% 0	4.55% 1	22.73% 5	36.36% 8	36.36% 8	22	4.05

Workshop 017: Cross-Asset Allocation

Q4 If there's little to no demand for cross-asset allocation, why do you think that's the case?

Answered: 4 Skipped: 18



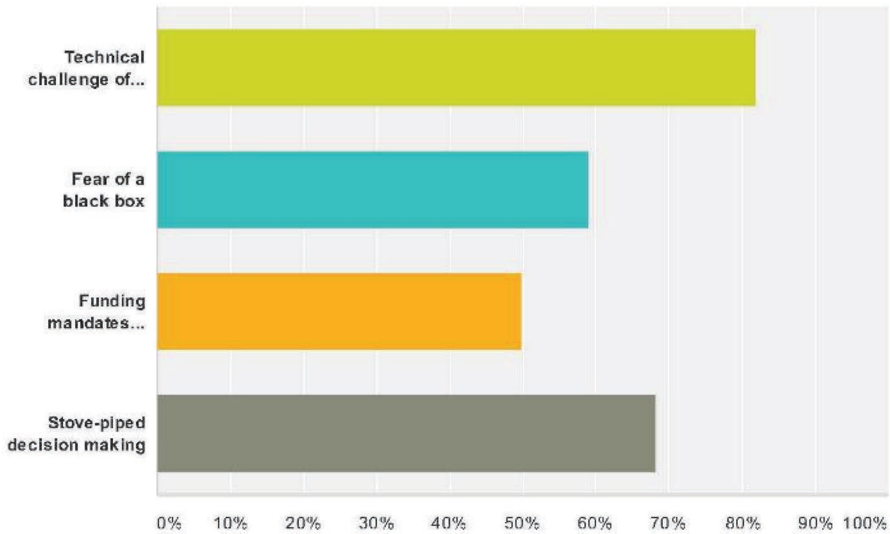
Answer Choices	Responses	
Our agency has just never considered it	75.00%	3
Our agency is comfortable with/confident in our current allocation process	0.00%	0
We didn't realize it's possible	25.00%	1
Total		4

#	Other (please specify)	Date
1	N/A	4/23/2014 2:55 PM
2	N/A - We have high demand at the system level, not the project level. We have no intention of trying to optimize investments between Bridge X and Pavement Segment Y. Instead, we use a goal-oriented, data-driven process to allocate total investment amounts between bridges and pavements (among other asset classes), then optimize within the asset class.	4/21/2014 10:37 AM

Workshop 017: Cross-Asset Allocation

Q5 What challenges or hurdles has your agency faced (or you imagine you might face) when it comes to cross-asset allocation? (check all that apply)

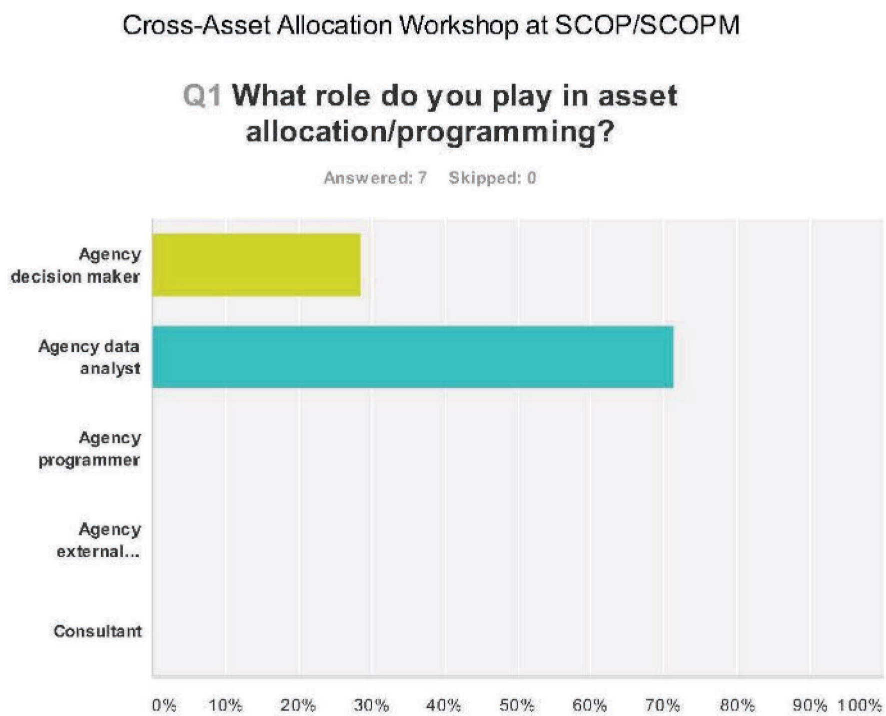
Answered: 22 Skipped: 0



Answer Choices	Responses	
Technical challenge of comparing data	81.82%	18
Fear of a black box	59.09%	13
Funding mandates (geographic requirements/modal allocation requirements/legislative mandates)	50.00%	11
Stove-piped decision making	68.18%	15
Total Respondents: 22		

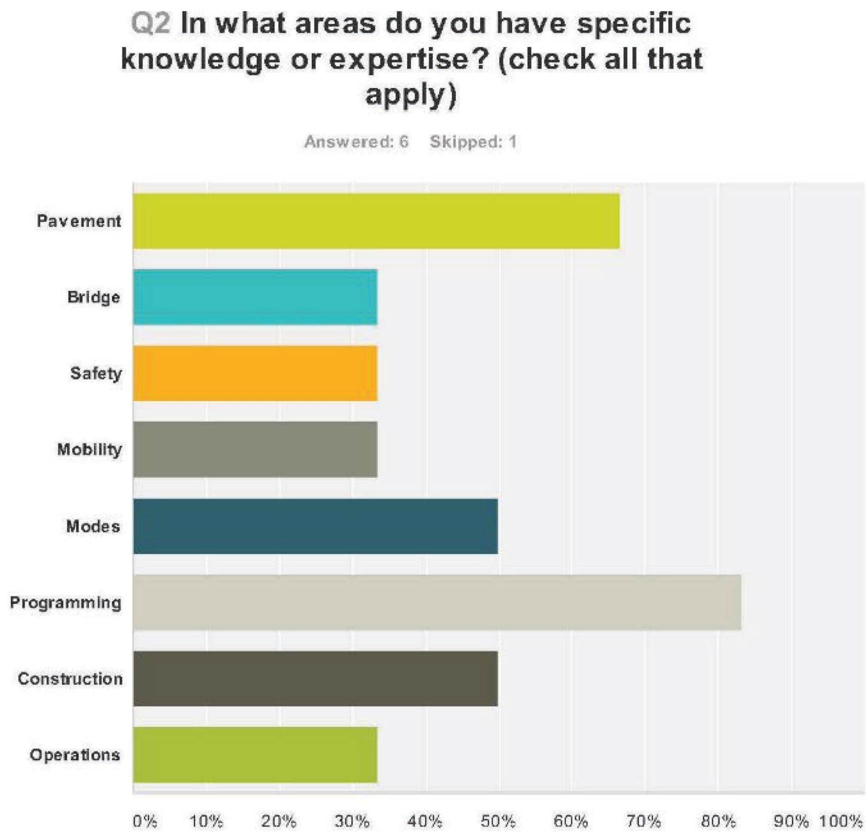
#	Other (please specify)	Date
1	Lack on understanding of how the trade-offs will be quantified.	4/23/2014 8:35 AM
2	Lack of comparable objectives	4/21/2014 3:23 PM
3	Developing meaningful performance measures	4/21/2014 11:29 AM
4	Shifting priorities necessary to meet customer (i.e. transportation system user) and other stakeholder demands.	4/21/2014 10:37 AM

AASHTO SCOP/SCOPM Conference Workshop



Answer Choices	Responses	
Agency decision maker	28.57%	2
Agency data analyst	71.43%	5
Agency programmer	0.00%	0
Agency external communications	0.00%	0
Consultant	0.00%	0
Total		7

Cross-Asset Allocation Workshop at SCOP/SCOPM

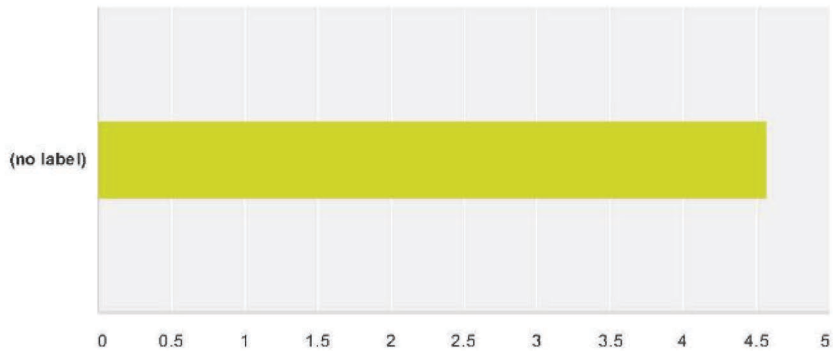


Answer Choices	Responses	
Pavement	66.67%	4
Bridge	33.33%	2
Safety	33.33%	2
Mobility	33.33%	2
Modes	50.00%	3
Programming	83.33%	5
Construction	50.00%	3
Operations	33.33%	2
Total Respondents: 6		

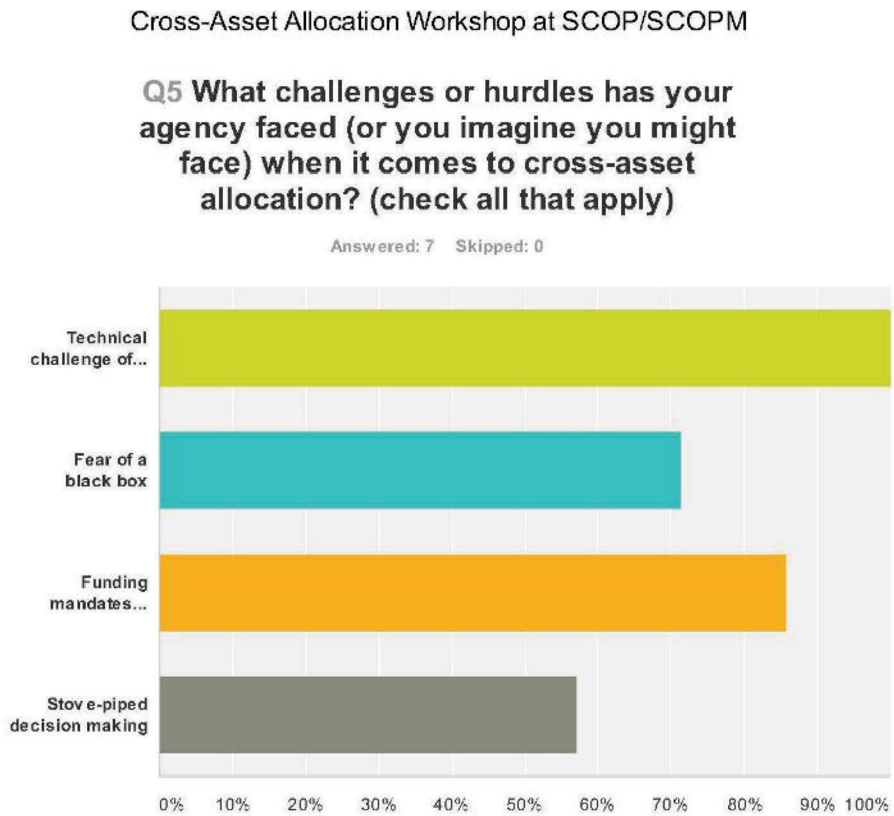
Cross-Asset Allocation Workshop at SCOP/SCOPM

Q3 Within your agency or client-base, to what extent is there demand for cross-asset allocation?

Answered: 7 Skipped: 0



	None 1	2	Somewhat 3	4	Considerable 5	Total	Average Rating
(no label)	0.00% 0	0.00% 0	0.00% 0	42.86% 3	57.14% 4	7	4.57

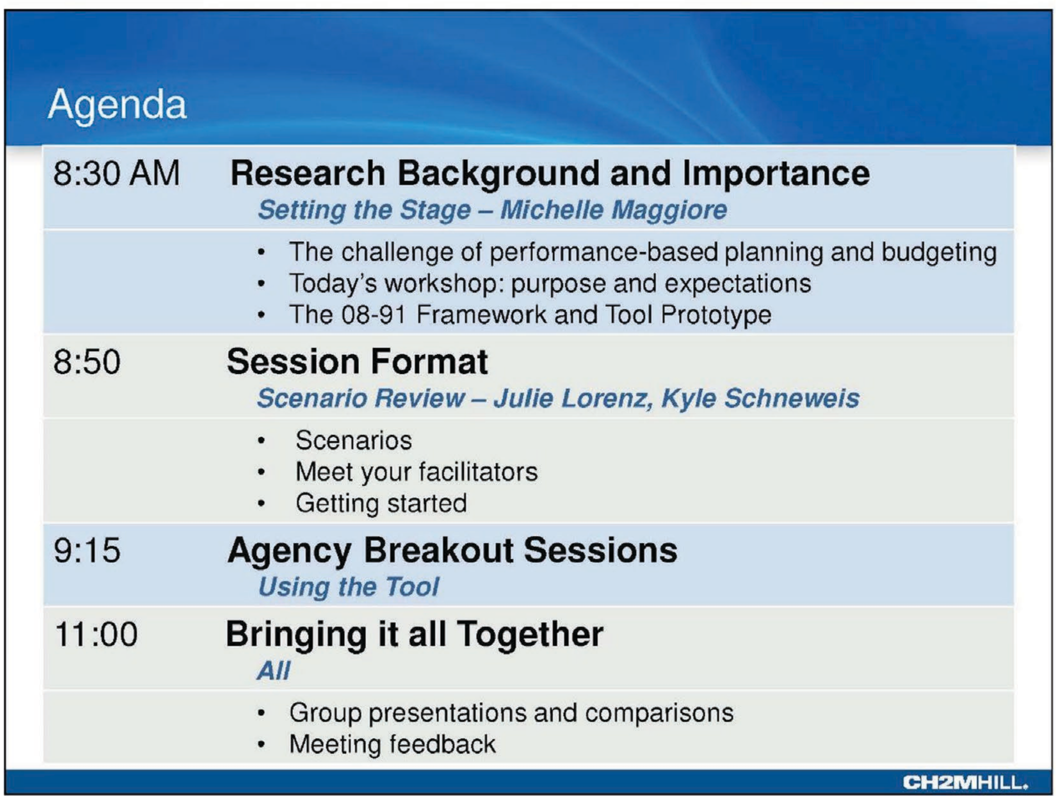


Answer Choices	Responses	
Technical challenge of comparing data	100.00%	7
Fear of a black box	71.43%	5
Funding mandates (geographic requirements/modal allocation requirements/legislative mandates)	85.71%	6
Stove-piped decision making	57.14%	4
Total Respondents: 7		

APPENDIX B

Workshop Materials


CH2MHILL.
Performance Management and Asset Management
NCHRP 08-91
Cross-Asset Resource Allocation and the Impact on System Performance
Workshop 017
April 28, 2014


Agenda
8:30 AM Research Background and Importance
Setting the Stage – Michelle Maggiore
• The challenge of performance-based planning and budgeting
• Today's workshop: purpose and expectations
• The 08-91 Framework and Tool Prototype
8:50 Session Format
Scenario Review – Julie Lorenz, Kyle Schneweis
• Scenarios
• Meet your facilitators
• Getting started
9:15 Agency Breakout Sessions
Using the Tool
11:00 Bringing it all Together
All
• Group presentations and comparisons
• Meeting feedback
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NCHRP 08-91 Background, Importance, and Framework

Michelle Maggiore, P.E.
CH2M HILL

Research Background

- Develop a performance-based cross-asset resource allocation framework
- Address gaps in practice relating to:
  - Setting targets and allocating resources based on performance measures and agency preferences
  - Lack of systematic and transferable tools/methods for optimizing resource allocation across assets

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What challenges does your agency face? (Survey)

- Considerable demand for cross-asset allocation, but little history
- At the same time, no respondents completely comfortable with current allocation process

Answer Choices	Responses	
Technical challenge of comparing data	81.82%	18
Fear of a black box	59.09%	13
Funding mandates (geographic requirements/modal allocation requirements/legislative mandates)	50.00%	11
Stove-piped decision making	68.18%	15
Total Respondents: 22		

#	Other (please specify)	Date
1	Lack on understanding of how the trade-offs will be quantified.	4/23/2014 8:35 AM
2	Lack of comparable objectives	4/21/2014 3:23 PM
3	Developing meaningful performance measures	4/21/2014 11:29 AM
4	Shifting priorities necessary to meet customer (i.e. transportation system user) and other stakeholder demands.	4/21/2014 10:37 AM

Today – Purpose and Expectations

- Share Research conducted to date
- Test the Tool Prototype
  - Does it support real-life investment considerations?
  - Could it be modified to better reflect agency needs?
  - Does it provide valuable information to quickly and easily communicate the impacts of budgeting on system performance?
- Have some fun
  - Interact as groups with a focus on the three questions listed above
  - Let us operate the Tool (we can teach you later)

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Framework

Goals and Objective Identification → Performance Metric Evaluation → Project Impact Assessment → Decision Science Application → Tradeoff Analysis

- Tool Prototype developed to employ 08-91 Framework:
  - Simple and consistent with good performance-based planning practice
  - Flexible for any agency goal or performance measure identified as important
  - Can be applied by analyzing/ pooling projects ("bottom up") or by comparing cost to performance curves ("top down")
  - Agency must collect the data to measure performance and assess the impacts of the projects on network performance

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Framework

Goals and Objective Identification → Performance Metric Evaluation → Project Impact Assessment → Decision Science Application → Tradeoff Analysis

"You've got to have a goal in mind, or you will never have the opportunity to claim it."

- Today's case study format will establish a strategic direction for the Tool Prototype demo
- In practice, an inclusive goal development will improve "buy in"
- Goals will include national and state priorities

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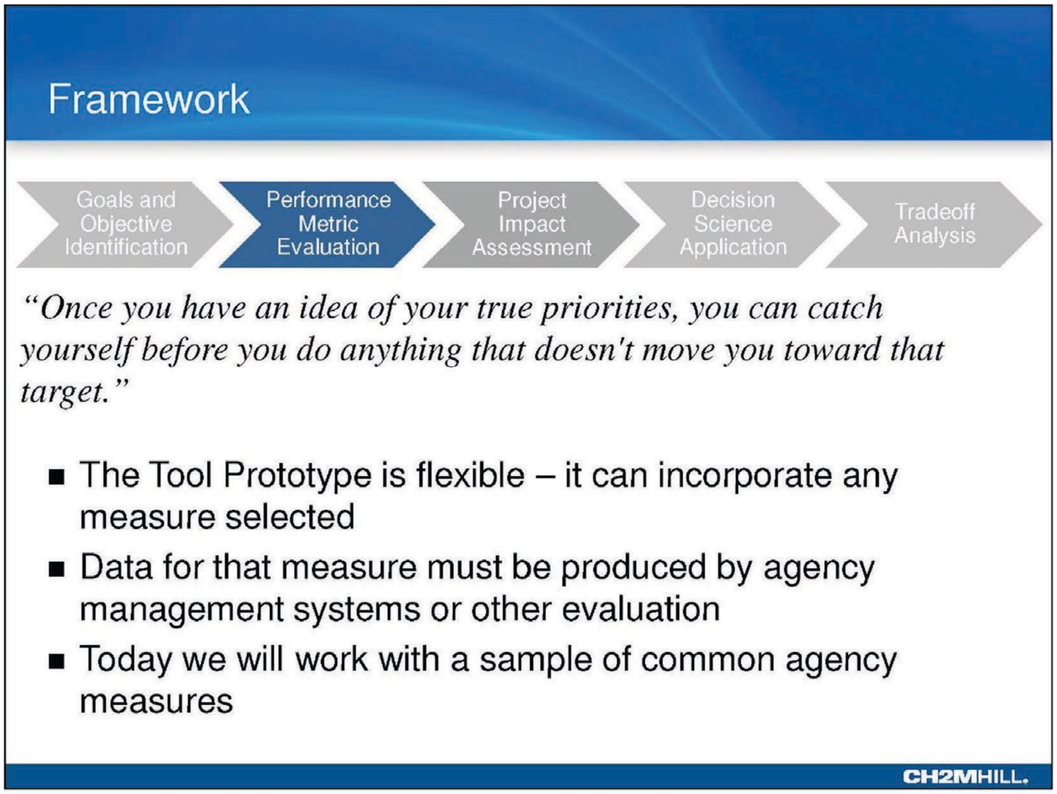
Framework
Goals and Objective Identification
Performance Metric Evaluation
Project Impact Assessment
Decision Science Application
Tradeoff Analysis
"Once you have an idea of your true priorities, you can catch yourself before you do anything that doesn't move you toward that target."
■ The Tool Prototype is flexible – it can incorporate any measure selected
■ Data for that measure must be produced by agency management systems or other evaluation
■ Today we will work with a sample of common agency measures
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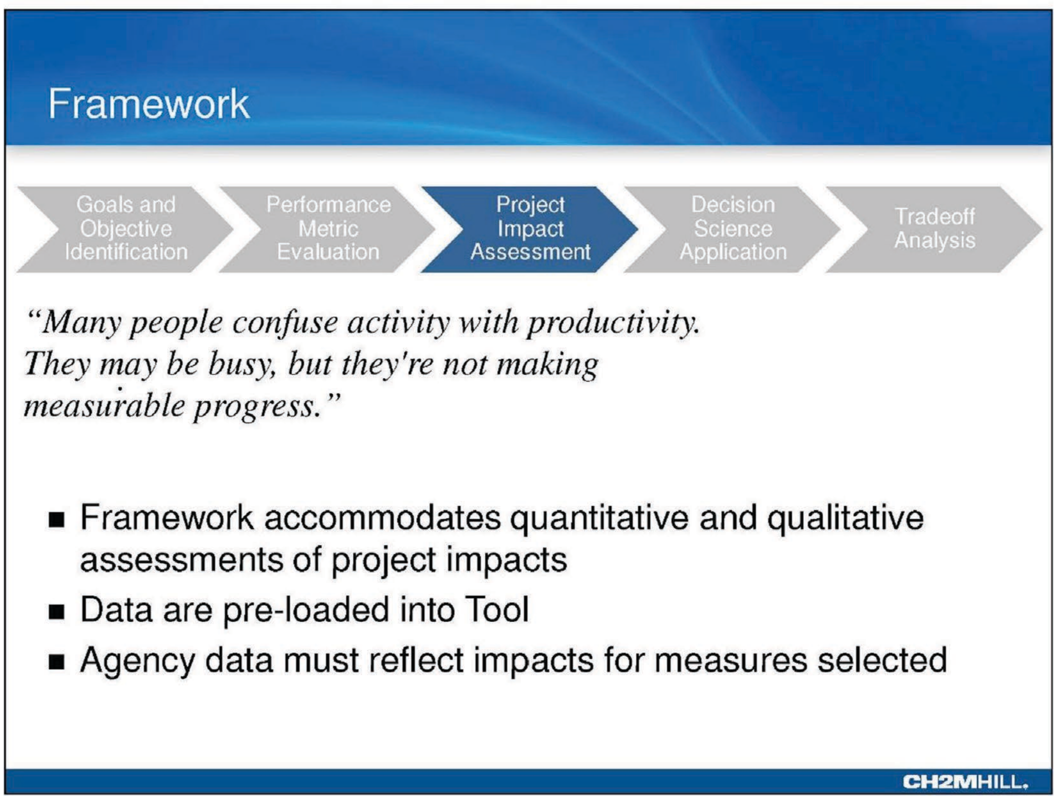
Framework
Goals and Objective Identification
Performance Metric Evaluation
Project Impact Assessment
Decision Science Application
Tradeoff Analysis
"Many people confuse activity with productivity. They may be busy, but they're not making measurable progress."
■ Framework accommodates quantitative and qualitative assessments of project impacts
■ Data are pre-loaded into Tool
■ Agency data must reflect impacts for measures selected
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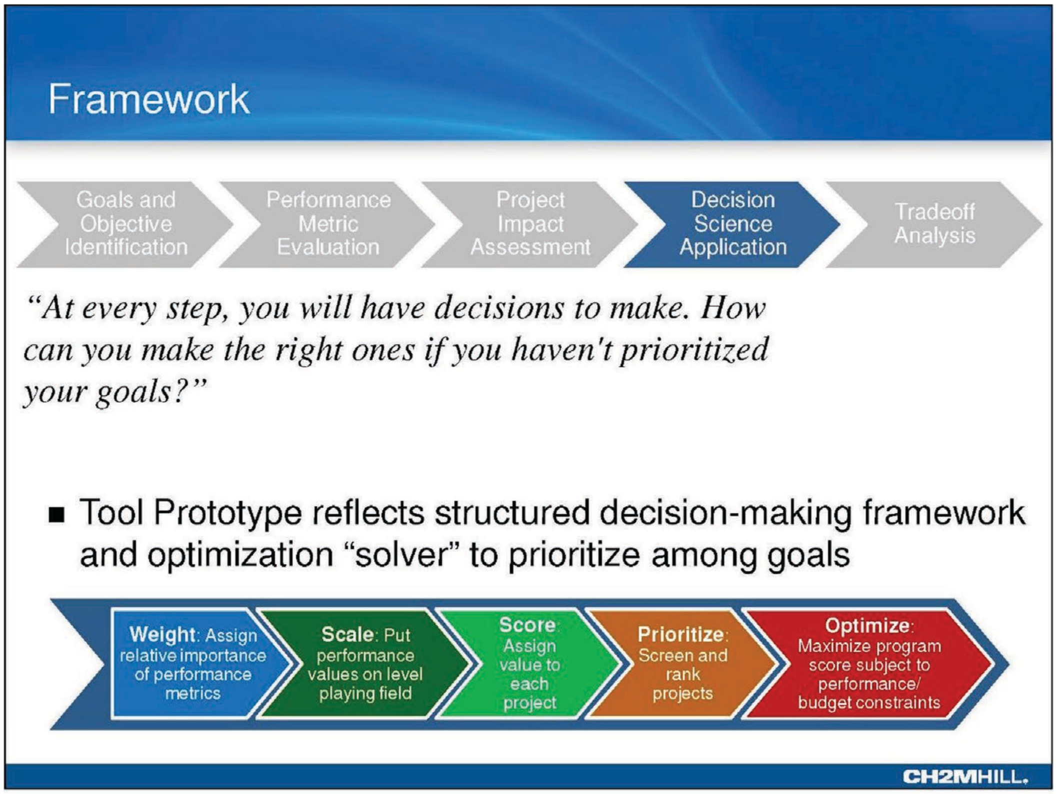
Framework
Goals and Objective Identification
Performance Metric Evaluation
Project Impact Assessment
Decision Science Application
Tradeoff Analysis
"At every step, you will have decisions to make. How can you make the right ones if you haven't prioritized your goals?"
Tool Prototype reflects structured decision-making framework and optimization "solver" to prioritize among goals
Weight: Assign relative importance of performance metrics
Scale: Put performance values on level playing field
Score: Assign value to each project
Prioritize: Screen and rank projects
Optimize: Maximize program score subject to performance/ budget constraints
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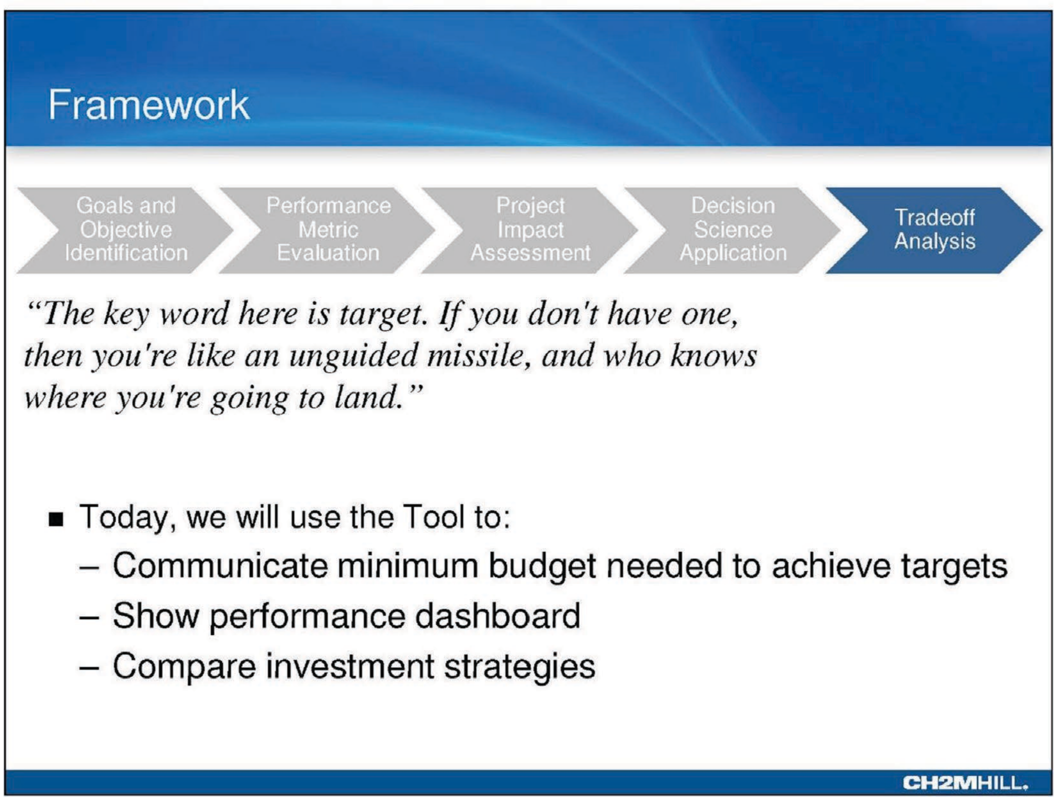
Framework
Goals and Objective Identification
Performance Metric Evaluation
Project Impact Assessment
Decision Science Application
Tradeoff Analysis
"The key word here is target. If you don't have one, then you're like an unguided missile, and who knows where you're going to land."
Today, we will use the Tool to:
– Communicate minimum budget needed to achieve targets
– Show performance dashboard
– Compare investment strategies
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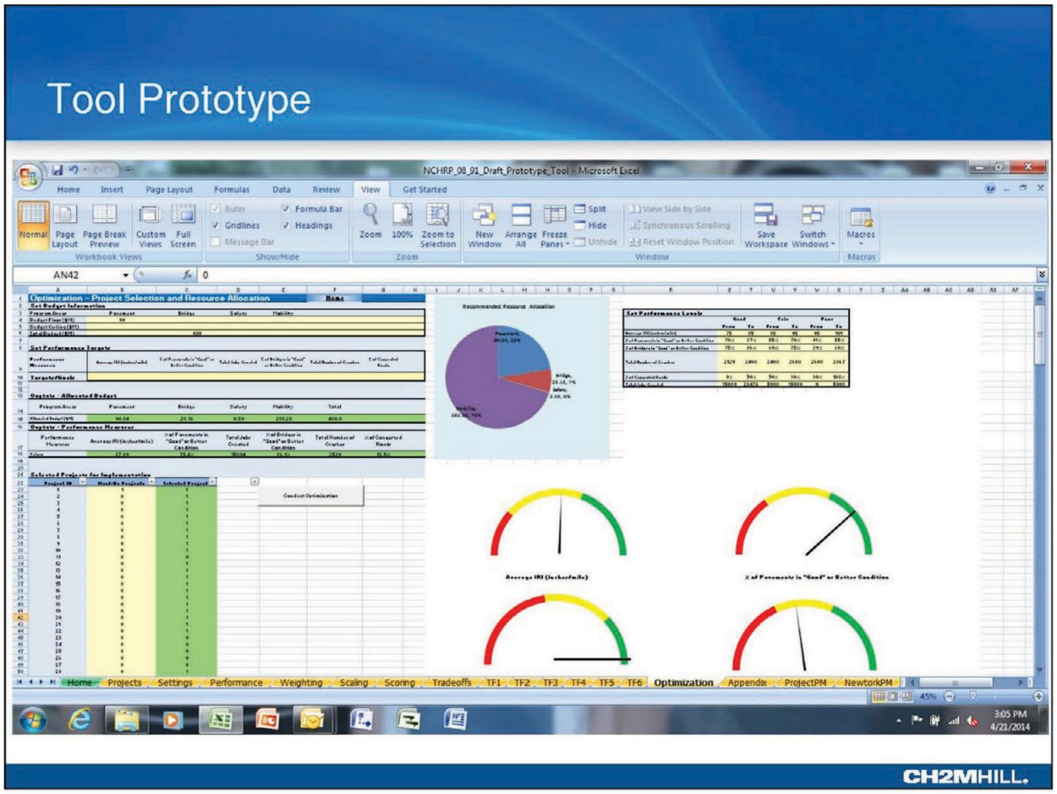
Tool Prototype
NCHRP_08_91_Draft_Prototype_Tool - Microsoft Excel
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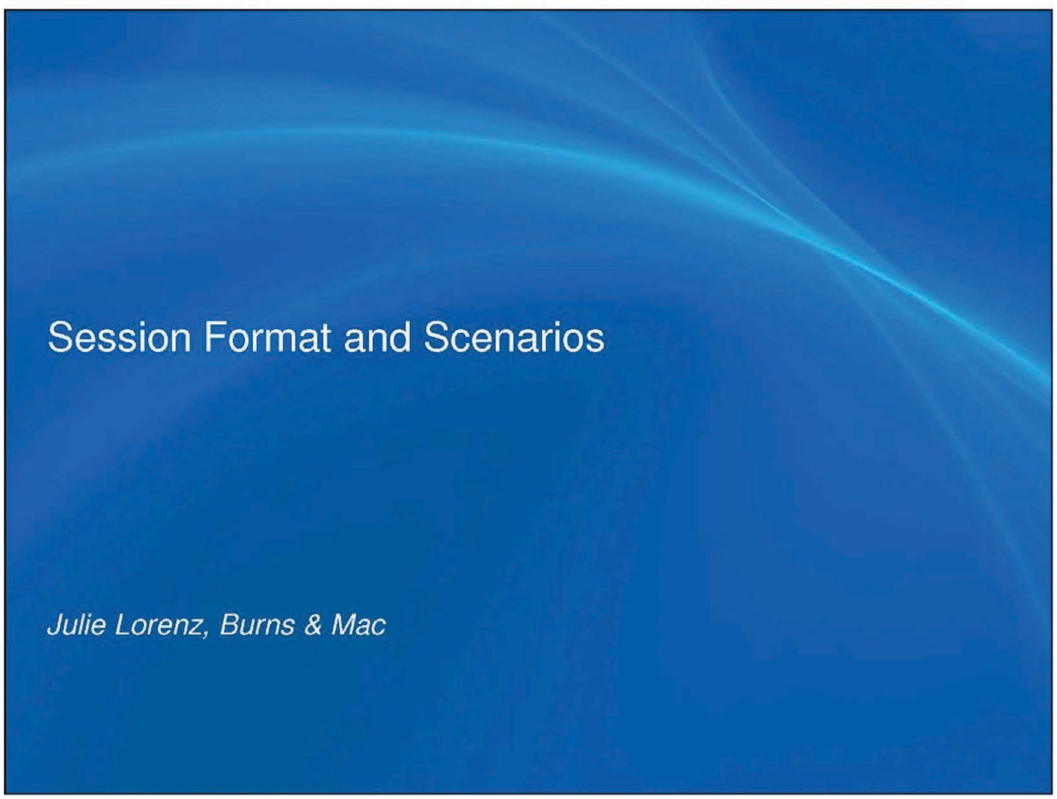
Session Format and Scenarios
Julie Lorenz, Burns & Mac

Today's Workshop

- Scenarios provide context for goals and target setting
- Groups work through four activities and record results

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Scenario 1

- **An agency in "preservation mode."** In trying to hold it all together, what mobility sacrifices must be made?

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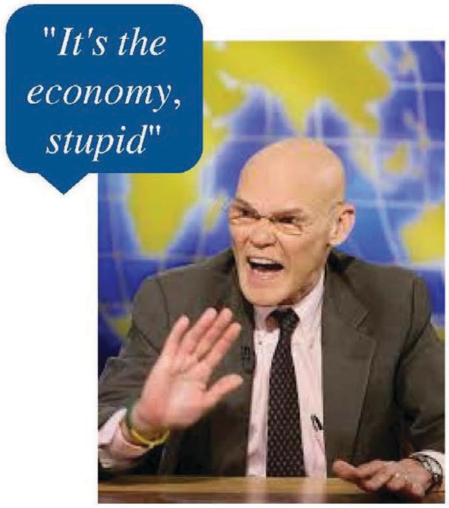
Scenario 2



- **A state committed to job creation.** How can the agency's capital program support economic development while maintaining asset condition and safety goals?

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Scenario 3

- **Untangling a confused legislature**. The agency must continue to prioritize mobility because of restrictions on its capital program while trying to meet internal state-of-good-repair goals.

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Agency Discussion

- Introduce group facilitators
- Discuss scenario and roles:
  - How does your scenario compare / contrast w your agency?
  - Who will be your Chief Engineer?
  - Who will present your work to the larger group?
  - Identify immediate questions to be answered

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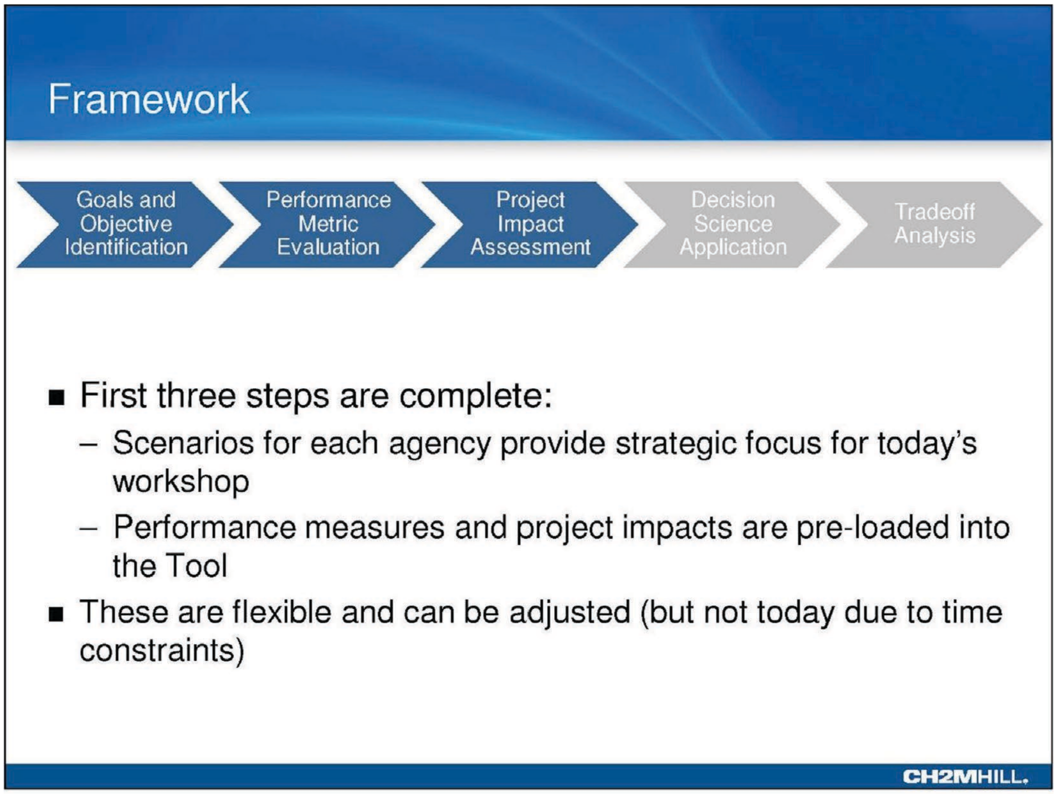
Let's Get to Work

Kyle Schneweis, High Street Consulting


Framework
Goals and Objective Identification
Performance Metric Evaluation
Project Impact Assessment
Decision Science Application
Tradeoff Analysis
First three steps are complete:
– Scenarios for each agency provide strategic focus for today's workshop
– Performance measures and project impacts are pre-loaded into the Tool
These are flexible and can be adjusted (but not today due to time constraints)
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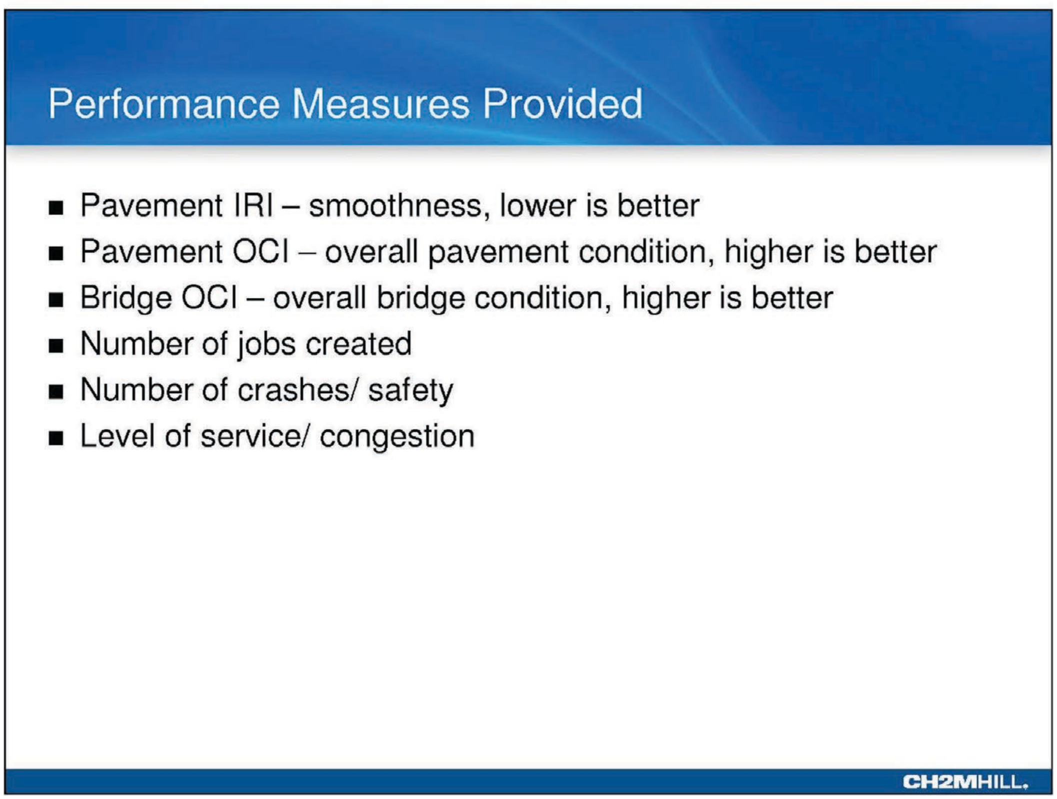
Performance Measures Provided
Pavement IRI – smoothness, lower is better
Pavement OCI – overall pavement condition, higher is better
Bridge OCI – overall bridge condition, higher is better
Number of jobs created
Number of crashes/ safety
Level of service/ congestion
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Framework

- Your focus for today:
  - Activity 1: Weighting all performance measures
  - Activity 2: Define targets
  - Activity 3: Optimizing your program
  - Activity 4: Get to know the Tool

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Tool Introduction

- Facilitators share Tool Tabs (to be used today)
  - Home Screen
  - Project Inputs
  - Performance Measures – inputs and selection
  - Weighting
  - Tradeoffs

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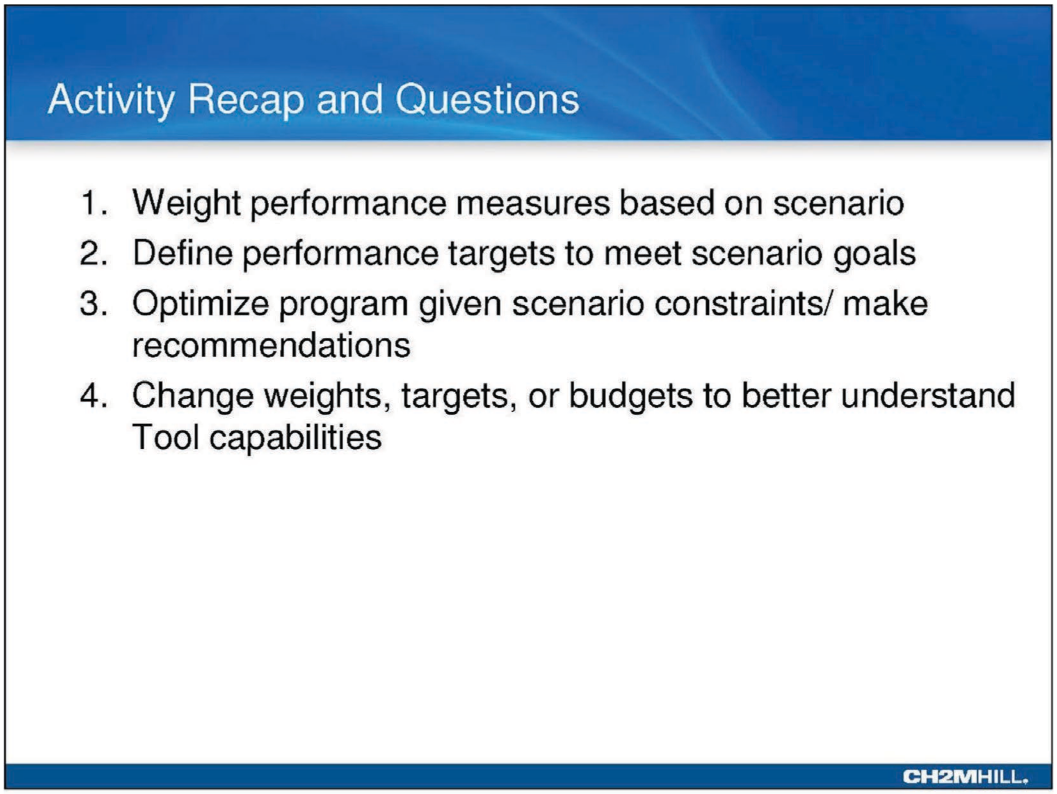
Activity Recap and Questions
1. Weight performance measures based on scenario
2. Define performance targets to meet scenario goals
3. Optimize program given scenario constraints/ make recommendations
4. Change weights, targets, or budgets to better understand Tool capabilities
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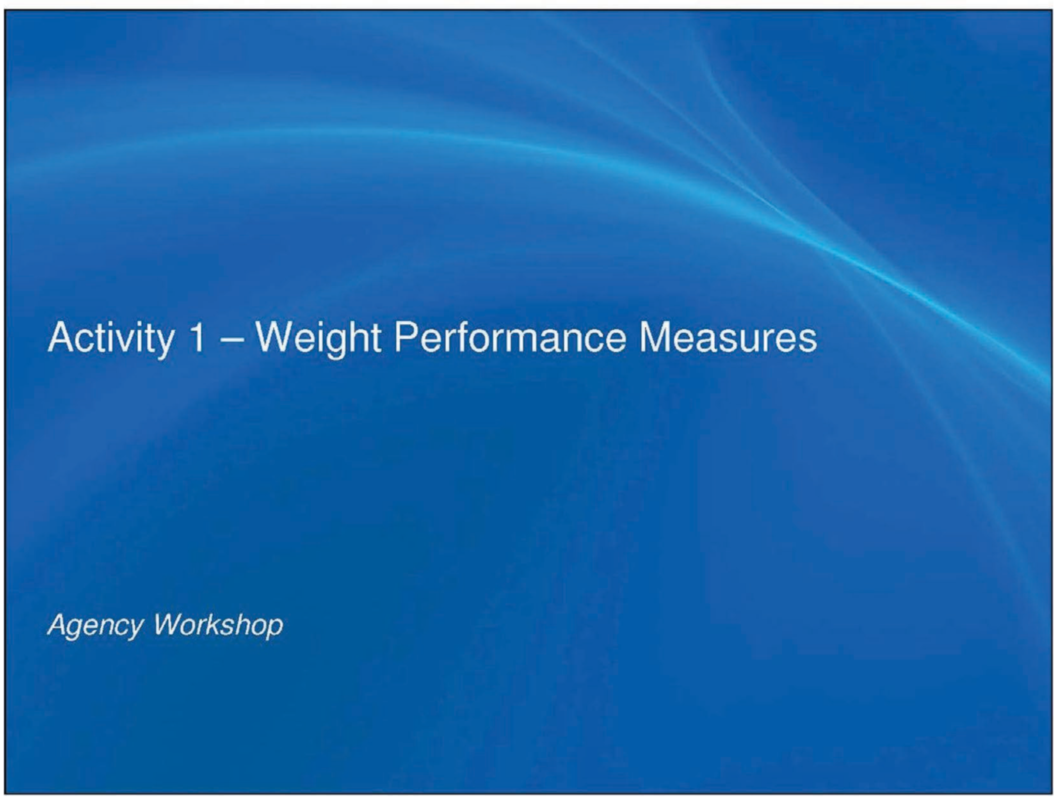
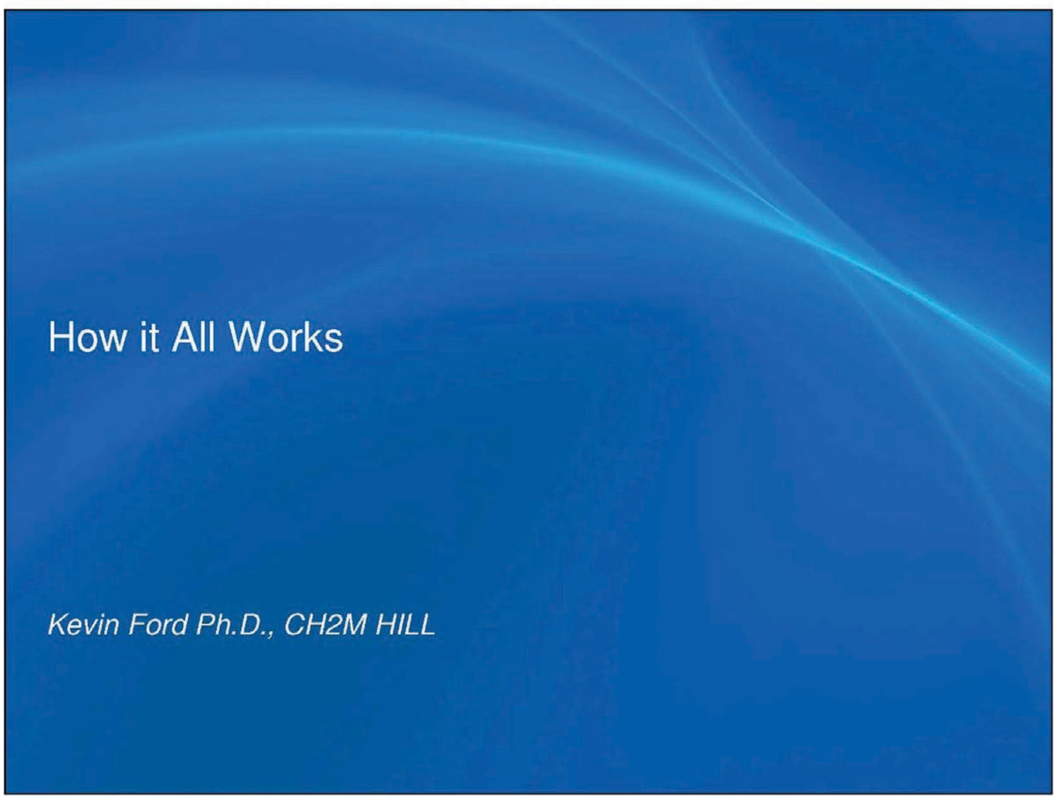
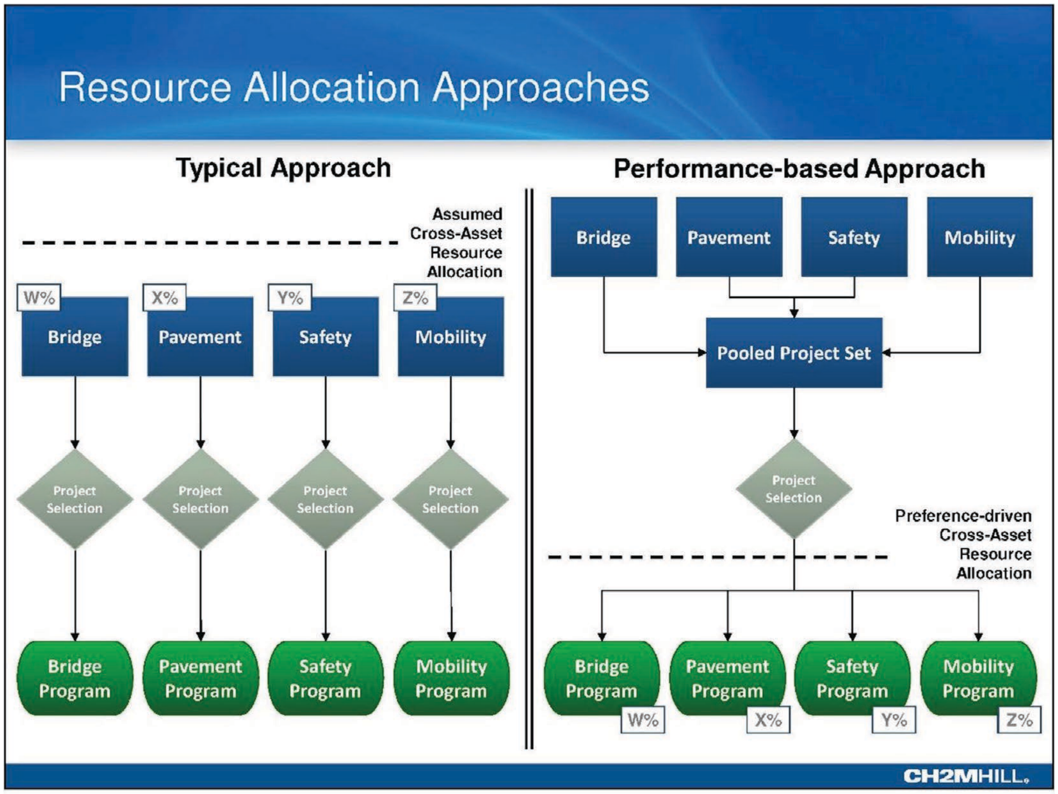

Activity 1 – Weight Performance Measures
Agency Workshop


Activity 2 – Set Targets
Agency Workshop


How it All Works
Kevin Ford Ph.D., CH2M HILL


Resource Allocation Approaches
Typical Approach
Assumed Cross-Asset Resource Allocation
W%
X%
Y%
Z%
Bridge
Pavement
Safety
Mobility
Project Selection
Bridge Program
Pavement Program
Safety Program
Mobility Program
Performance-based Approach
Bridge
Pavement
Safety
Mobility
Pooled Project Set
Project Selection
Preference-driven Cross-Asset Resource Allocation
Bridge Program
Pavement Program
Safety Program
Mobility Program
W%
X%
Y%
Z%
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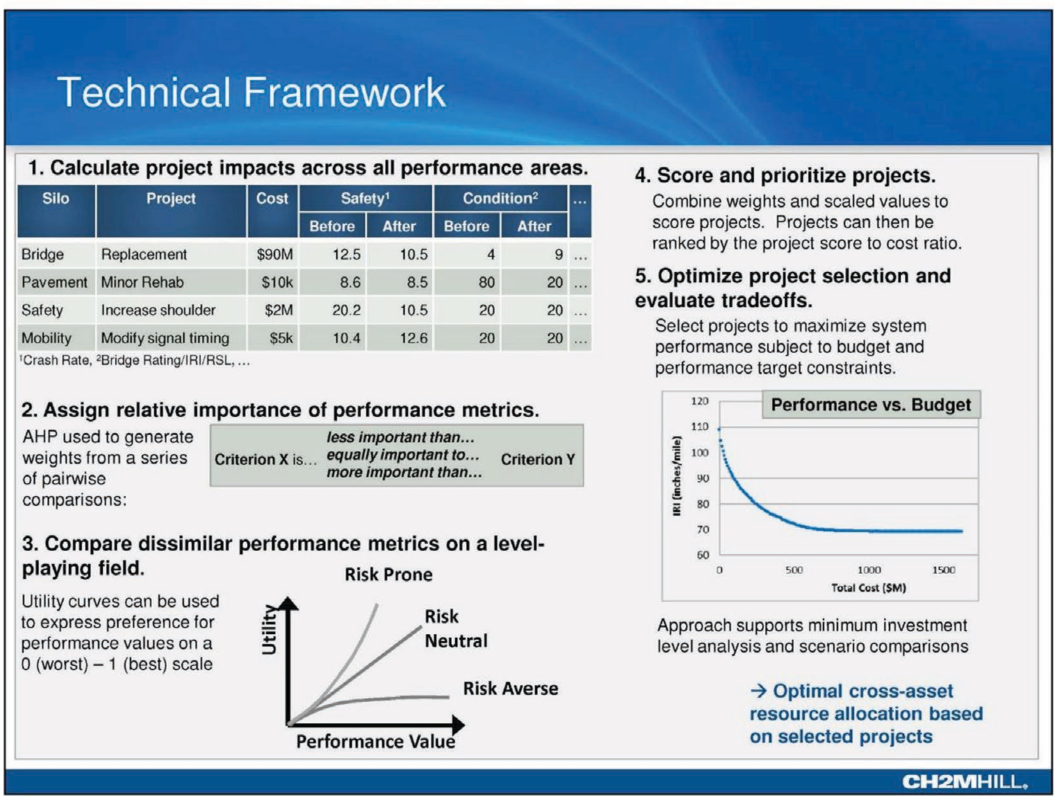
Technical Framework
1. Calculate project impacts across all performance areas.

Silo	Project	Cost	Safety[1] Before	Safety[1] After	Condition[2] Before	Condition[2] After	…
Bridge	Replacement	$90M	12.5	10.5	4	9	…
Pavement	Minor Rehab	$10k	8.6	8.5	80	20	…
Safety	Increase shoulder	$2M	20.2	10.5	20	20	…
Mobility	Modify signal timing	$5k	10.4	12.6	20	20	…

[1]Crash Rate, [2]Bridge Rating/IRI/RSL, …
2. Assign relative importance of performance metrics.
AHP used to generate weights from a series of pairwise comparisons:
Criterion X is… less important than… equally important to… more important than… Criterion Y
3. Compare dissimilar performance metrics on a level-playing field.
Utility curves can be used to express preference for performance values on a 0 (worst) – 1 (best) scale
Risk Prone
Risk Neutral
Risk Averse
Utility
Performance Value
4. Score and prioritize projects.
Combine weights and scaled values to score projects. Projects can then be ranked by the project score to cost ratio.
5. Optimize project selection and evaluate tradeoffs.
Select projects to maximize system performance subject to budget and performance target constraints.
Performance vs. Budget
IRI (inches/mile)
120
110
100
90
80
70
60
0
500
1000
1500
Total Cost ($M)
Approach supports minimum investment level analysis and scenario comparisons
→ Optimal cross-asset resource allocation based on selected projects
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"Bottom-up" vs. "Top-down" Optimization

- Allocation approach depends on data availability and tradeoff curves
- In either approach preferences can be incorporated with slight distinctions in the optimization problem

Maximize: Program Score
Subject to: Financial Constraints and/or Performance Targets
By changing: Allocation Percentages ("Top-down")

By changing ↓

Silo	Project ID	Project Score	Project Cost	Program?
Bridge	1	**80**	$2.5 M	**Yes**
Pavement	2	85	$4.0 M	No
Mobility	3	**75**	$2.0 M	**Yes**
Safety	4	50	$0.1 M	No
Total	Maximize →	**155**	**$4.5 M** ←	Subject to X budget

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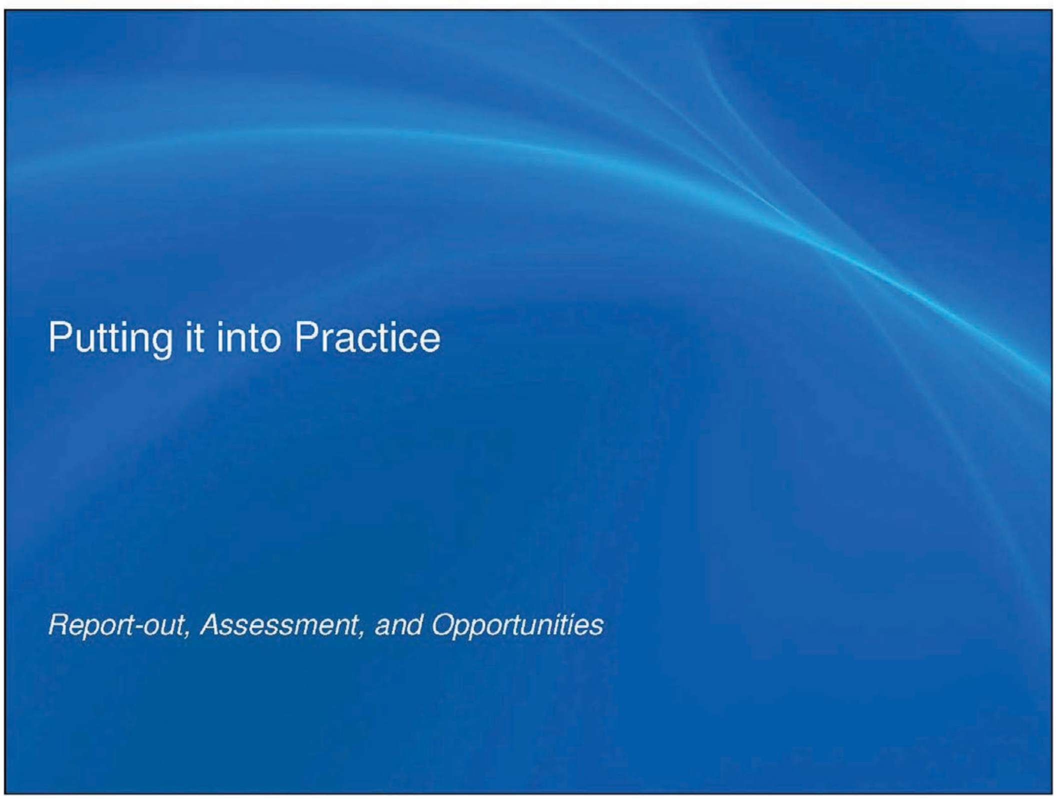
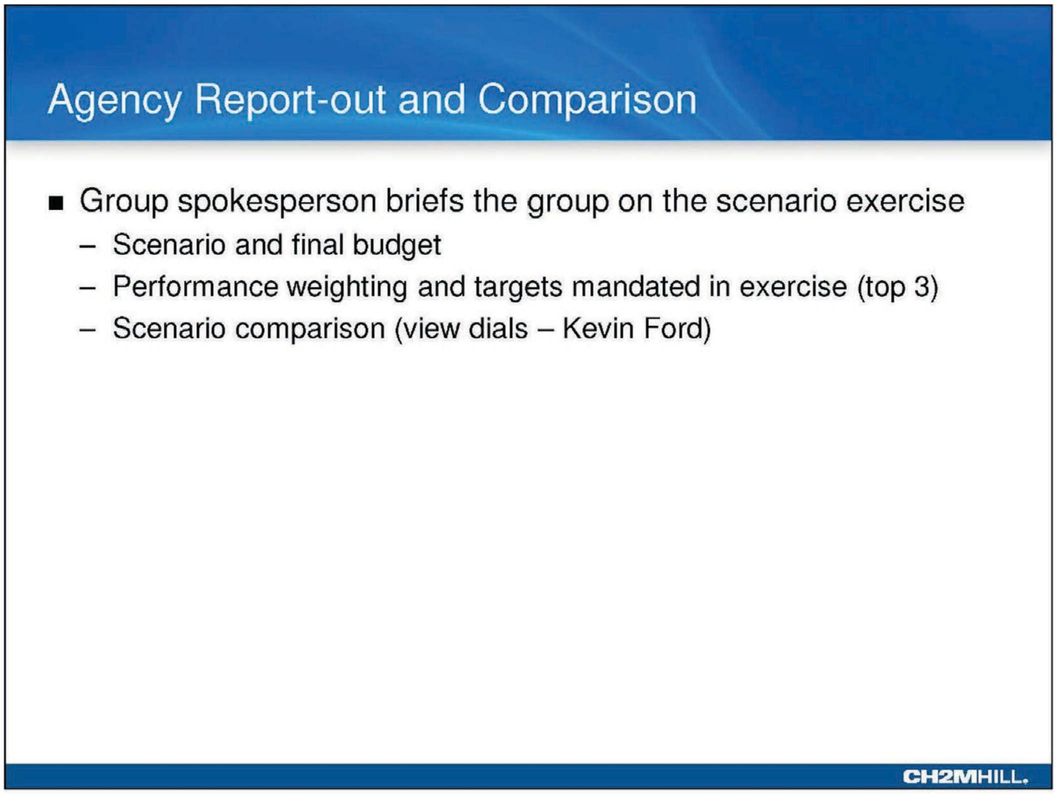
Activity 3 – Optimize Program

Agency Workshop


Activity 4 – Get to know the Tool


Putting it into Practice
Report-out, Assessment, and Opportunities


Agency Report-out and Comparison
Group spokesperson briefs the group on the scenario exercise
– Scenario and final budget
– Performance weighting and targets mandated in exercise (top 3)
– Scenario comparison (view dials – Kevin Ford)
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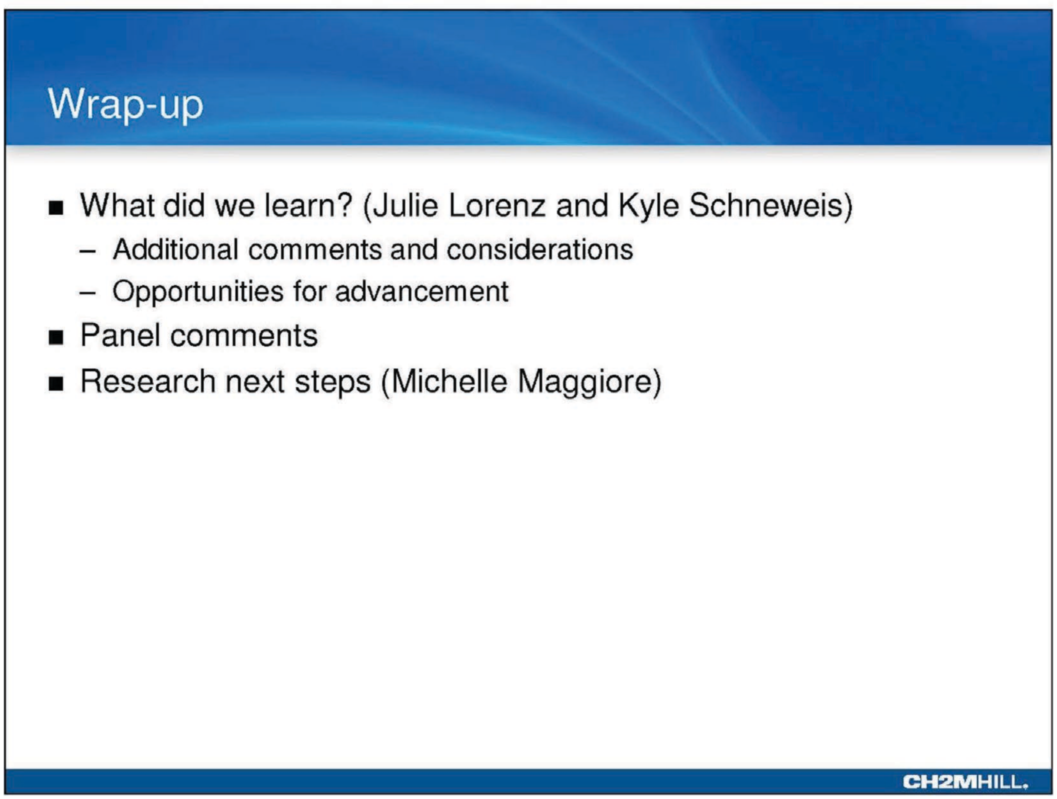
Wrap-up
What did we learn? (Julie Lorenz and Kyle Schneweis)
– Additional comments and considerations
– Opportunities for advancement
Panel comments
Research next steps (Michelle Maggiore)
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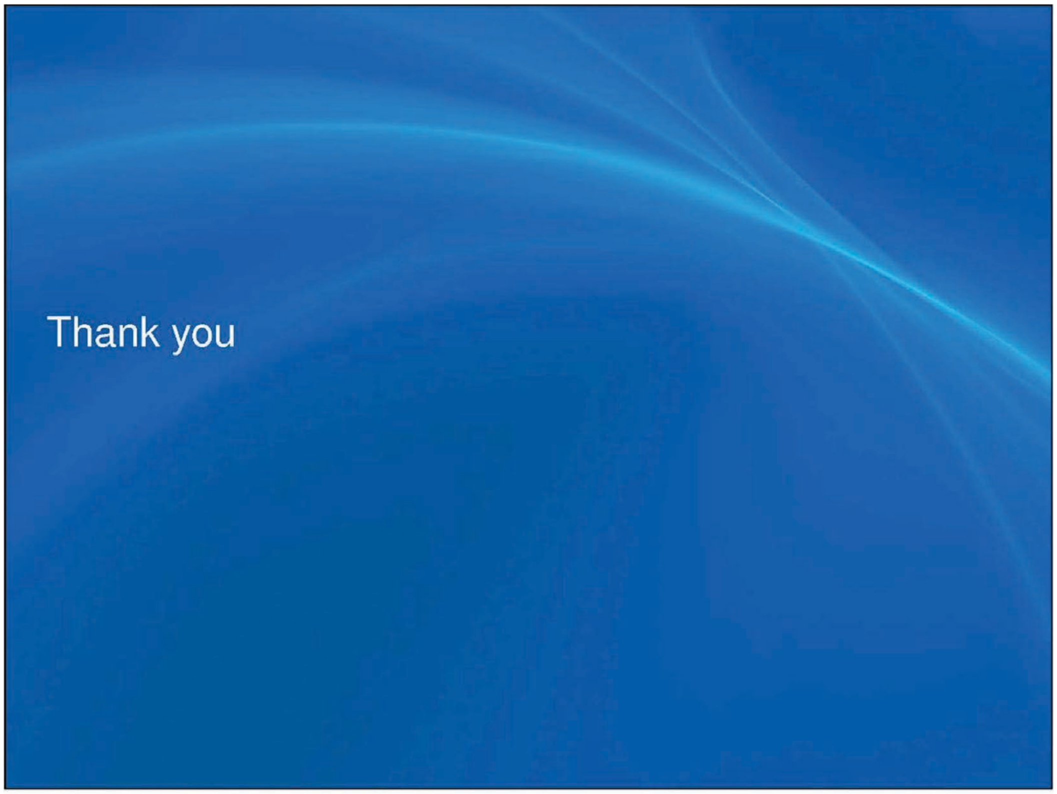
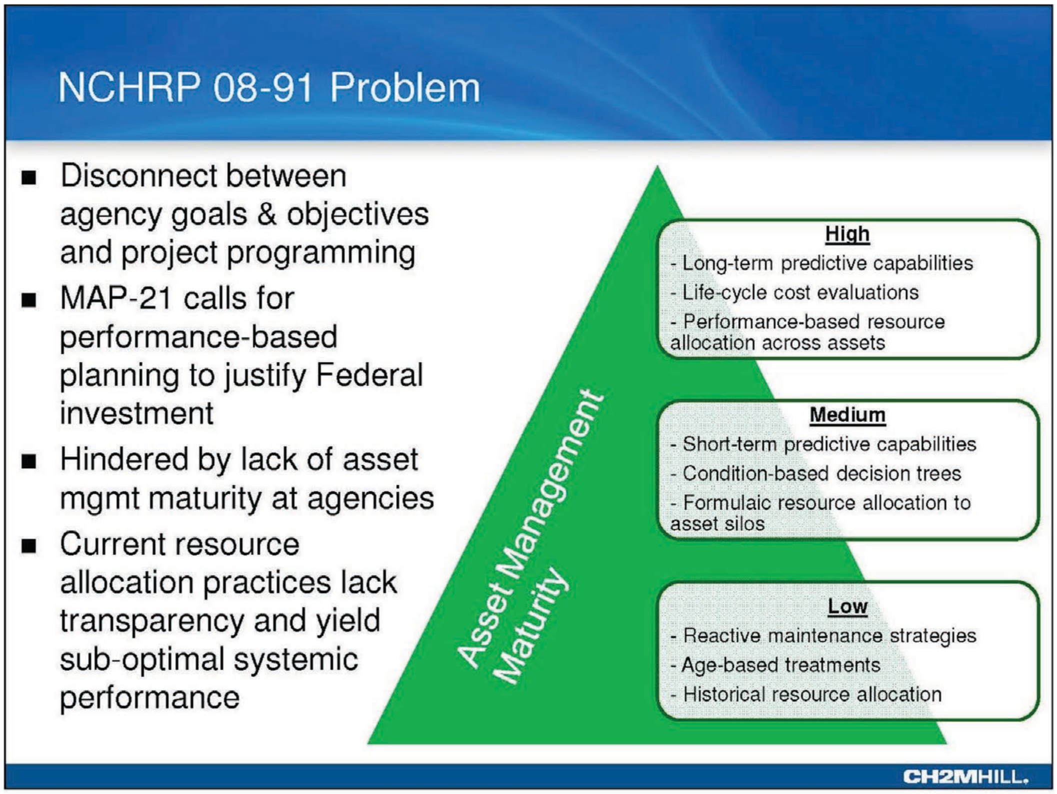

Thank you


NCHRP 08-91 Problem
Disconnect between agency goals & objectives and project programming
MAP-21 calls for performance-based planning to justify Federal investment
Hindered by lack of asset mgmt maturity at agencies
Current resource allocation practices lack transparency and yield sub-optimal systemic performance
Asset Management Maturity
High
- Long-term predictive capabilities
- Life-cycle cost evaluations
- Performance-based resource allocation across assets
Medium
- Short-term predictive capabilities
- Condition-based decision trees
- Formulaic resource allocation to asset silos
Low
- Reactive maintenance strategies
- Age-based treatments
- Historical resource allocation
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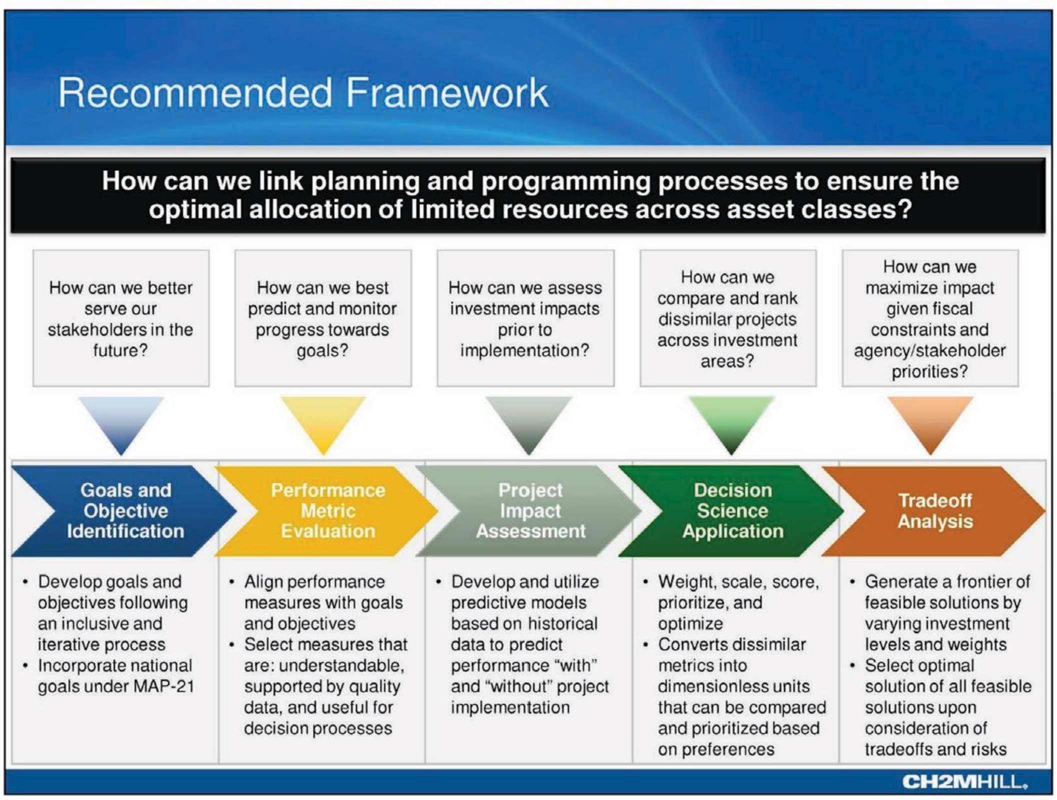
Recommended Framework
How can we link planning and programming processes to ensure the optimal allocation of limited resources across asset classes?
How can we better serve our stakeholders in the future?
How can we best predict and monitor progress towards goals?
How can we assess investment impacts prior to implementation?
How can we compare and rank dissimilar projects across investment areas?
How can we maximize impact given fiscal constraints and agency/stakeholder priorities?
Goals and Objective Identification
Performance Metric Evaluation
Project Impact Assessment
Decision Science Application
Tradeoff Analysis
• Develop goals and objectives following an inclusive and iterative process
• Incorporate national goals under MAP-21
• Align performance measures with goals and objectives
• Select measures that are: understandable, supported by quality data, and useful for decision processes
• Develop and utilize predictive models based on historical data to predict performance "with" and "without" project implementation
• Weight, scale, score, prioritize, and optimize
• Converts dissimilar metrics into dimensionless units that can be compared and prioritized based on preferences
• Generate a frontier of feasible solutions by varying investment levels and weights
• Select optimal solution of all feasible solutions upon consideration of tradeoffs and risks
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APPENDIX C

Scenario Handouts

These materials were used at the April 28, 2014, workshop in Miami, Florida, as part of the TRB 10th National Conference on Transportation Asset Management.

All subsequent workshops used a variation of these materials.

Workshop: 017 Cross-Asset Allocation (NCHRP Project 08-91)

Monday, April 28, 2014, 8:30 a.m. – Noon

Hello and welcome. You are here today to bring the NCHRP Project 08-91 cross-asset resource allocation framework to life. You have been assigned to a team that will operate as a transportation agency. You will navigate through a case study that is designed to simulate a real-world decision environment and arrive at a recommended allocation strategy given the priorities of your agency and the demands placed upon it. Your active and thoughtful participation is requested to make this experience both fun and worthwhile. Let's get to work!

Scenario #1: Preservation Mode

Inspired to improve her city within your agency's district—and hopefully for the benefit of others as well—Mayor Florida contacted your transportation secretary and convinced her to make system preservation the number one transportation priority for the state and your district. Following this discussion and the setting of a strategic preservation goal for the state, the transportation secretary is requesting your agency's help to determine how best to allocate your district's $400 M budget to achieve a state of good repair for highway and bridge assets while addressing performance requirements across the remaining transportation priorities.

Your job – Develop a $400 M program to get to a state of good repair without getting stuck in traffic

Scenario #1: An Agency in Preservation Mode

Inspired to improve her city within your agency's district—and hopefully for the benefit of others as well—Mayor Florida contacted your transportation secretary and convinced her to make system preservation the number one transportation priority for the state and your district. Following this discussion and the setting of a strategic preservation goal for the state, the transportation secretary is requesting your agency's help to determine how best to allocate your district's $400 M budget to achieve a state of good repair for highway and bridge assets while addressing performance requirements across the remaining transportation priorities.

Activity 1 –Performance Measures and Weighting

1a. Weighting

- (Participants). Review the pair-wise comparison exercise in the supplemental worksheet to understand the weighting process. Record preferred weights on individual worksheets.
- (Participants). As a group, complete the weighting exercise for each performance measure. Measures have been provided based on a sample data set obtained from the Utah DOT. These are examples of common measures only and do not reflect all the measures that the tool can incorporate.

1b. Weighting Override

After you presented your weights to your transportation secretary, she has provided the following guidance for your weights (Table 1). Your district must use these weights to complete the exercise [Expert Override]. The weights of the group can be further explored in Activity 4.

Table 1. Required performance measures and weights.

Performance Measure	Weight
Pavement IRI	15%
Pavement OCI	15%
Number of Jobs Created	5%
Bridge OCI	45%
Number of Crashes	15%
Level of Service	5%
TOTAL	100%

Note: IRI = international roughness index; OCI = overall condition index.

Activity 2 – Target Setting/Unconstrained Needs

2a. Set Targets – TF4

The agency must address preservation as its priority. What targets are optimal?

- (Participants). Discuss and record targets for each performance measure in Table 2

Table 2. Proposed targets.

Performance Measure	Target
Average IRI	
% Pavements in "Good" or Better Condition	
Total Jobs Created	
% Bridges in "Good" or Better Condition	
Total Number of Crashes	
% of Congested Roads	

Note: IRI of 80 and 85% for pavement/bridge percentages are "good" for this data set. Additionally, for the data set provided, 15,000 jobs, 2,200 crashes, and 10% congested roads represent near optimal conditions.

2b. Develop Unconstrained Needs – TF4

- How much would it cost to achieve your targets listed in Table 2? ____________
- Would it be valuable to know the total costs required to achieve LOWER targets? Record reduced targets in Table 3.
- Use TF4 to input lower target values from Table 3 and record total cost: ____________

Table 3. Reduced targets.

Performance Measure	REDUCED Target
Average IRI	
% Pavements in "Good" or Better Condition	
Total Jobs Created	
% Bridges in "Good" or Better Condition	
Total Number of Crashes	
% of Congested Roads	

The mayor and secretary are on the same page; however, the legislature has also established performance targets (Table 4) for use in prioritizing projects. These have been mandated.

- Determine and record the unconstrained cost of meeting these mandated targets across all performance areas: ____________
- Use these targets for the remainder of the exercise

Table 4. Mandated performance targets.

Performance Measure	Target
Average IRI	80
% Pavements in "Good" or Better Condition	85%
Total Jobs Created	15000
% Bridges in "Good" or Better Condition	85%
Total Number of Crashes	2200
% of Congested Roads	10%

Activity 3 – Constrained Program Optimization

In this exercise, the group will develop an optimal program based on the mandated performance targets. Additional targets can be tested in Activity 4.

Given the mandated performance targets, answer the following questions and record your results:

- Can 85% good or better condition be achieved for pavement and bridge assets with a total budget of $400 M? ____________
- Is the $400 M budget sufficient to achieve 85% good or better condition for bridge and pavement assets and ensure that total crashes do not exceed 2,200? ____________
- Is the $400 M budget sufficient to achieve 85% good or better condition for bridge and pavement assets and ensure that the percentage of congested roadways does not exceed 20% after removing the crash constraint? ____________
- As a gesture of good will, your agency decides to perhaps endorse implementation of the governor's signature expansion project. If the $400 M budget is maintained, can a pavement average of 80 IRI and 85% of bridge assets in good or better condition be achieved if a portion of the budget is earmarked for the $32 M expansion project (#280)? ____________(You might want to try both with and without the 20% congestion constraint.)

Given your analysis, what would your agency's recommended budget and outcomes look like and/or what total budget would you request? (Choose your preferred allocation and performance outcomes to share with the group during report-out.)

Outputs - Allocated Budget						
Program Areas	Pavement	Bridge	Safety	Mobility	Total	
Allocated Budget ($M)						
Outputs - Performance Measures						
Performance Measures	Average IRI (inches/mile)	% of Pavements in "Good" or Better Condition	Total Jobs Created	% of Bridges in "Good" or Better Condition	Total Number of Crashes	% of Congested Roads
Values						

Activity 4 – Your Budget

Now that you know how the tool works, take some time to evaluate a larger or smaller budget ($350–$500 M). Activities may include determining the following (example of $500 M budget is provided):

1. The optimal allocation for your budget using your original weights in exercise 1a (Remove the expert override)

2. The outcomes of different targets using these weights

You can also use Trade-offs 4, 5, and 6 to conduct additional analyses:

- Targets (TF4) – Lower targets until a minimum budget less than $500 M is achieved
- Budget Allocations (TF5) – Run optimization at $500 M with previous preferences and choose other budget allocations (all totaling to $500 M)
- Weights (TF6) – Use weights from Activity 1 and re-prioritize for $500 M

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Scenario #2: Economic Development and Mobility – "It's the Economy ..."

How did your state governor become the most liked/ tweeted/ followed figure in the state? "It's simple," he says, "give the people what they want." As the former director of your agency, the governor has decided to run for a reelection on a platform of transportation system expansion and job creation. Immediately following his successful campaign speech, the governor contacted the director of your agency to discuss how to bring his vision to life. "I promised congestion reduction because I know that's what resonates with my voters," he said, "and it will create 15,000 new jobs in your district. But I know from being in your shoes not long ago that we must also take care of what we have, especially our bridges." Your DOT director is enlisting your help to evaluate whether it is truly possible to achieve an acceptable level of service on roadways in your district while also addressing other transportation priorities—all for a total budget of $400 M.

Your job – Create jobs and destroy potholes with a $400 M budget

Scenario #2: Economic Development and Mobility

How did your state governor become the most liked/ tweeted/ followed figure in the state? "It's simple," he says, "give the people what they want." As the former director of your state DOT, the governor has decided to run for a reelection on a platform of transportation system expansion and job creation. Immediately following his successful campaign speech, the governor contacted the director of your agency to discuss how to bring his vision to life. "I promised congestion reduction because I know that's what resonates with my voters," he said, "and it will create 15,000 new jobs in your district. But I know from being in your shoes not long ago that we must also take care of what we have, especially our bridges." Your DOT director is enlisting your help to evaluate whether it is truly possible to achieve an acceptable level of service on roadways in your district while also addressing all other transportation priorities—for a total budget of $400 M.

Activity 1 –Performance Measures and Weighting

1a. Weighting

- (Participants). Review the pair-wise comparison exercise in the supplemental worksheet to understand the weighting process. Record preferred weights on individual worksheets.

- (Participants). As a group, complete the weighting exercise for each performance measure. Measures have been provided based on a sample data set obtained from the Utah DOT. These are examples of common measures only and do not reflect all the measures that the tool can incorporate.

1b. Weighting Override

With a strategic vision of system expansion and job creation in mind, the governor and state DOT director weighed various transportation priorities against each other to assign relative importance (Table 1). Your district must use these weights to complete the exercise [Expert Override]. The weights of the group can be further explored in Activity 4.

Table 1. Required performance measures and weights.

Performance Measure	Weight
Pavement IRI	10%
Pavement OCI	10%
Number of Jobs Created	20%
Bridge OCI	20%
Number of Crashes	10%
Level of Service	30%
TOTAL	100%

Activity 2 – Target Setting/ Unconstrained Needs

2a. Set Targets – TF4

- The agency must show the governor that it is addressing his priorities in the district's capital program. What targets are optimal to meet his desires?
- (Participants). Discuss and record targets for each performance measure in Table 2.

Table 2. Proposed targets.

Performance Measure	Target
Average IRI	
% Pavements in "Good" or Better Condition	
Total Jobs Created	
% Bridges in "Good" or Better Condition	
Total Number of Crashes	
% of Congested Roads	

Note: IRI of 80 and 85% for pavement/bridge percentages are "good" for this data set. Additionally, for the data set provided, 15,000 jobs, 2,200 crashes, and 10% congested roads represent near optimal conditions.

2b. Develop Unconstrained Needs – TF4

- How much would it cost to achieve your targets listed in Table 2? _____________
- Would it be valuable to know the total costs required to achieve LOWER targets? Record reduced targets in Table 3.
- Use TF4 to input lower target values from Table 3 and record total cost: _____________

Table 3. Reduced targets.

Performance Measure	REDUCED Target
Average IRI	
% Pavements in "Good" or Better Condition	
Total Jobs Created	
% Bridges in "Good" or Better Condition	
Total Number of Crashes	
% of Congested Roads	

- The legislature has also established performance targets (Table 4) for use in prioritizing projects. These have been mandated.
- Determine and record the unconstrained cost of meeting these mandated targets across all performance areas: ____________
- Use these targets for the remainder of the exercise

Table 4. Mandated performance targets.

Performance Measure	Target
Average IRI	80
% Pavements in "Good" or Better Condition	85%
Total Jobs Created	15000
% Bridges in "Good" or Better Condition	85%
Total Number of Crashes	2200
% of Congested Roads	10%

Activity 3 – Constrained Program Optimization

In this exercise, the group will develop an optimal program based on the mandated performance targets. Additional targets can be tested in Activity 4.

Given the mandated performance targets, answer the following questions:

- If 15,000 total jobs created be achieved with a total budget of $400 M, how do the programmed outcomes compare with the mandated targets/what happens to congestion? Does it seem like 15,000 jobs will allow for no more than 10% congested roads?
- Is the $400 M budget sufficient to achieve 85% good or better condition for bridge assets if you must also ensure that there are no more than 2,200 crashes? What happens to congestion?
- Is the $400 M budget sufficient to achieve 85% good or better condition for bridge and pavement assets and ensure that the percentage of congested roadways does not exceed 20% after removing the crash constraint? ____________

To increase his popularity with voters who are concerned about congestion, the governor has asked your agency to implement a major expansion project. If the $400 M budget constraint is maintained, can the targets of 15,000 jobs created and no more than 15% congested roadways be achieved if a portion of the budget is earmarked for a $32 M expansion project (#280)?

Given your analysis, what would your agency's recommended budget and outcomes look like and/or what total budget would you request? (Choose your preferred allocation and performance outcomes to share with the group during report-out.)

Outputs - Allocated Budget						
Program Areas	Pavement	Bridge	Safety	Mobility	Total	
Allocated Budget ($M)						
Outputs - Performance Measures						
Performance Measures	Average IRI (inches/mile)	% of Pavements in "Good" or Better Condition	Total Jobs Created	% of Bridges in "Good" or Better Condition	Total Number of Crashes	% of Congested Roads
Values						

Activity 4 – Your Budget

Now that you know how the tool works, take some time to evaluate a larger or smaller budget ($350–$500 M). Activities may include determining the following (example of $500 M budget is provided):

1. The optimal allocation for your budget using your original weights in exercise 1a (Remove the expert override)

2. The outcomes of different targets using these weights

You can also use Trade-offs 4, 5, and 6 to conduct additional analyses:

- Targets (TF4) – Lower targets until a minimum budget less than $500 M is achieved
- Budget Allocations (TF5) – Run optimization at $500 M with previous preferences and choose other budget allocations (all totaling to $500 M)
- Weights (TF6) – Use weights from Activity 1 and re-prioritize for $500 M

Workshop: 017 Cross-Asset Allocation (NCHRP Project 08-91)

Monday, April 28, 2014, 8:30 a.m. – Noon

Hello and welcome. You are here today to bring the NCHRP Project 08-91 cross-asset resource allocation framework to life. You have been assigned to a team that will operate as a transportation agency. You will navigate through a case study that is designed to simulate a real-world decision environment and arrive at a recommended allocation strategy given the priorities of your agency and the demands placed upon it. Your active and thoughtful participation is requested to make this experience both fun and worthwhile. Let's get to work!

Scenario #3: Confused Legislature

For the last 10 years, to satisfy the desires of your state's constituents, your state legislature has set aside $250 M in funding for major system expansion projects, leaving less money for system preservation (total budget of $400 M). When a small bridge in a remote area of the state collapsed last month—fortunately resulting in no fatalities or injuries—the legislature quickly blamed your agency for not better preserving its highways and bridges. However, it failed to reexamine its historical set aside for mobility projects. Faced with the recent catastrophe, your agency must show the legislature that you are addressing (or trying to address) pavement and bridge condition as part of your current prioritized program while complying with the legislative mandate to prioritize mobility projects. The legislature still requires a 30% priority weighting for mobility projects in the prioritization program.

Your job – Untangle the performance priorities and optimize a $400 M program

Scenario #3: Confused Legislature

For the last 10 years, to satisfy the desires of your state's constituents, your state legislature has set aside $250 M in funding for major system expansion projects, leaving less money for system preservation (total budget of $400 M). When a small bridge in a remote area of the state collapsed last month—fortunately resulting in no fatalities or injuries—the legislature quickly blamed your agency for not better preserving its highways and bridges. However, it failed to reexamine its historical set aside for mobility projects. Faced with the recent catastrophe, your agency must show the legislature that you are addressing (or trying to address) pavement and bridge condition as part of your agency's current prioritized program, while complying with the legislative mandate to prioritize mobility projects. The legislature still requires a 30% priority weighting for mobility projects in the prioritization program.

Activity 1 –Performance Measures and Weighting

1a. Weighting

- (Participants). Review the pair-wise comparison exercise in the supplemental worksheet to understand the weighting process. Record preferred weights on individual worksheets.
- (Participants). As a group, complete the weighting exercise for each performance measure. Measures have been provided based on a sample data set obtained from the Utah DOT. These are examples of common measures only and do not reflect all the measures that the tool can incorporate.

1b. Weighting Override

In Senate Bill 5000, the legislature has required the following weights for transportation priorities (Table 1). Your agency must use these weights to complete the exercise [Expert Override]. The weights of the group can be further explored in Activity 4.

Table 1. Required performance measures and weights.

Performance Measure	Weight
Pavement IRI	15%
Pavement OCI	15%
Number of Jobs Created	10%
Bridge OCI	20%
Number of Crashes	10%
Level of Service	30%
TOTAL	100%

Activity 2 – Target Setting/ Unconstrained Needs

2a. Set Targets – TF4

Your agency wants to address preservation as its priority; however, the legislature is concerned about increasing congestion levels in the state. What targets are optimal?

- (Participants). Discuss and record targets for each performance measure in Table 2.

Table 2. Proposed targets.

Performance Measure	Target
Average IRI	
% Pavements in "Good" or Better Condition	
Total Jobs Created	
% Bridges in "Good" or Better Condition	
Total Number of Crashes	
% of Congested Roads	

Note: IRI of 80 and 85% for pavement/bridge percentages are "good" for this data set. Additionally, for the data set provided, 15,000 jobs, 2,200 crashes, and 10% congested roads represent near optimal conditions.

2b. Develop Unconstrained Needs – TF4

- How much would it cost to achieve your targets listed in Table 2? _____________
- Would it be valuable to know the total costs required to achieve LOWER targets? Record reduced targets in Table 3.
- Use TF4 to input lower target values from Table 3 and record total cost: _____________

Table 3. Reduced targets.

Performance Measure	REDUCED Target
Average IRI	
% Pavements in "Good" or Better Condition	
Total Jobs Created	
% Bridges in "Good" or Better Condition	
Total Number of Crashes	
% of Congested Roads	

Immediately following the catastrophe, your legislature established performance-based planning requirements to increase accountability and transparency in transportation decision making. As part of this exercise, the legislature set performance targets to define state-of-good-repair thresholds across performance categories (Table 4).

- Determine and record the unconstrained cost of meeting these mandated targets across all performance areas: ____________
- Use these targets for the remainder of the exercise

Table 4. Mandated performance targets.

Performance Measure	Target
Average IRI	80
% Pavements in "Good" or Better Condition	85%
Total Jobs Created	15000
% Bridges in "Good" or Better Condition	85%
Total Number of Crashes	2200
% of Congested Roads	10%

Activity 3 – Constrained Program Optimization

In this exercise, the group will develop an optimal program based on the Table 4 mandated performance targets. Additional targets can be tested in Activity 4.

Given the mandated performance targets, answer the following questions:

- Can 85% good or better condition can be achieved for pavement and bridge assets when $250 M of the total $400 M budget is set aside for mobility projects? ____________
- Can 80% be achieved for pavement and bridge when $250 M of the total $400 M budget is set aside for mobility projects? __________What happens to congestion performance?

  ____
- Can 85% good or better condition be achieved for pavement and bridge assets if the total budget is increased to $450 M and the $250 M set aside for mobility is maintained? ___What if the number of crashes cannot exceed 2,200? ____________
- At a total budget of $400 M, your legislature will lower the bridge and pavement state-of-good-repair threshold to 80% good or better, but will also earmark your agency's critical $29 M pavement improvement project (#114) in the same budget. Is it possible to implement the $29 M project and achieve 80% good or better condition for pavement and bridge assets when $250 M of the $400 M budge is reserved for mobility projects? ____ With the same budget constraint and set aside, is it possible to implement the $29 M project and achieve the original target of 85% good or better condition for pavement and bridge assets?

- Is it possible to implement the $29 M project and achieve 85% good or better condition for pavement and bridge assets if the total budget is increased to $450 M and the set aside is maintained?

Given your analysis, what would your agency's recommended budget and outcomes look like and/or what total budget would you request? (Choose your preferred allocation and performance outcomes to share with the group during report-out.)

Outputs - Allocated Budget						
Program Areas	Pavement	Bridge	Safety	Mobility	Total	
Allocated Budget ($M)						
Outputs - Performance Measures						
Performance Measures	Average IRI (inches/mile)	% of Pavements in "Good" or Better Condition	Total Jobs Created	% of Bridges in "Good" or Better Condition	Total Number of Crashes	% of Congested Roads
Values						

Activity 4 – Your Budget

Now that you know how the tool works, take some time to evaluate a larger or smaller budget ($350–$500 M). Activities may include determining the following (example of $500 M budget is provided):

1. The optimal allocation for your budget using your original weights in exercise 1a (Remove the expert override)

2. The outcomes of different targets using these weights

You can also use Trade-offs 4, 5, and 6 to conduct additional analyses:

- Targets (TF4) – Lower targets until a minimum budget less than $500 M is achieved
- Budget Allocations (TF5) – Run optimization at $500 M with previous preferences and choose other budget allocations (all totaling to $500 M)
- Weights (TF6) – Use weights from Activity 1 and re-prioritize for $500 M

APPENDIX D

Workshop Discussions

Asset Management Conference Workshop

On April 28, 2014, 20 people registered for the TRB 10th Annual Asset Management Conference in Miami, Florida, for a workshop where participants used role playing and real-life planning scenarios to work with the tool and provided the research team with feedback on the tool's usability/value and the need for refinements. The areas of expertise of the attendees included asset management, bridge design, bridge modeling, bridge planning, central preconstruction, operations, pavement management, pavement modeling, program development, program finance, project development, traffic and safety, traffic management, traffic operations, and transportation.

Following are possible refinements, based on participant feedback, that could help ensure that the tool best meets the participants' agencies' needs. In addition, there are suggested or possible uses of the tool listed based on comments received from the participants.

Suggestions for Refinement

- A few refinements were suggested regarding making the mechanics of using the tool more user-friendly. For example, the user currently weights performance measures against each other using a numerical, nine-point comparative scale. Attendees suggested that a **sliding bar** between measures might be easier to use for this task to avoid confusion about how to value relative priorities.
- There was a desire to **save each scenario/run** within the tool so that subsequent runs could be compared.
- A participant asked what capacity the tool would have to support **risk and sensitivity analysis**, particularly since MAP-21 includes requirements for agencies to incorporate them into their planning and decision-making processes. Risk will be incorporated into the tool by including standard deviations around the budget and performance measures, which will then enable the development of confidence factors. It was also pointed out that economic models already exist and may be useful to agencies in accommodating these MAP-21 provisions.

Opportunities for Tool

- Currently, the tool's output gives the value of performance measures as a result of implementing certain projects or portfolios of projects. Some attendees expressed a desire to show trend lines, not just points in time, commenting that it would be useful to see if asset conditions are improving or worsening.
- Participants expressed a desire to have the tool show the impact of the delay of a project, with respect to both project cost and system performance.

- Participants expressed a desire for the tool to reflect the entire network of a state/agency and not just one data set of projects. Integrating the tool with existing network data sets (such as pavement condition indices) would be useful. The research team pointed out that further work and refinement would allow for different classifications of roadways and their value on the network to be addressed within the tool.

Additional Discussion/Observations/Concerns

- There was discussion on what performance measures/allocation areas should be included in the tool. The sample data set used for the Miami workshop included safety, which not all DOTs consider to be a stand-alone allocation area. The flexibility of the tool allows for customization so that states/agencies can use whichever areas/performance measures work best for their unique circumstances and decision-making support needs.
- It was noted that the prototype tool depends on data being entered for each project, including the impact of the project on various performance measures. Concern was expressed that this type of information does not exist in many states/agencies, and the tool is only as good as the data that are entered into it. The research team acknowledged that executive leadership will have to be convinced of the value of such data collection and its reliability and further noted that as states/MPOs continue to expand their data sets, many mandated by MAP-21, information will be more readily available for use within the tool.

Conclusions

Both the cross-asset resource allocation framework and the tool prototype were well received by the participants. Workshop attendees were active in their breakout group exercises, and the discussion was both lively and informative. Overall, participants indicated that there was value in the technical analysis capabilities of the tool as well as the ability to use the tool to support and inform decision-maker and stakeholder discussions regarding performance targets, measures, and investment strategies.

The pre-workshop surveys indicated skepticism that a tool like the cross-asset allocation tool could be developed. While many saw the usefulness, there was genuine concern about implementation. With the tool prototype now developed and tested with audiences across the country, questions about how the tool can be used have replaced those of if the tool can be developed.

Utah Department of Transportation Workshop

On June 16, 2014, in Salt Lake City, Utah, 25 workshop participants used role playing and real-life planning scenarios to work with the tool and provided the research team with feedback on the tool usability/value and the need for refinements. The areas of expertise of the attendees included asset management, bridge design, bridge modeling, bridge planning, central preconstruction, operations, pavement management, pavement modeling, program development, program finance, project development, traffic and safety, traffic management, traffic operations, and transportation.

Following are suggested or possible uses of the tool listed based on comments received from the participants.

Opportunities for Tool

- **Optimize projects.** Use existing management system to generate lists of project and then use this tool to optimize. At that point, the optimized projects can be used to feed STIP.

- **Identify investment programs. Programs could be defined in a variety of ways, including:**
  - Asset/operational classes, and
  - Regions.
- **Identify performance measures. Measures could be identified based on:**
  - MAP-21 rulemaking,
  - State metrics, or
  - Differences in systems/measures (seemed to be some disagreement on OCI measure, for example).
- **Evaluate data availability and management systems, including:**
  - Gap assessments of measures and predictive abilities,
  - Organize data for cross-asset before/after, and
  - Identify ability to automate linkage of systems to cross-asset tool.
- **Analyze investments.** Participants suggested that this tool is not so much a "cross-asset" tool as a "cross-investment" tool. The tool could be expanded to look across modes and has the ability to consider performance with regard to operations (e.g., congestion) instead of just physical infrastructure.

AASHTO SCOP/SCOPM Conference Workshop

On June 20, 2014, in Scottsdale, Arizona, a combined AASHTO SCOP/SCOPM workshop was held with 21 participants using role playing and real-life planning scenarios to work with the tool and provided the research team with feedback on the tool usability/value and the need for refinements. The areas of expertise of the attendees included bridges, construction, mobility, modes, operations, pavement, programming, safety, and transit.

Following are possible refinements, based on participant feedback, that could help ensure that the tool best meets the participants' agencies' needs. In addition, there are suggested or possible uses of the tool listed based on comments received from the participants.

Suggestions for Refinement

- Develop a simple, understandable user guide.
- To aid and help simplify the weighting process, develop a sliding-scale graphic approach (as opposed to the current 9/1 to 1/9 structure).
- Focus on making the tool as user friendly as possible, specifically in terms of changing performance measures or program areas.
- Additional consideration might be given to how agencies can generate candidate project lists. Research in this area might need to be conducted.
- Tool guidelines should identify minimum data requirements and optional data.

Opportunities for Tool

- Could qualitative assessments (e.g., "high," medium," and "low" scores for a given performance area) be substituted for quantitative numbers if adequate data are not available?
- How could the tool provide better outputs on job creation? Perhaps it could be linked to one of the SHRP 2 products to improve job creation forecasting.
- Improve awareness of the tool by conducting a webinar, or apply some of the implementation lessons learned from SHRP 2.
- NCHRP might consider an implementation/pilot program as follow-on research.
- Include discussion of the tool in the quarterly FHWA roundtable—people could be put on the program to discuss the tool.

Additional Discussion/Observations/Concerns

- Would be interesting to look at how well the tool can work with an existing (unscrubbed) data set.
- Concern that there are not predictive data at the project level.

New Jersey Department of Transportation Workshop

On June 25, 2014, in Trenton, New Jersey, seven workshop participants used role playing and real-life planning scenarios to work with the tool and provided the research team with feedback on the tool usability/value and the need for refinements. The areas of expertise of the attendees included capital investment planning and development, pavement and drainage management, project management, project planning, statewide planning, and statewide strategies.

Following are possible refinements, based on participant feedback, that could help ensure that the tool best meets the participants' agencies' needs. In addition, there are suggested or possible uses of the tool listed based on comments received from the participants.

Suggestions for Refinement

- Participants thought that it would be beneficial to add in funding splits to more accurately match sources of funding with eligible projects.
- Participants thought that a **sliding scale** would help when it comes to setting weights.
- Intrigued how to incorporate smart-growth policies into the tool.
- Highlighted local system integration as locals actually maintain part of NHS, so would like tool to show their responsibility with and without local input.
- Biggest concerns were how to incorporate program line items—for instance, bridge deck overlay budget is one line item, not a project-by-project data set.

Opportunities for Tool

- Not so much a "cross-asset" tool as a "cross-investment" tool; attendees liked that the process could be expanded to look across modes and has the ability to consider performance with regard to operations (e.g., congestion) instead of just physical infrastructure.
- Participants liked having ability to compare scenarios and project sets against one another.
- Liked looking at projects across metrics, recognizing linkage between drainage and roadway deterioration for example, or large-scale projects that affect several areas.
- Liked that the process is data-driven—that is the direction they are going.

Additional Discussion/Observations/Concerns

- New Jersey is unique in having more flexibility with state and toll dollars, so appreciated concept of allocating funds that are not pre-dedicated to a specific silo.
- There is a need for good data; wondered how accurate/reflective what they currently have is.
- Participants were more likely to use top-down approach and were surprised to see bottom-up approach.
- Concerned that the tool's optimization could give different answer than management system optimization.
- Lots of discussion around safety being important but not the driver of projects, usually tacked on in ancillary projects.
- Said scale of project is important to identify when determining impacts like mobility.
- Said that "everything works if you don't measure it."

North Dakota Department of Transportation Workshop

On August 18, 2014, in Bismarck, North Dakota, 10 workshop participants used role playing and real-life planning scenarios to work with the tool prototype and provided the research team with feedback on the tool usability/value and the need for refinements. The areas of expertise of the attendees included bridges, construction, design, operations, pavement, planning, programming, and transportation programs.

Following are possible refinements, based on participant feedback, that could help ensure that the tool best meets the participants' agencies' needs. In addition, there are suggested or possible uses of the tool listed based on comments received from the participants.

Suggestions for Refinement

- Does not tell when to build project just to build in x time frame.
- Show stakeholders in real time.
- Can maintenance be added?

Opportunities for Tool

- Is not linked to safety counter measures yet.
- Values different than those of taxpayers out west.
- Helpful to municipalities; move assets.
- Optimize timing of project construction.
- Get from pavement management to here.

Additional Discussion/Observations/Concerns

- In North Dakota, there were questions about how the tool fits into the current programming system. The agency is overwhelmed by the need to expand the system and is shifting from a perspective of "what's best for pavement?" to "what's best for the system?"
- Concern about the subjective nature of some of the data examples was expressed. Participants also noted that while this tool has subjective elements, it allows more objective analysis than the North Dakota Department of Transportation currently employs across asset classes.
- The group noted that more data per measure would be beneficial to analysis and recognized some benefit to using the tool with external stakeholders.

Illinois Department of Transportation Workshop

On August 26, 2014, in Springfield, Illinois, 34 workshop participants used role playing and real-life planning scenarios to work with the tool and provided the research team with feedback on the tool usability/value and the need for refinements. The areas of expertise of the attendees included bridges and structures, cost and estimate, highways, land acquisition, location studies, operations, pavement management, planning, performance and cost support, programming, project and environmental studies, structural services, systems planning and services, transportation planning, and urban planning.

Following are possible refinements, based on participant feedback, that could help ensure that the tool best meets the participants' agencies' needs. In addition, there are suggested or possible uses of the tool listed based on comments received from the participants.

Suggestions for Refinement

- Participant mentioned that weightings and targets should be set at the state rather than district level to direct investments made at all levels of the state.
- In terms of implementing the tool for programming purposes, a participant suggested making a gradual transition and comparing outcomes from this approach to what would have been programmed using past processes.
- Illinois has a highly centralized programming process, and a potential tool enhancement could be to provide recommended allocations by district given optimization programs.
- There was a question concerning whether different phases of projects can be incorporated into the tool (e.g., preconstruction) even if they do not yet have tangible performance benefits so the district, and broadly Illinois DOT, can get credit for implementing this work.

Opportunities for Tool

- It was suggested that the tool would be most useful for capital programming.
- The tool could be useful in informing target setting, which is required to be done by states under MAP-21.
- It was noted that the tool could be used to better coordinate and communicate between adjoining districts.
- There is value to the proposition of approach and the tool:
  - Compliance with federal requirements established under MAP-21.
  - Accountability, transparency (internally and externally with stakeholders and public), and transferability of knowledge and processes (e.g., for succession planning).
  - States are increasing adopting performance-based planning and programming as well as supporting tools and processes to improve decision-making capabilities and the ability to communicate the rationale behind the consequences resulting from investment decisions.
  - The tool documents the decision process to support transparency and accountability.

Additional Discussion/Observations/Concerns

- The tool does not handle selecting scope of projects; projects are determined in individual management systems (e.g., using life-cycle–based activity selection) and then provided as inputs to the tool.
- The tool has no predictive capabilities; the performance impacts with and without project implementation are inputs derived from individual data management systems with performance forecasting capabilities.
- There were questions regarding whether the tool can handle set asides (e.g., for safety programs).
- Current processes and tools constrain staff's abilities to effectively prioritize projects for fast-track capital program and to quickly respond to questions regarding project prioritization and programming.
- Illinois has a centralized programming process. The central office distributes funding to districts, which are in most cases "spoon fed" prioritized projects.
- There was limited acceptance of the suggested performance-based cross-asset allocation approach at the staff level (those in attendance).
- In the past, federal funding has been primarily applied for expansion, while state resources have been primarily applied toward maintenance and preservation.

- There was interest from this group in knowing and reporting on where federal funding is going and what is being delivered as a result.
- There was a question regarding how the tool can be applied at different levels of statewide planning, including by regional and local agencies.

California Department of Transportation Workshop

On August 27, 2014, in Sacramento, California, workshop participants used role playing and real-life planning scenarios to work with the tool and provided the research team with feedback on the tool usability/value and the need for refinements.

Following are possible refinements, based on participant feedback, that could help ensure that the tool best meets the participants' agencies' needs. In addition, there are suggested or possible uses of the tool listed based on comments received from the participants.

Suggestions for Refinement

- Suggestion from the discussion of using climate change resiliency as a potential measure.
- Discussion about using proxy measures where appropriate (e.g., percent trucks for goods moved).
- It would be a good idea to develop a public outreach tool. This improved data visualization would allow the public to see if the system's health is going up or down.
- For Caltrans, worker safety in addition to roadway safety is an important department initiative.
- Accessibility and community considerations (e.g., historical bridge) are not incorporated in current analysis.
- A suggested enhancement—have the tool automatically diagnose inconsistent AHP choices; summarize projects programmed by district.
- There are limitations of the framework and tool—primarily data requirement. It is not an easy process to define the framework, which is a significant policy process. Transparency/black-box issue (still exists to some extent).

Opportunities for Tool

- It was noted during the discussion that this tool enables comparison of benefits of dissimilar projects (e.g., culverts, pavement, and mobility).
- Perceived value of tool: preprocessing effort at planning level as the original allocation among silos dictates what can be done within individual silos.
- Tool is useful for communications (stakeholders, public, legislators).

Additional Discussion/Observations/Concerns

- There was discussion noting that there are not too many measures for multi-objective optimization and this will dilute their importance.
- There was a desire for a repeatable, consistent method for rating projects.
- Caltrans is looking at software or freeware options to support prioritization once criteria are determined.
- Caltrans has concept and idea for multi-objective decision-making process but has not determined the selection criteria.
- Caltrans' budget has some funds that are committed and some (~$1 billion) that are discretionary. Caltrans is looking at how to spend discretionary funds.
- Caltrans is investigating a road user charge because tax base is insufficient.

- It was noted that the AHP in the tool is confusing.
- At the asset management executive follow-up meeting: Caltrans has been talking about this cross-asset optimization process and is looking to implement.

Kansas Department of Transportation Workshop

On September 8, 2014, in Topeka, Kansas, 12 workshop participants used role playing and real-life planning scenarios to work with the tool and provided the research team with feedback on the tool usability/value and the need for refinements. The areas of expertise of the attendees included bridges, budget, construction and materials, management engineering, pavement, performance measures, planning, program and project management, and transportation safety and technology.

Following are possible refinements, based on participant feedback, that could help ensure that the tool best meets the participants' agencies' needs. In addition, there are suggested or possible uses of the tool listed based on comments received from the participants.

Suggestions for Refinement

- There was a question about how long the evaluation period is. Because it is 1 year and does not look out to impacts that might occur over 3 to 5 more years, there was an observation that DOTs seem to want a tool that would look at project impacts for more than just 1 year since impacts accrue over time.
- Programming by goal area is difficult; the number of alternatives can become unmanageable if scopes keep changing.
- There was concern from the participants about how much time is needed to build out the data to run the tool. During the discussion, the consultant noted that it can be quite an effort to build out the data depending on the quality and range of existing data. It was also noted that the DOT needs to get several bureaus together representing several areas in order to get a balanced view for the value weighting exercise. Kansas DOT noted that this tool would be helpful when putting together a long-range plan or an asset management plan.

Opportunities for Tool

- Kansas DOT commented that the tool could be helpful in giving stakeholders choices and trade-offs, but only if they understand the context of the decision. For example, allocating 5% of the overall construction budget to transit might not seem like a large percentage, but it is an enormous amount of funding relatively speaking to previous allocations.
- There was significant discussion about how the tool might be used to gauge trade-offs when performance matters—if targets cannot be hit because you are losing funds.

Additional Discussion/Observations/Concerns

- Overall, Kansas DOT is very familiar with scoring and prioritizing projects, having used a priority formula approach for well over 20 years. However, the optimization across asset classes during scoring and prioritization of projects is a new concept to Kansas DOT.
- There was a conversation about total jobs and concern that it is subjective. They asked if the tool would work without that input. The answer is yes, and states can measure whatever they want.
- There was discussion about the sorts of projects/asset classes that would be best considered by the tool. Specifically, a participant asked about including lighting projects, to which the consultant responded that for those smaller parts of projects, those probably should not be included as a class of project.

Missouri Department of Transportation Workshop

On September 9, 2014, in Jefferson City, Missouri, six workshop participants used role playing and real-life planning scenarios to work with the tool and provided the research team with feedback on the tool usability/value and the need for refinements. The expertise of the attendees included organizational performance, planning, and transportation system analysis.

Following are possible refinements, based on participant feedback, that could help ensure that the tool best meets the participants' agencies' needs. In addition, there are suggested or possible uses of the tool listed based on comments received from the participants.

Suggestions for Refinement

- There was a question during the workshop about whether the tool can take a longer-term view. The response is that this is something that can be done, but Missouri DOT (or any other DOT) would have to have a measure that reflects length of time of measuring performance. For example, you would have to have remaining service life as a data set.
- Missouri DOT notes that it has scored and evaluated trade-offs for pavement but has not optimized pavement. It asked if this tool is helpful for optimizing within a class. The consultant pointed out that this tool could be used at the district level to discuss and compare ports to highways and other modes.
- There was a question about whether the tool would be able to help in knowing if goals can be achieved with a particular set of projects.
- There was another comment that it would be helpful to compare benefits per mode rather than project by project.
- There was a good discussion around the idea of using an expert panel to assign outcomes of projects and that it is okay if scores are not calculated with extreme correctness. Working through the exercise of assigning outcomes and the values of weighting exercise is a good place to start the discussion and builds on many assumptions that currently are not considered in a systematic way.
- Currently, the tool's output gives the value of performance measures as a result of implementing certain projects or portfolios of projects. Some attendees expressed a desire to show trend lines, not just points in time, commenting that it would be useful to see if asset conditions are improving or worsening.
- Participants expressed a desire to have the tool show the impact of the delay of a project with respect to both project cost and system performance.
- Participants expressed a desire for the tool to reflect the entire network of a state/agency and not just one data set of projects. Integrating the tool with existing network data sets (such as pavement condition indices) would be useful. The research team pointed out that further work and refinement would allow for different classifications of roadways and their value on the network to be addressed within the tool.
- Need to make sure changing performance measures or program areas are user friendly. A friendlier user interface is desired.

Opportunities for Tool

- The tool seems valuable within the MAP-21 context so a state can see how money is spent to achieve targets.
- The tool is helpful in optimizing investment in maintenance. This way, a state can see if it invests significant amounts of additional funds in maintenance and does not use these amounts, then perhaps those funds can be used for other purposes.

Additional Discussion/Observations/Concerns

- This tool would help for consistency across some districts—meaning that some districts would embrace the tool more and some less.
- There is a strong need to clearly document what types of data need to be loaded into the tool for it to work effectively.
- Evolve the tool to include disinvestment; an evolving and solid approach to the current economic and financial challenges of transportation.
- Types of data input will be critical to the usability of the tool for many DOTs.
- Missouri DOT noted that districts try to reach statewide goals for pavement, bridges, and other areas, and that some districts are closer to achieving these goals than others. The consultant team commented that the tool can be used at the district level.

Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation