Resource Allocation Logic Framework to Meet Highway Asset Preservation

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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Resource Allocation Logic Framework to Meet Highway Asset Preservation

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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In addition, the research team acknowledges the contributions of the NCHRP Project 14-21 panel and numerous state DOT members, who participated in phone interviews to provide information on the state-of-the-practice of allocating resources for preservation and maintenance activities.

FOREWORD

By Andrew C. Lemer
Staff Officer
Transportation Research Board

This report presents a logic framework for allocating limited highway asset preservation funds among competing demands to achieve high levels of system performance. The report also presents a spreadsheet-based computational tool that implements the framework. The tool uses linear programming optimization to allocate resources across asset classes or geographic regions, subject to constraints that typically must be considered in such decision-making, to achieve target asset performance or condition levels. Prototypical application scenarios and case-study examples illustrate how transportation agency staff may use the framework to assist resource allocation decisionmaking.

State departments of transportation (DOTs) and other government agencies have invested significant resources in building our nation's highway system. The investments are embodied in the pavements, bridges, lighting, signals, signage, intelligent transportation system (ITS) devices, pavement markings, drainage systems, traffic barriers, landscaping, noise walls, rest areas, and other assets that constitute the network. These various assets, distributed geographically through a highway system, are expected to provide many years of service.

DOTs undertake asset preservation activities to protect past investments and thereby ensure that the full value of these investments is realized. These activities include both maintenance and rehabilitation. A DOT's resources for preservation activities are inevitably limited and often inadequate to undertake all of the activities that agency staff believe are needed. How to allocate limited resources among competing needs to achieve the greatest benefit is a complex, continuing problem that all DOTs face.

The objectives of NCHRP Project 14-21 were to describe in practical, usable terms an analysis framework that DOT staff may use to allocate resources across principal categories of highway assets to ensure system preservation, and to demonstrate the framework's application. An analysis framework of this sort must reflect the fundamental principles under which a DOT operates, for example, how classes of assets are defined and how the agency administers the system for which it is responsible. The framework must also reflect how asset condition and performance are characterized and measured and the condition and performance targets that a DOT seeks to meet. The framework must effectively account for the constraints to be met by the agency, for example ensuring reasonable balance of effort within all parts of the system. For the framework to be useful, it must not impose unrealistic demands on agency staff for extensive data or excessively complex computation.

A research team led by Booz Allen Hamilton reviewed available literature and current practices that decisionmakers use to support resource allocation and considered ways that DOTs typically undertake to allocate preservation resources. The team assessed DOT data quality and availability; forecasting tools used in management of various categories of assets, risks, and liabilities that agency management must consider; and the changeability of priorities that such agencies may experience. Based on this assessment, the team specified a logical framework using linear-programming optimization.

The team developed a spreadsheet-based approach to implementing the optimization framework and developed examples of its application using data provided by several DOTs. A workshop was held to engage the NCHRP Project 14-21 panel and other invited DOT practitioners to comment on the optimization approach and help the team to refine specific implementation details to enhance the framework's utility.

This report presents in detail the overall logic framework and the proposed procedures for developing and applying the framework to inform an agency's resource allocation decisionmaking. A demonstration model (in Excel workbook format) was developed to accompany this report (see text box for details). The files are functional illustrations of the procedure applied under scenarios typical of conditions a DOT may face. DOT staff may adapt the spreadsheet files or develop their own implementation of the logic framework tailored to the specific characteristics of their own agency and system.

The following spreadsheet files are available for download from the NCHRP Project 14-21 web page at http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=2718:

NCHRP 14-21_Resource_Allocation_Model_Demo_July2012 - Baseline.xlsm
NCHRP 14-21_Resource_Allocation_Model_Demo_July2012 - Scenario 2.xlsm
NCHRP 14-21_Resource_Allocation_Model_Demo_July2012 - Scenario 3.xlsm
NCHRP 14-21_Resource_Allocation_Model_Demo_July2012 - Scenario 4.xlsm

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Note: Many of the photographs, figures, and tables in this report have been converted from color to grayscale for printing. The electronic version of the report (posted on the Web at www.trb.org) retains the color versions.

SUMMARY

Resource Allocation Logic Framework for Highway Asset Preservation

Introduction and Approach

The overarching goal of the National Cooperative Highway Research Program (NCHRP) Project 14-21, "Resource Allocation Framework to Meet Highway Asset Preservation Needs," is to develop an analysis framework that state DOTs can use as a guide and tool to allocate highway system preservation resources across various principal asset groupings, preservation activities, and regions within their jurisdiction. There is no widely accepted logic framework to address preservation resource allocation decisions that account for a broader (multi-asset) view of preservation program needs, nor does a sound logic framework exist for adjusting and optimizing allocations and results accountability across all asset groups—after the inevitable funding constraints and priority changes are introduced.

It is not uncommon in resource allocation processes that preservation needs for some highway asset groups are initially estimated based on priorities and expected performance or condition results. Tools exist to support this estimation—particularly for bridge structures and pavement, but these tools do not effectively support optimization decisions on the division of available resources between asset groupings and regions. Minimal decision support is currently available to estimate preservation needs and allocation adjustments for asset groupings outside the bridge or pavement domains.

The research team performed extensive literature review and conducted numerous interviews on the processes followed and state-of-the-practice for preservation resource allocation. With analysis of this information, the team derived a clarified statement of the highway preservation resource allocation problem to be considered, and the key decision factors for resource allocation. The research team then formulated a mathematical model to represent the essence of the problem, and to guide solution logic and computations. A solution was then derived based on the mathematical model, applying standard linear programming algorithms and appropriate objective functions. To validate the logic and practicality of the mathematical model, the analysis and linear optimization were developed further, using Microsoft Office Excel and the integrated Solver function.

An initial test solution was developed for demonstration of the logic based on plausible state preservation program structures and underlying data sets for asset inventories, costs, deterioration rates, asset condition, and performance goals. The initial data set was adapted from real state DOT data gathered from document research and prior project experience of the research team. This model was demonstrated and then further tested in two state DOT case applications.

Based on the results of the case studies and recognizing that there is a significant variety of user approaches and taxonomies for preservation resource allocation, the research team developed a streamlined Excel-based model that permits users to enter appropriate preservation program taxonomies, inventory performance and deterioration estimates, priorities, and performance goals. The logic demonstration model is scalable to a wide set of user-defined asset/activity groupings (AAG) and multiple districts. The model offers optimized allocations across all AAGs that are supported by data or reasonable estimates of inventory, average condition, deterioration rates, and unit costs. Alternative allocation solutions are built in for specific AAGs that are not supported by sufficient data or reasonable estimates. The demonstration model is available in Excel workbook format on the NCHRP Project 14-21 web page at www.trb.org.

Logic Framework and Model

The Resource Allocation Logic Framework and supporting mathematical model determine the optimal investment allocations by AAG for specific allocation cycles and specific regions or districts given statewide goals and objectives, available funding constraints, and performance thresholds. Figure S-1 is a high-level view of the allocation logic. Key outputs from the resource allocation model include realistic performance/condition expectations (both performance/condition and timelines to achieve targets) by AAG after allocations are adjusted to conform to funding limitations and other strategic variables.

Once the strategic inputs and targeted performance/condition (left side of the diagram), and the data inputs (top right side of the diagram) are introduced, the computations and objective function optimize and compute allocations to match available resources, as well as achievable performance results that are accountable to the investments (unshaded blocks). If the performance and timeline results are unacceptable to decisionmakers, adjustments to AAG performance goals or to the overall funding commitment can be made, resulting in new allocation and performance results.

The predicted end-of-cycle performance/condition rating results for each AAG (after funds-available adjustments), when compared with desired targets, is useful to assess the

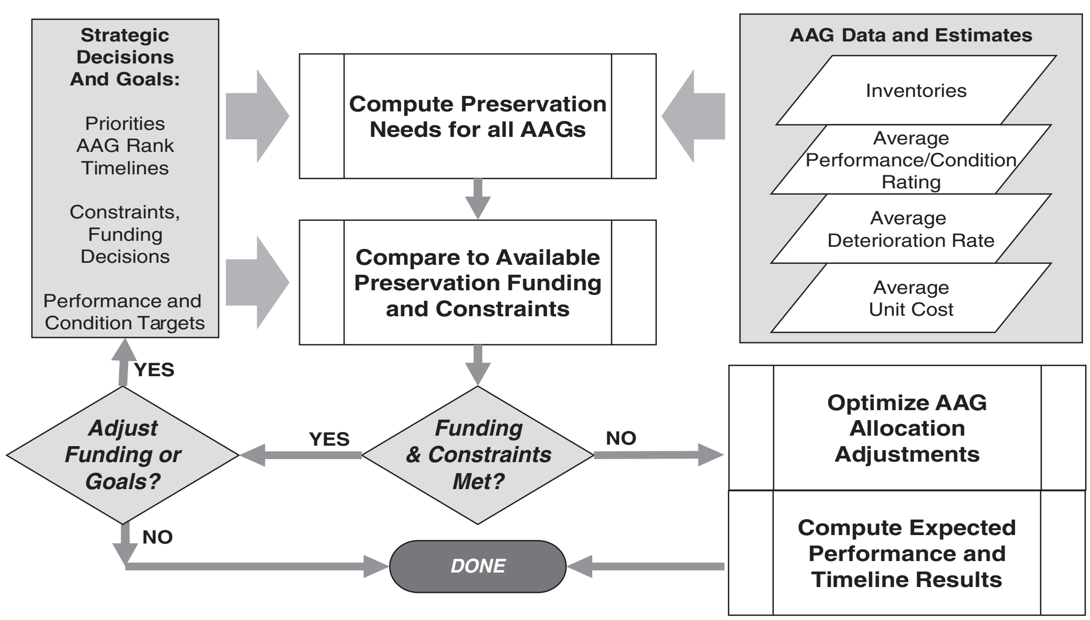

Figure S-1. Allocation logic overview.

effects of funding shortfalls on preservation of the road network. This will help to calibrate stakeholder expectations and high-level decisionmaking on funding in subsequent cycles.

The allocation solution is primarily designed to address situations where (a) available preservation funding is less than estimated or computed overall preservation needs and (b) asset performance or condition ratings for specific AAGs are below desired targets. Where the opposite is the case, we assume the allocation challenge is met by simply estimating the preservation needs for each asset group and jurisdiction and funding the need or possibly by reassessing the rating targets and priorities for a more aggressive preservation program.

The allocation solution and model are not intended to have granularity below the District/AAG level; rather the solution is intended to provide a logical total preservation funding envelope for an AAG within a jurisdiction—either district or state. Neither selection of specific projects nor preservation tactics are intended to derive from this logic model. These are considered technical decision within the work planning process.

Solution options were developed for users to treat specific AAGs that lack key data or estimates to compute and optimize allocation needs in the way intended by the framework.

Key Conclusions

The Resource Allocation Logic Framework is fundamentally based on needs. Optimization applies to the adjustments of needed allocations to match available funds. A needs-based determination of allocation resources means that it is necessary (a) to connect preservation investments directly to expected performance/condition results and (b) to enable correction of expected performance/condition outcomes commensurate with any positive or negative allocation adjustments. Connecting investments to results requires reasonably reliable data *or estimates* on AAG-specific inventories, average performance/condition, average deterioration, and average preservation unit costs. Key conclusions include the following:

- Based on literature review and interviews, each state DOT has unique practices, definitions, account structure, and taxonomies for the allocation of funds to preservation—there is no one-size-fits-all solution.
- Inventory, performance/condition, deterioration, and preservation unit cost data availability for non-bridge pavement (NBP) assets is very scarce among DOTs, making it challenging to apply a complete analytical approach for allocating resources, without significant estimating and judgment.
- Agencies track performance metrics and asset inventory in unique ways, so the framework is flexible for a wide range of definitions of both asset-activity groupings and performance standards.
- Deterioration is a very strong driver of preservation need. Where deterioration-based preservation need exceeds funding allocations for any particular AAG, performance improvement is not possible; rather performance can be expected to regress. In these cases, optimized allocation of available funds would seek to minimize this regression across AAGs.

Guidance

Several suggestions are included for activities to support and enhance adoption of the Resource Allocation Logic Framework. These are further discussed in Chapter 7.

1. **Average Deterioration Rates.** Research is suggested to support improved methods for determination or estimating of average deterioration rates for various AAGs. This is a very important factor in the allocation logic framework.

2. **Asset Inventory and Condition Management.** Compilation of practical NBP inventory and condition assessment and management approaches (in use by DOTs) would be useful and helpful to potential users of the allocation logic framework, both for enhanced resource allocation and for other asset management purposes.
3. **Objective Functions for Optimizing Resource Allocation.** It makes sense that preferred optimization strategies (and therefore objective functions) would vary considerably across multiple DOTs. Prospective users of the allocation logic framework would benefit from the exercise of developing the right object functions and collecting ideas and preferences from multiple peer agencies.
4. **Added Case Applications for Logic Framework.** Additional case applications would support, build, and communicate confidence among prospective adopters of the Resource Allocation Logic Framework.
5. **Methodology to Facilitate Initial Adoption of the Resource Allocation Logic Framework.** The team envisions that an adopting DOT will want to populate a full version of the framework with the actual AAG taxonomy and real-time estimates or facts on inventory, unit costs, performance status, deterioration, and so forth. It will likely run and calibrate the allocation results in parallel with the normal allocation process.
6. **Development and/or Sponsorship of Practitioner Training.** Training support is likely to be needed at both strategic and modeler/operator levels for effective assessment, adoption, and implementation of the Resource Allocation Logic Framework, and to build acceptance and deployment of the allocation framework.
7. **Application of the Framework to Other Resource Allocation Areas.** It may be useful to explore application of the logic more broadly to maintenance and infrastructure improvement programs. The logic model can support any application with any taxonomy, a quantifiable inventory, performance ratings that can be normalized, and known average cost factors to link investment to results.

CHAPTER 1

Introduction

1.1 Project Background

The highway system infrastructure includes several commonly described asset groupings. These groupings typically include pavements and pavement markings, bridge structures, lighting, traffic control devices, signage, Intelligent Transportation Systems (ITS), drainage structures, traffic barriers, landscaping, noise barriers, and rest areas. State DOTs manage various programs to maintain, preserve, and rehabilitate these assets to extend their useful life and ensure that they can provide safe and acceptable service throughout it. State DOTs have to balance various considerations and points of view on priorities as they allocate (usually) scarce resources across and within their highway management programs. Overall, it is challenging for states to balance multiple priorities; to optimize the allocation of these resources to meet expectations on service performance; and, at the same time, to maximize expected useful life from existing assets. Large-scale replacement of failed or badly deteriorated highway assets is far beyond the means of most agencies and will be for the foreseeable future.

The challenge in developing a logic framework to support allocation decisions across the wide variety of highway asset groupings has not been met to date. Many decision-support and planning tools are available to support project selection, estimation, accounting, and operational decisions, but these tools tend to be specialized and focused technically on particular assets. There is no widely accepted logic framework to address resource allocation decisions that account for a broader (multi-asset) view of preservation program needs.

The overarching goal of the NCHRP Project 14-21, "Resource Allocation Framework to Meet Highway Asset Preservation Needs," is to develop an analysis framework that state DOTs can use as a guide and tool to allocate highway system preservation resources across various principal asset groupings, preservation activities, and regions within their jurisdiction. To achieve this goal, this project has three main objectives:

1. Develop and describe a practical logic framework (including principles, objective functions, and constraints) using operations research methodologies.
2. Develop a logic process to apply the logic framework.
3. Develop a demonstration application of the logic framework using example cases and data.

To accomplish these objectives and ensure the success of this project, the research team developed and implemented a detailed technical process (shown in Figure 1-1) to guide the research plan, analyses, and activities.

1. **Formulate the Resource Allocation Problem.** As a first step, the research team studied the relevant information and developed a well-defined statement of the highway preservation resource allocation problem to be considered. This study included determining the appropriate objectives, the constraints on what can be done, and interrelationships among the areas to

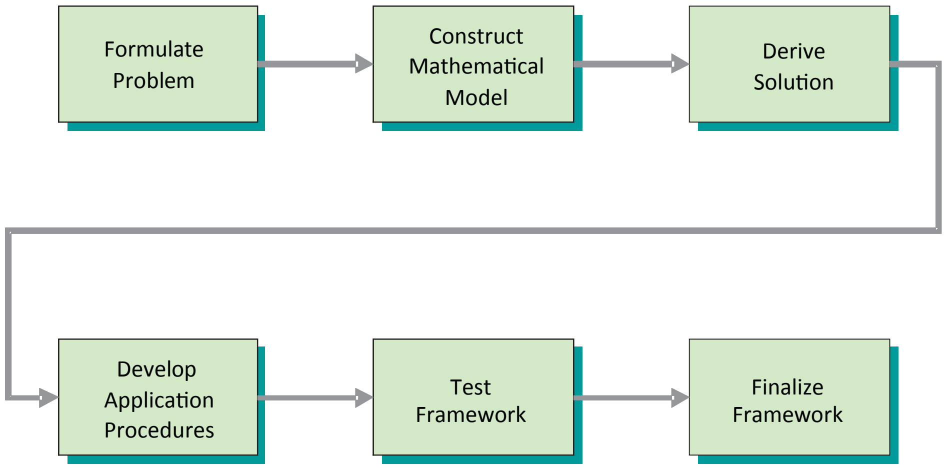

Figure 1-1. NCHRP Project 14-21 Resource Allocation Logic Framework technical approach overview.

study. This was a crucial process, because it greatly affected the relevance and practicality of the research results.

2. **Construct a Mathematical Model.** After defining the decision factors for resource allocation, the research team formulated the resource allocation problem for analysis and solution, to construct a mathematical model that represents the essence of the problem. The mathematical model broadly defines the problem and guides the computational solutions. This tool aided in making the overall structure of the problem comprehensible and revealed important cause-and-effect relationships.
3. **Derive a Solution from the Model.** After formulating the mathematical model, the next step was to derive a solution from this model. This is an analytical step in which one of the standard algorithms of operations research was applied. To ensure the model is practical and can be easily used by DOT managers and applied in broad programmatic investment decision processes, the analysis and linear optimization model were developed using Microsoft Office Excel and Microsoft Solver.
4. **Develop Application Procedures.** In parallel with developing a logic framework for the resource allocation problem, the team developed appropriate processes and logic to put the logic framework to practical use, recognizing that there is a significant variety of user approaches and program structures for preservation resource allocation. These processes will help to guide state DOTs in optimizing resource allocation in a way that recognizes preservation resource needs and reflects programmatic priorities and system performance goals for asset condition and life.
5. **Test and Demonstrate the Logic Framework.** An initial solution model was developed for demonstration of the logic based on plausible state preservation program structures and underlying data sets for asset inventories, costs, deterioration rates, asset condition, and performance goals. This data set was adapted from real state DOT data gathered from document research and prior project experience of the research team. This solution model was demonstrated for the NCHRP Project 14-21 panel, and then further tested in two case applications and a workshop with panel members and resource management subject matter experts (SME). These cases engaged real-world processes and program structures extant at two state DOTs. After the casework and workshop, numerous refinements and streamlining changes were made to the logic framework based on the findings. The refinements were made to provide greater flexibility and scalability in the preservation program asset and activity taxonomies that can be applied as well as to accommodate realities in the availability and quality of key data

sets and estimates needed to fully exercise the optimization potential of the solution. The latter accommodation will support useful application of the logic framework with which data and estimates are presently available while enabling the phasing in of more features when that data is developed.

6. **Finalize the Framework.** Based on the results of the case studies and the workshop, the research team developed a streamlined Excel-based solution model that permits users to enter appropriate preservation program taxonomies, information on available data sets, and program priorities and goals. The model is scalable to a wide set of user-defined asset/activity groupings (AAG) and multiple districts (statewide allocations can be rolled up from district totals or computed as a "single" district). The model incorporates comments and findings from the workshop, and it offers optimized allocations across all AAGs that are supported by data or reasonable estimates of inventory, average condition, deterioration rates, and unit costs. For specific AAGs that are not supported by this data or reasonable estimates for these factors, alternative optimization approaches are built in. Particulars on these options are treated extensively in Chapter 6, and example versions of the model solutions are found in the text and Appendix E.

1.2 Organization of the Report

This report summarizes the methodology for developing an analysis framework that state DOTs can use as a guide to allocate limited resources to maintain crucial transportation and highway assets. The following describes the organization of this report:

- **Chapter 2: Literature Review.** This chapter addresses the current state-of-the-practice in preservation resource allocation.
- **Chapter 3: Resource Allocation Solution Context and Requirements.** This chapter describes the decisionmaking context for preservation resource allocation within state DOTs. This includes determining the appropriate objectives and the constraints on the process.
- **Chapter 4: Resource Allocation Logic Framework Development.** This chapter formulates the resource allocation computational model as a basis for optimization.
- **Chapter 5: Case Studies and Workshop Findings.** This chapter describes the key findings from the case studies and workshop that were conducted to test application of the Resource Allocation Logic Framework.
- **Chapter 6: Resource Allocation Logic Framework.** This chapter describes the solutions developed to optimize resource allocation. Assumptions, formulae, data and estimates, prioritization, and optimization logic are discussed and detailed with examples. It provides alternative approaches for application of the logic framework as well as key considerations in data collection and estimation of key factors, including deterioration and unit costs. A companion demonstration model (in Excel workbook format) is available on the NCHRP Project 14-21 web page at www.trb.org.
- **Chapter 7: Conclusion.** This chapter wraps up key lessons learned from the research and casework, summarizing a number of key challenges for DOTs to address in adopting the Resource Allocation Logic Framework in support of agencies' regular allocation processes. Suggestions are offered to facilitate understanding, acceptance, and deployment of the logic framework.
- **Appendix A.** Literature Review Summary
- **Appendix B.** State DOT Interview Guidebook
- **Appendix C.** References
- **Appendix D.** Acronyms
- **Appendix E.** Instructions to Activate Solver in Excel Program

CHAPTER 2

Literature Review

The research team began the work by augmenting our understanding of the current state-of-the-practice in resource allocation. We focused on the policies and principles that typically govern the practices in use as well as the data, methods, and constraints that affect preservation resource allocation decisions. The research team (a) reviewed relevant information available in current literature—research articles, journals, NCHRP reports and so on and (b) interviewed cognizant managers at nine state DOTs to understand the logic process and decisionmaking tools used to allocate preservation funds.

The research team's review of relevant reports, journals, and articles found that useful literature on preservation resource allocation is limited. In general, there is a lack of information on how state DOTs actually conduct or practice preservation resource allocation. For instance, limited information is available on the following:

- Processes adopted to develop preservation budget at the state and district levels
- Factors that affect the resources available for preservation
- Logic process that state DOTs adopt to allocate preservation resources across different highway assets and districts/regions
- The role of performance measures and targets in the preservation resource allocation process
- Data, analytical tools, and methods used to support preservation resource allocation decisions

The team interviewed managers involved in the resource allocation process at the following state DOTs:

- Florida
- Maryland
- Michigan
- Minnesota
- Nevada
- Oregon
- Wyoming
- Utah
- Washington

The interviews were typically an hour long and involved three or four state DOT participants. The team sent relevant materials and an interview guide in advance to the point of contact at each state DOT to ensure selection of the appropriate participants and allow them to prepare for the discussion. Appendix B provides the interview guide. Typical participants in the interviews included representatives from maintenance management, pavement management, bridge management, capital programs, asset management, traffic and safety, and planning.

2.1 Business Case

2.1.1 Defining Highway Preservation

The team established a working definition of *preservation*—actions to restore and maintain assets in good condition and to extend useful service life. The following definition of *preservation maintenance* is from *NCHRP Report 551*(*1*):

Definition of System Preservation (Source: *NCHRP Report 551* (*1*))

System preservation encompasses work to extend the life of existing facilities (and associated hardware and equipment) and to repair damage that impedes mobility or safety. The purpose of system preservation is to retain the existing value of an asset and its ability to perform as designed. System preservation counters the wear and tear of physical infrastructure that occurs over time due to traffic loading, climate, crashes, and aging. **It is accomplished through both capital projects and maintenance actions.**

The Federal Highway Administration (FHWA) (*2*) and Bridge Preservation Expert Task Group (BPETG) (*3*) have developed definitions for *pavement* and *bridge preservation.* Per BPETG, "For a treatment to be considered pavement preservation, one must consider its intended purpose. As shown in table 1, the distinctive characteristics of pavement preservation activities are that they restore the function of the existing system and extend its service life, not increase its capacity or strength." According to an FHWA memorandum (*2*) to local and state transportation agencies, pavement preservation includes three components:

- **Minor Rehabilitation.** This includes structural enhancements that extend the service life of highway systems or improve its load-carrying capacity.
- **Preventive Maintenance.** This includes cost-effective treatment of the existing roadway to retard future deterioration and maintain or improve the functional condition of the system without significantly increasing the structural capacity.
- **Some Routine Maintenance Activities.** This includes planned work performed on a routine basis to maintain and preserve the condition of the highway system or to respond to specific conditions and events that restore the highway system to an adequate level of service (LOS).

Depending on the timing of the application, nature of the distress, and type of activity, certain routine maintenance activities are classified as preservation and eligible for federal funding. Any corrective maintenance that is not part of planned maintenance is normally not considered part of preservation under these definitions and guidelines.

The same memorandum explains and provides examples for these three components. *Minor rehabilitation* refers to nonstructural enhancements necessary because of age and environmental exposure. Examples of preventive maintenance activities include asphalt crack sealing; chip sealing; slurry or micro-surfacing; thin and ultra-thin, hot-mix asphalt overlay; concrete joint sealing; diamond grinding; dowel-bar retrofit; and isolated, partial, or full-depth concrete repairs to restore functionality of the slab (e.g., edge spalls or corner breaks). Examples of pavement-related routine maintenance activities include cleaning of roadside ditches and structures, maintenance of pavement markings and crack filling, pothole patching, and isolated overlays.

The state DOT interviews revealed that many states consider some routine preventive maintenance, corrective maintenance, and minor rehabilitation work activities to be part of the preservation program, because they are important to extending useful life. Most of the state DOTs interviewed actually allocate preservation resources based (at least in part) on factors driven by asset condition and actual or expected service levels. Many states also determine resource allocation for typical "routine maintenance" (e.g., locally performed pothole repair, crack sealing) based on historical factors (e.g., last year's budget and district staffing levels for this work).

Ideally, determination of *preservation* needs should consider measures and estimates of the *expected useful life* of an asset along with condition and traffic load factors. Only a few of our interviewees indicated this orientation, and we recognize that there is a difference of opinion on the precision and certainty of measures associated with useful life estimates.

The boundary between preservation and maintenance is obscure, and states use leeway in interpreting the guidelines on this. However, the interpretive issue is not a critical problem in developing the framework for preservation resource allocation.

2.1.2 Resource Allocation Processes

In addition to the interview findings, the research team relied heavily on two NCHRP products: NCHRP Project 20-68 scan tour report (*4*) and *NCHRP Web-Only Document 154* (*5*).

These discussions provide an overview of the following:

- State DOTs' organization context and stakeholders in budget development and resource allocation
- Preservation resource allocation process, addressing the broader context within which preservation allocation decisions are typically made, development of budget, allocation of funds across various programs, and allocation of resources within the preservation program

2.1.2.1 Organizational Context

State DOTs are typically hierarchical organizations, with a cabinet-level officer as the highest ranking transportation official. This officer is usually under oversight by a transportation commission or legislative committee. There is no standard organizational structure; however, the central office under direction by the top official typically executes policymaking, planning, programming, budgeting, and administrative functions.

In some states, district administrators and officials are directly accountable to the top official for both preserving and maintaining the highway assets and have a strong role in top-level decisionmaking on program priorities and geographic distribution of resources for preservation of most asset groups. This is a decentralized model as defined below.

Our interviews revealed that a more centralized model is common, where much of the preservation resource allocation decisionmaking appears to take place centrally. We also observed hybrid versions, particularly regarding bridge preservation programs (usually centrally managed) or statewide safety or mobility programs:

- In a **centralized model,** the central office leads the development of the budget, definition of needs, identification of improvements or projects, and direction of preservation resources. The regional or district offices typically support the budget development process by providing inputs requested by the central office and refine the projects identified by the central office. The states that have strong legislative oversight tend to have a centralized model.

- In a **decentralized model,** the regional or district offices have more autonomy in the development of the budgets, definition of needs, and decisions on significant improvement or preservation projects. In this model, the central office may provide support in the budget development process and usually provides guidance on project selection by the district offices.
- The **hybrid model** is a blend of both centralized and decentralized models, with specific variations based on program. For example, the initial allocation to all programs is made centrally, with virtually all bridge projects prioritized, selected, and administered centrally; pavement preservation projects are budgeted and recommended centrally, but specific pavement projects are selected and managed in the districts. Resources for other programs, such as traffic, safety, and roadside asset preservation, also tend to exhibit variations on this hybrid model. Overall, the interviews showed that this model is the more common context for typical resource allocation approaches.

2.1.2.2 Process Context for Resource Allocation

Figure 2-1 summarizes the overall resource allocation logic flow that we observed, notwithstanding the specific organizational models or state DOT entities studied. This is context for the preservation resource allocation processes that are the primary focus of this research.

The state DOT's policy, performance goals, and priorities drive the overall allocation process. The overall highway budget can include tax revenues, user fee collections, federal funding, credits, and funding from other sources. The DOT organizes funds with certain mandates, constraints, rules, or policies on their specific use. The DOT prioritizes budgets for each program (including the preservation program) and designates funding based on high-level strategies, policies, and performance objectives for the highway program. This prioritization involves DOT executive leadership and may involve state legislative committees or oversight commissions as well as other stakeholder interests outside of the DOT. Methodology, rationale, and analytic support for this decisionmaking vary significantly in practice, ranging from negotiation and adjustment of historical "shares" for various programs to data-driven decision models based on program performance and need.

The following sections discuss findings in performance targeting, prioritization among programs, and allocation within preservation programs.

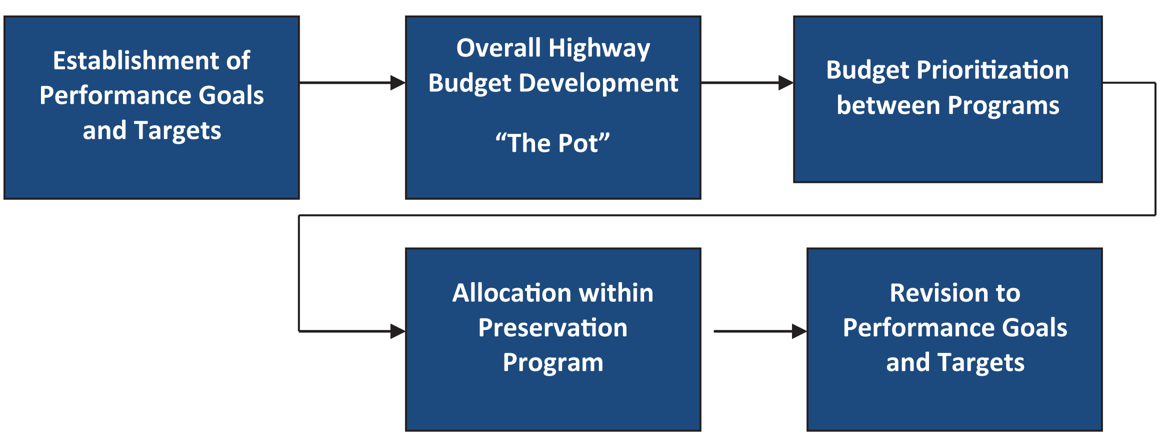

Figure 2-1. Logic process adopted by state DOTs to allocate highway resources.

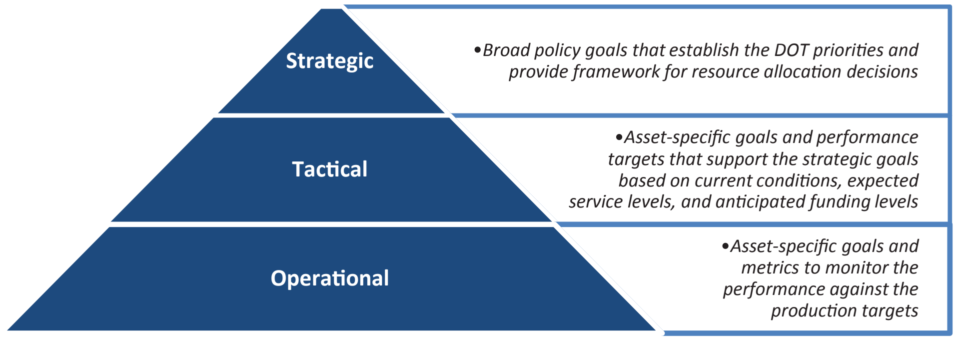

Figure 2-2. Performance goals and targets by level.

2.1.2.2.1 Establishment of Performance Goals and Targets. Setting performance goals is usually a tiered process and occurs at the strategic, tactical, and operational levels, as shown in Figure 2-2.

At the top tier, the state legislature, state transportation commission or advisory committee, governor, and executive leadership usually define the strategic policy framework and the blueprint to make investment decisions. These goals and targets are usually broad and are not frequently updated. For example, Washington State law establishes the following policy goals for its transportation program:

Washington State law (RCW 47.04.280) establishes the policy goals for the transportation program

Preservation. To maintain, preserve, and extend the life and utility of prior investments in transportation systems and services.

Safety. To provide for and improve the safety and security of transportation customers and the system.

Mobility. To improve the predictable movement of goods and people throughout the state.

Environment. To enhance Washington's quality of life through transportation investments that promote energy conservation, enhance healthy communities, and protect the environment.

Stewardship. To continuously improve the quality, effectiveness, and efficiency of the transportation system.

At a tactical level, the goals and targets are typically more asset specific (although still high level) and support the strategic goals and policies. These goals and targets are updated more often (i.e., annually or once every 2 years) depending on budget cycles. The target values for the performance metrics are determined based on the current asset condition and projected asset condition and may be constrained by resource availability for the cycle. Pavement condition indices and bridge condition indices are a few examples of asset-specific performance metrics at the tactical level. For example, the Florida state legislature defines the following performance targets for the state highway system:

Performance Targets Established in the Florida State Legislature

- Ensure that 80 percent of the pavement on the state highway system meets department standards.
- Ensure that 90 percent of the department-maintained bridges meet department standards.
- Ensure that the department achieves 100 percent of acceptable maintenance standard on the state highway system.

Finally, at an operational level, central or district offices (depending on the program and management model) assess needs and typically use inventory-specific and condition metrics for pavement and bridges. In some cases, this has been extended to other asset groups. These goals and targets are also sometimes updated annually or once every 2 years, depending on the DOT budget cycle.

2.1.2.2.2 Budget Prioritization among Programs. There are varying degrees of state legislature involvement in program budget prioritization decisions. In states with legislature playing an active role in these decisions, mandates or statutes might define how the funds should be distributed across different programs and even to districts (e.g., using a formula basis). It is not uncommon for state legislatures or transportation commissions to define and mandate specific policy goals and priorities and set performance standards for various programs within the highway program.

Budget prioritization typically follows the program structure established in each state's highway program. For example, Washington State's highway program has two main components: the Preservation Program and the Improvement Program. Other states break out more programs at the top level (e.g., preservation, safety, mobility, expansion, maintenance). Either way, most highway management resources flow through these programs after funding is divided among them. Figure 2-3 presents an example highway program structure.

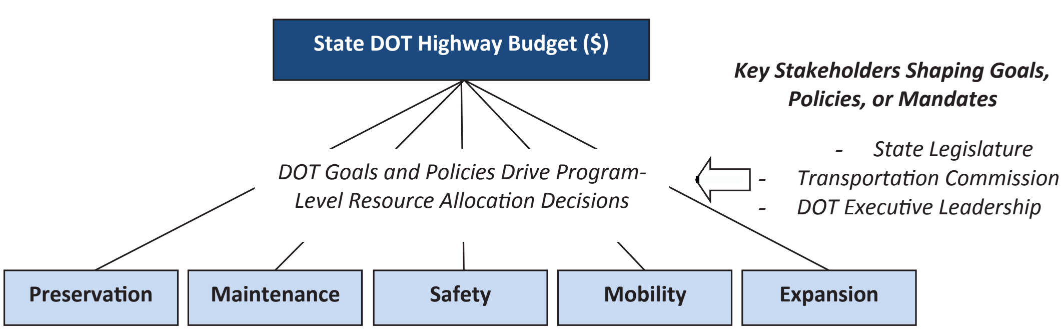

Figure 2-3. Program budget prioritization—typical.

Many of the interviewed states prioritize safety and preservation needs over other programs. They fund emergency programs, including snow removal and high-priority rehabilitation activities, separately or off the top, followed by other prioritized programs.

The following are some examples of program-level prioritization:

- In Florida, the Florida DOT Executive Board, which is composed of a department secretary, assistant secretaries, deputy secretaries, and program heads, is involved in resource allocation. In Florida, the state legislature requires funding the preservation and maintenance of the existing highway system first. The state legislature also has a formula for distributing discretionary capital funds, as needed.
- In Minnesota, Chapter 152 legislative direction provides guidance for prioritizing programs. Until 2004, the Minnesota DOT regarded preservation as a top priority and fully funded the preservation program over safety, mobility, and local community needs. Since then, because of divergence between the projected costs and anticipated revenues, the state has realized that this is not sustainable and has sought to implement a more balanced budget program.
- The Utah Transportation Commission is the governing body responsible for making the state's investment policies and setting strategic goals. The first priority is system preservation, followed by system performance improvement, and then capacity enhancement.
- In Wyoming, program priority and resource allocation decisions are primarily based on the input provided by the district offices and the DOT executive staff. The state legislature is not actively involved in resource allocation decisions.

2.1.2.3 Resource Allocation within the Preservation Program

Our interviews and recent work with state DOTs found wide variations in approaches and the rationale for resource allocation decisions within preservation programs. All of the observed approaches have the following common objectives:

- Allocation of preservation resources to two primary asset groups (bridges, pavements)
- Allocation of preservation resources to other asset groups, including drainage, signs, guardrail, lighting, sound barriers, grouped in various ways
- Allocation of resources to specific districts, locations, roadway classifications, or projects

Our interviews and recent work also found wide variations in the execution of resource allocation approaches:

- Basis for resource allocation decisions—whether history driven, inventory driven, or needs driven
- Tools for decisionmaking—whether useful measures, models, and analytic models are available to facilitate and support allocation decisions
- Process for reaching resource allocation decisions—whether the logic process is top-down, bottom-up, or a combination of both, depending on asset grouping
- Accountability and control of resource allocation—centralized or decentralized

We found from the available literature and our interviews that most state DOTs reported using a data-driven, performance-based approach to resource allocation. In those cases, the performance measures and targets play three key roles in assessing the results of year-to-year investments. Resource allocation decision practices within preservation programs also range from history-based to much more sophisticated models, and most approaches incorporate bridge and pavement inventory and condition data as a foundation for decisionmaking.

Confidence was generally high in available inventory and specific condition-rating information for bridge and pavement assets. All states interviewed reported having a Bridge Management System (BMS) and a Pavement Management System (PMS) that track and monitor the condition of the bridges and pavements, respectively. State DOTs widely adopt the ability to forecast asset conditions based on varying investment levels for bridges and pavements.

Confidence was not as evident for the availability of inventory and condition data for other system assets; only a few DOTs had specific programs or methods in place to assess needs/condition for their other asset categories. Allocation for these tended to be based on a combination of historical budgets and periodic sample condition surveys to determine whether adjustments to allocations were needed.

We found a preponderance of top-down centralized approaches to allocation of preservation resources. Generally, control of allocations and project selection was centralized for bridge preservation. For pavements, allocation tended to be centralized, but districts had greater influence on specific project selection and execution. Allocations for other asset types were generally less specific as to the particular asset types to be invested in, and control of project selection and execution was at the district level.

Another dimension to resource allocation is the use of various analytical methods and tools to assess and compare the cost and benefits of alternative treatments and to identify the best treatment for the individual assets. A common principle used by the states is identification of preservation investments that can maximize the useful life of the asset. Fairly sophisticated analysis tools and models are necessary for resource allocation tools to effectively target extension of useful asset life. These tools would need to integrate reliable condition data with cost–benefit algorithms to address both estimated remaining asset life and projected deterioration. One of the DOTs interviewed indicated it already uses lowest life-cycle cost and benefit–cost approaches to identify improvements and to select preservation projects.

2.2 Data Collected and Maintained for Resource Allocation

To support resource allocation decisions, most state DOTs collect and maintain asset inventory and condition/performance data. The research team collected numerous samples and state-specific examples of this information, which were used to develop case information. This section provides an overview and characterization of inventory and condition/performance data in use.

2.2.1 Asset Data

State DOTs spend significant effort to collect and maintain asset inventory data. Most DOTs interviewed have good bridge and pavement information. As shown in the Table 2-1, according to interviews conducted with nine state DOT agencies, information needed for data-driven resource allocation is typically much more limited for other asset types.

The data overview indicates the challenge practitioners face in implementing data-driven resource allocation logic that reflects needs. Outside the bridge/pavement area, condition and performance data is usually limited to estimation based on sample inspection programs. This can be acceptable for the purpose intended but is nevertheless costly to manage and perform. The need for consistent inspection protocols and sufficient frequency of inspection rounds to support the business cycles drives the cost of this kind of effort.

In a technical sense, inventory and condition/performance data is useful for managing the quality of service (e.g., safety, function) that an asset provides but is not sufficient alone to address useful life, which is intended to be a principal objective of preservation programs. To assess useful life as part of preservation resource allocation logic, reasonable estimates need to be

Table 2-1. Asset data overview.

Asset Group	Example Types	Data Collected/Estimated/Maintained		
		Inventory	Condition/Performance	Useful Life
Bridges		●	●	◑
Pavements		●	●	◔
Drainage	Culverts	●	◕	○
	Drains	◕	◔	○
	Pipe	◑	◔	○
Safety	Signals	●	◕	◔
	Lighting	◕	◑	○
	Signs	◕	◕	◔
	Marking	●	◕	◔
	Guardrail	◕	◔	○
Roadside	Shoulders	●	◑	○
	Barriers	◕	◔	○
	Walks	◕	○	○
	Landscape	◑	◔	○
Others	Toll Plazas	●	◔	○
	Weigh Station	●	◔	○
	Rest Areas	●	◑	○

● = All maintain useful data
◕ = Most maintain useful data
◑ = Some maintain useful data
◔ = Few maintain useful data
○ = Rarely maintain this data

added for factors driving asset deterioration (e.g., traffic loads, accidental damage rates). Standards for useful life assumptions are also needed for particular assets as well as knowledge of the present status of the asset in its useful life cycle. As can be expected, there is a growing body of knowledge in this area for bridge and pavement but little useful research for other assets. Nevertheless, reasonable assumptions and principles can be applied to other assets to aid resource allocation logic, as long as the application is consistent and until sufficient results accumulate to adjust them.

2.2.1.1 Bridges and Pavements

Most state DOTs have detailed bridge and pavement data that usually spans several years. Bridge and pavement data are typically collected through coordination between the central and regional or district offices and maintained centrally at the state level. The data directly feeds the BMS and PMS.

Most state DOTs have developed guidance manuals on how and what data should be collected and maintained to monitor the bridge and pavement performance. Data collection occurs on an annual or less frequent basis. The data-collection process is typically a survey of sample data but, in some cases, is more comprehensive. For example, some states collect the pavement condition data on all state and interstate highways annually, while collecting arterial and local road data less frequently. Sensor-mounted vehicles typically collect pavement condition data, although some DOTs continue to use visual inspection. Typical data elements captured address rutting, cracking, International Roughness Index (IRI), coverage and faulting, ride quality, and structure or pavement quality. Bridge inspection and rating are performed using broadly accepted standard inspection protocols and rate various elements of the bridge structure.

2.2.1.2 Other Highway Assets

Data-collection and maintenance methods for assets other than bridges and pavements are not rigorous, and the existing data's usefulness suffers. For example, states usually have at least inventory and (sometimes) condition status data on traffic signals maintained in central or local database systems. For other assets, inventory and condition data are not available except as approximations or may only be obtained from field books and records filed at the regional or district maintenance offices for other purposes. Visual inspection is the most common method of collecting data for most non-bridge/pavement (NBP) assets, and much of this inspection is either ad hoc or performed on a sample basis.

2.2.2 Asset Data Management Systems

The Intermodal Surface Transportation Equity Act (ISTEA) mandated that states implement management systems for highway pavement, bridges, highway safety, traffic congestion, public transportation facilities and equipment, and intermodal transportation facilities and systems. In response, most state DOTs have developed data management systems to support asset management practices and to comply with any federal or state mandates. However, these data management systems are typically not designed or implemented to support resource allocation processes as a functional objective. Although most states typically follow federal guidelines for data collection, the standards are scarce on how certain types of data are to be collected, stored, or reported. Most agencies have data-collection programs in place and possess significant amounts of data. However, with the development of asset management strategies, some states have implemented approaches to integrate various asset-specific data elements to help optimize asset management decisions. Our research does not focus on asset management, which involves planning decisions to balance and optimize acquisition, maintenance, preservation, rehabilitation, or replacement of assets. Rather, we address resource allocation logic frameworks for preservation—a subset or outgrowth of asset management. Table 2-2 summarizes information on the most common asset data systems in use by state agencies.

2.2.3 Performance Measures

The central office usually handles the formulation of policy goals and definition of performance measures to ensure consistency in data collection and measurement. Many state DOTs now use performance measures to monitor the performance of their investments, and some have linked the resource allocation decisions to current and targeted performance levels.

Performance measures are typically used to help determine the investment needs necessary to meet state DOTs' statewide goals pertaining to preservation, safety, and mobility. In general, the performance measures that state DOTs use to evaluate the performance of bridges and pavements are similar, consistent among states, and well defined when compared to the performance measures used for other asset types. In most states, only limited information is available on performance for asset categories other than bridges and pavements.

Most states either have or are in the process of establishing programs to collect performance measures for asset types, at least for the mandated programs. Table 2-3 lists some commonly used performance measures.

NCHRP Report 551 recommends measures that are suitable to support resource allocation logic for broader program prioritization (see Table 2-4). Appendix A provides excerpts from the report.

Most states have adopted a performance-based resource allocation process model, where practical, and they also use system-level performance measures to help assess and report key results of preservation activities.

Table 2-2. Asset data systems common to state DOTs (*4*) (*6*).

Data Category	Database System
Roadway Data	**Highway Performance Management System (HPMS).** Includes data in highway inventory, condition, performance, and operations. It also describes functional characteristics, performance, and operations. **PMS Database.** Most state agencies collect pavement data to support PMS, but there is no standard format for how the information is collected and stored. Different state agencies collect different pavement data, and examples of pavement data include pavement type, lane width, shoulder width, number of lanes, layer thickness, pavement layer material, drainage, subgrade type, cracking, IRI, and rutting data.
Structure Data	**National Bridge Inventory (NBI).** NBI is a federally mandated database of bridge inventory and conditions, and this data is submitted to FHWA. The NBI data set contains condition/rating data by bridge component: deck, superstructure, substructure, channel/channel protection, and culvert. It also contains data on a bridge's functionality, such as under clearances and load-posting information. **Pontis BMS.** The Pontis database contains additional data on the distribution of conditions by condition state for each structural element of the superstructure, including elements such as girders, stringers, and floor beams.
Safety Feature and Facility Data	Most state DOTs collect and maintain asset inventory data of their safety features and facilities. The data is stored in a variety of ways, ranging from filed books to database applications. There are no standards for collecting asset data for safety features and facilities, and data availability varies from one agency to another. LOS is commonly used to support performance-based budgeting or resource allocation. Commonly used safety data includes Fatality Analysis Reporting System (FARS), Highway Safety Information System (HSIS), State Crash Data Systems, and State Highway Safety Improvement Plans (HSIP).
Mobility Data	State DOTs typically use HPMS as a source of mobility data. The FHWA Highway Economic Requirements System (HERS-ST) uses HPMS data to generate mobility measures. Most state DOTs maintain databases for tracking highway inventory and traffic data in addition to what they report to FHWA through the HPMS Program. However, there are no standards for how and what additional data are collected and stored.

Although many agencies maintain and use high-level performance measures, there is little consensus on accepted principles for setting realistic performance targets (*5*). Setting targets too high can lead to over-investment and, at the same time, failure to meet expectations. Setting targets too low can lead to under-investment and reduced performance—not a good return on any investment. The basic need is to establish better data and experience on the actual relationships between investment levels and performance. The most likely approach to this is to (1) apply a

Table 2-3. Common performance measures for asset types (based on state DOT interviews).

Asset Types	Example Performance Measures
Safety	Accident occurrence and fatality rates
Pavement	Ride quality, roughness index, crack, potholes, depressions, pavement markers, usage
Bridges	Bridge condition rating, structural appearance, roughness index, safety
Mobility	Congestion delays, peak volumes
Signals	Operating status, inspected condition
Signs	Reflectivity, age
Rest Areas	Inspected condition, complaint levels

Table 2-4. Sample performance measures for program prioritization.

Performance Category	Example Performance Measures
Preservation	Pavement condition index, bridge health index, remaining life, debt index
Mobility and Accessibility	Congested travel, travel time index, average travel time, average travel cost, etc.
Safety	Accident rates, fatality rates, number of crashes
Environment	Air quality, groundwater quality, protected species, noise
Operations and Maintenance	Traffic signal failure rate, incident clearance time, signal and pavement marking retro-reflectivity, customer satisfaction rating
Social Impacts	Customer perception of congestion severity, quality of life
Economic Development	Transportation costs, volume of freight movement
Security	Performance during emergencies, such as flood or fire
Delivery	Efficiency and effectiveness in use of resources and impacts on customers that need to be considered in evaluation of alternative delivery strategies, etc.

consistent methodology for performance-based resource allocation and (2) continually assess accumulated results over time to calibrate key assumptions on the effects of investments on asset performance and useful life expectations.

At this juncture, it is appropriate to distinguish between a framework for allocation of preservation resources and the broader framework and principles commonly understood for asset management. The research team views *asset management* as encompassing a much wider and longer term decisionmaking and priority-setting spectrum involving a balance among capacity building, infrastructure improvement, preservation, maintenance, and operations management. For this process, the research team is focusing specifically on a logic framework for allocation (between asset groups or activities) of resources designated for asset preservation. This is seen as a shorter cycle transactional process that will likely leverage some performance/condition data and deterioration data[1] important to asset management but is focused on optimal allocation of available funds designated for preservation.

Figure 2-4 presents additional examples of key performance measures for preservation and other program objectives. *NCHRP Report 632* (*6*) recommended these for use in the context of interstate highway asset management.

2.3 Analytical or Optimization Techniques

Several state DOTs have taken a data-driven approach to resource allocation in which estimated needs (based on asset data, policy goals, and performance targets) are used to guide resource allocation decisions. State DOTs have adapted existing analysis tools and developed new approaches to do this. This chapter describes commonly used analysis tools and optimization techniques used to allocate resources.

2.3.1 Analysis Tools

To conduct investment analysis that predicts the anticipated change in asset condition for different investment levels, state DOTs employ a variety of analysis tools and techniques. Although the tools used vary from one state to another, most state DOTs use some type of BMS to manage

[1]Including PMS and BMS inventory, condition, deterioration, and cost data.

Category	Asset Type	Measure Type	Measure
Preservation	Pavement	Structural Adequacy	Present Serviceability Rating (PSR) or an agency's pavement condition index
		Ride Quality	International Roughness Index (IRI)
	Bridges	Structural Deficiency	Percent classified as Structurally Deficient (SD), weighted by deck area
	Signs	Asset Performance	Percent functioning as intended
	Pavement Markings/ Delineators	Asset Performance	Percent functioning as intended
	Guardrails	Asset Performance	Percent functioning as intended
Mobility		Travel Time	Travel time index
		Delay	Delay per vehicle in hours
Safety		Crash Rate	Number of crashes expressed as number per year and per VMT
		Fatality Rate	Number of fatalities expressed as number per year and per VMT
Environment		Agency-specific report card of environmental milestones	Pass/fail indication for each measure

Source: Reproduced from NCHRP Report 632.

Figure 2-4. Recommended core performance measures for interstate highway asset management.

bridges and PMS to manage pavements. Most states also typically use either the added functionality of the data management systems or stand-alone tools that interface with the management systems. Apart from bridges and pavements, most states do not use any sophisticated tools and methods to conduct analysis.

Examples of tools adapted for investment analysis include FHWA's HERS-ST (Indiana DOT), Multi-Objective Optimization System, AssetManager NT (Caltrans), Road Quality Forecasting System (Michigan DOT), and Bridge Condition Forecasting System (Michigan DOT). To conduct project-level analysis like benefit–cost analysis or life-cycle cost analysis, states typically use stand-alone tools. These systems use data from other management systems or require project-specific inputs to perform the analysis. In addition, some states have Geographic Information System (GIS)-based tools, databases, and stand-alone Excel spreadsheet systems to collect and maintain data and conduct analysis.

Some states also use special programs such as the Maintenance Rating Program (MRP) to manage data and evaluate funds needed for maintenance activities. The Maintenance Division or Office typically manages these programs, which are used to set the desired levels of service for each asset type. MRP typically provides guidance for conducting a visual and mechanical evaluation of routine highway maintenance conditions. The purpose of this evaluation is to provide information that should be used to schedule and prioritize routine maintenance activities and provide uniform maintenance conditions that meet established departmental objectives.

The analysis tools that state DOTs use vary depending on the level of maturity of the state's asset management program and the volume and quality of data collected and maintained to support the analysis (see Table 2-5). *NCHRP Report 551* presents a summary of common analytical tools available to state DOTs to manage highway assets.

Table 2-5. Summary of analysis tools in use by state DOTs.

Tool	System Type	Available From	Notes
AssetManager NT	Investment analysis	AASHTO	Integrates investment analysis results from multiple sources
AssetManager PT	Needs and Project Evaluation	AASHTO	Prioritizes projects based on user-specified measures
BCA.Net	Needs and Project Evaluation	FHWA	Performs benefit/cost analysis for highway improvements
BLCCA	Needs and Project Evaluation	NCHRP	Bridge preservation life cycle cost analysis
DIETT	Risk Assessment	NCHRP	Prioritizes risks to transportation choke points
HDM-4	Investment Analysis	McTrans, Presses de l'ENPC (Paris)	Simulates highway investment needs, condition and performance
HERS-ST	Investment Analysis	FHWA	Simulates highway investment needs, condition and performance
IDAS	Needs and Project Evaluation	McTrans and PCTrans	Evaluates network impact of ITS improvements
MOOS Bridge Level Model	Needs and Project Evaluation	NCHRP	Assist in developing bridge-level strategies using data from Pontis. Also can be used to prioritize investments to mitigate bridge risks
MOOS Network Level Model	Investment Analysis	NCHRP	Uses data from the bridge-level model to perform multi-objective analysis
NBIAS	Investment Analysis	FHWA	Simulates bridge investment needs, condition and performance
PONTIS	Management System	AASHTO	BMS licensed by most U.S. state DOTs
REALCOST	Needs and Project Evaluation	FHWA	Performs benefit/cost analysis for pavement projects
STEAM	Needs and Project Evaluation	FHWA	Evaluates network impact of multimodal improvements
TRNS*PORT	Results Monitoring	AASHTO	Supports preconstruction, contracting, and construction management

Source: Reproduced from NCHRP Report 632.

2.3.2 Optimization Techniques

The literature review and state DOT interviews revealed the optimization techniques adopted by state DOTs to allocate resources. The following summarizes the key findings:

- Some state DOTs perform tradeoff analysis to determine the impact of varying levels of investment on asset condition and performance for major asset categories, such as pavements and bridges. Based on their practices, states have identified the optimal set of treatments for assets that are in different stages of their life cycle and condition. The states use lowest life-cycle cost, return on investment (ROI) analyses, or benefit–cost optimization while evaluating alternative treatments and choosing a cost-effective treatment.

- It is less common for states to conduct tradeoff analysis between programs or assets to optimize the resource allocation. In fact, one state DOT interviewed mentioned that the allocation of resources across programs and assets depends heavily on priorities and points of view.
- An impediment to the implementation of the techniques to optimize across assets and programs is the availability of quality data, agreed upon performance measures, and target performance values to measure progress across various programs on a consistent basis. States like Utah have taken huge strides to develop cross-asset management systems and use optimization techniques but also acknowledge that realizing the full potential of these systems requires development of metrics that are agreed upon by various stakeholders across various programs.

Most state DOTs recognize the importance of having an analytical approach to make investment decisions—especially given that the resources available are constantly dwindling in comparison with needs. *No known state DOT, however, has adopted a fully integrated cross-asset management approach to allocate resources to meet highway preservation needs.*

2.4 Outputs and Reporting

State DOTs recognize the importance of communicating the benefits or the outcomes of investment choices. State DOTs typically generate the reports to demonstrate the performance of the highway systems to the public. They also use these reports to monitor the system performance and justify the use of funds for preservation activities. To demonstrate the benefit of preservation and maintenance activities, some states publish an annual transportation performance report. These performance reports are typically made public through state DOT websites.

Some state DOTs use performance measure-based scorecards to communicate to the public the improvements that have been made to the transportation system as a result of the investments made in preservation. Other states are still trying to find practical ways to illustrate the benefits of investing in preservation and maintenance activities by focusing on the amount of money saved because of preservation activities and the improved safety of the system through investment in preservation.

The information presented in these typical performance reports published by some state DOTs includes the following:

- Statewide goals and objectives
- Performance measures that are used to monitor the goals
- Description and the process of collecting performance measures
- Current and future condition and performance of bridges
- Current and future condition and performance of pavements
- Safety measures
- Mobility measures
- Environmental measures
- Customer satisfaction

We have not found an example of a report that effectively enumerates the results or benefits (“money in the bank”) of investments to extend infrastructure life—one of the principle objectives of preservation programs. This is because solutions researched and offered have not produced a framework and credible computational model to link multi-asset investments and work done to results in terms of system condition, performance, or life.

2.5 Summary of Findings

The literature review and state DOT interviews provide an understanding of the current state of the practice in resource allocation and provide background resources that were used in the framework development as well as open channels for information sharing on this research. This section summarizes the main findings and presents the information in the standard Strengths, Weaknesses, Opportunities, Threats/Risks (SWOT) format:

- **Strengths.** This includes attributes or components of existing processes or models that are helpful or effective in achieving the resource allocation objective.
- **Weaknesses.** This includes attributes or components that hinder the processes or models from achieving the resource allocation objective.
- **Opportunities.** This includes conditions or additional information helpful in achieving the objective.
- **Threats or Risks.** This includes conditions or constraints that could present barriers to the objective.

2.5.1 Strengths

- Most state DOTs appear to have “preservation” as one of their top priorities in line for resources.
- Most state DOTs use a performance-based resource allocation process for a substantial subset of assets. To support this process, most state DOTs collect detailed asset and performance data.
- The current state-of-the-practice in resource allocation for bridges and pavements is mature in most states. Most state DOTs use asset management support systems, such as BMS or PMS, to help make investment decisions.
- A wealth of data is available on the performance and conditions of bridges and pavements, and some state DOTs use analysis tools to prioritize projects for these assets and forecast future conditions.
- Some state DOTs perform tradeoff analysis to determine what performance levels can be achieved for different levels of investments.
- States heavily use historical data to help guide the resource allocation process. This provides some consistency and limits major swings in how the assets are treated on a yearly basis.
- In some states, districts exercise extensive flexibility in the allocation and use of preservation funding.
- Most states realize the importance of having GIS and other tools to manage their asset data. States that do not have these tools are working toward developing them.
- Several states have programs in place to monitor the performance of the investments made in preservation.

2.5.2 Weaknesses

- Integration of multiple databases systems, such as PMS, BMS, and other asset inventories and databases, is not commonly practiced in the industry.
- Available data, analysis tools, and optimization techniques for assets other than bridges and pavements are generally rudimentary.
- Although the data-collection techniques and procedures are well established and standardized for bridges and pavements, most DOTs have limited standards for collecting and managing inventory and condition data for other asset types.
- Techniques for estimating *preservation* results (or extension of useful asset life) have been researched but are not widely accepted or used as part of the budgeting or resource allocation processes for preservation investment.

2.5.3 Opportunities

- Encourage state DOTs to collect data and performance measure standards for asset types, such as signals, signs, and guardrails, to better manage preservation needs for these assets.
- Encourage development and use of integrated data systems to manage asset and performance data for assets other than bridges and pavements.
- Consider better risk analysis as a part of the supporting rationale for investment prioritization for some asset types (e.g., bridges, traffic signals).
- Improve resource allocation optimization and tools.
- Make the Resource Allocation Logic Framework understandable and accessible to a wide DOT audience, including executive management, policymakers, legislators, program managers, and district managers.
- Develop a framework that is generic in application but provides principles and insight to state DOTs in adapting it to their respective business and operating structures.

2.5.4 Threats or Risks

- Optimization programs that apply operation research principles are likely to be considered black-box models.
- Analytical approaches and optimization techniques tend to produce scientific rather than practical solutions in the public sector, unless they have flexibility to incorporate mandates, decision thresholds, policy decisions, and other adjustments.
- Levels of estimating precision—though appropriate for support of high-level allocation decisions—may be unacceptable for those seeking to use the framework for unintended purposes that it cannot support.

CHAPTER 3

Resource Allocation Solution Context and Requirements

The primary objective of the Resource Allocation Logic Framework developed as a part of this project is to assist state DOTs in choosing the right mix of preservation investments given policy, funding, organizational, and other legislative and programmatic constraints. It is desirable to have a Resource Allocation Logic Framework that can assist state DOTs in adapting preservation investment strategies to accommodate legislative mandates and DOT goals, objectives, and priorities. Also, the Resource Allocation Logic Framework will be useful in assisting state DOTs and other key decisionmakers in evaluating and testing the impact of preservation funding allocation decisions on overall system performance. To satisfy these needs, funding should be linked to preservation needs and expected results and vice versa.

Resource allocation decisions are typically made based on a variety of policy, organizational, programmatic, and performance-based constraints and variables that present a challenge to state DOTs in meeting both their required and desired highway preservation needs. Figure 3-1 depicts the overall decisionmaking context for highway preservation resource allocation.

The linkage of investments to preservation needs and results across all assets has historically been a difficult and unmet challenge for highway agencies. This inability to link investments to needs and results has also been the bane of ROI models intended to support broader, overarching asset management decisionmaking. Partial progress has been made in addressing maintenance and preservation needs for bridge and pavement assets thanks to well-established systems that support planning for those assets. But other roadside and highway network assets do not benefit from similar planning systems and tend to be treated arbitrarily or neglected, even though they are important to the health, safety, and operational efficiency of the highway network.

Based on the literature review, technical experience, and input from panel members, the research team defined the highway preservation resource allocation challenge in the following sections.

3.1 Problem Statement

A crucial step in formulating an optimization model is constructing the objective function.

In a constrained[2] resource allocation process, decisionmakers typically have competing objectives to achieve, recognizing that not all objectives can be fully met in a given allocation time cycle. These objectives include reducing traffic accidents and fatalities related to an aging infrastructure, maximizing the lifespan of a particular asset type, and improving users' travel experience and quality of life. Objectives may in some cases be asset type specific. For example, DOTs

[2] Examples of constraints include funding limits, mandated requirements, and practical limits to the extent that allocations can be adjusted in each allocation time cycle without severe operational impact.

Figure 3-1. Decisionmaking context for allocating preservation funds.

may be specifically mandated to maximize bridge or pavement condition ratings, which are typically the most reported and most visible indicators of system health. Legislators, agency directors, transportation commissions, and the public expect these objectives to be achieved within specified timeframes or as soon as realistically possible.[3] To ensure that investments in preservation and maintenance are strategic and meet state goals and objectives, it is necessary to prioritize asset- or program-specific objectives to influence the allocation results.

Given these realities, *the objective of the allocation logic model is to effectively balance the preservation of the entire asset network and to progress toward specified goals, objectives, and expected measures in a desired time period.*

The object of this research is to develop a high-level framework to optimally allocate resources over major asset and activity groupings based on preservation needs and adjust them optimally based on user-selected priorities and goals. The framework will *not* be granular enough to support specific project planning and selection decisions, and it is not so intended.

3.2 Resource Allocation Solution Requirements

On defining the problem statement, the research team investigated best approaches to developing a Resource Allocation Logic Framework that most state DOTs can use to allocate resources across different asset types or preservation activities. The research team found that although there is some commonality in the terms used to describe asset types, there are many variations in the taxonomy that states employ to allocate for, account for, and execute preservation activities.

The research team used the information gathered on the state of the practice in resource allocation (through a literature review and phone interviews, as detailed in Chapter 2) to develop a Resource Allocation Logic Framework. The Resource Allocation Logic Framework is not meant to put the resource allocation challenges in a "black box"; rather, it is meant to supply an analytical approach that will make resource allocation decisions faster, more logically supportable, and transparent to users.

[3]This is an important issue for the allocation framework, because in contrast with the relatively short cycles of typical allocation processes, average highway system performance ratings improve or deteriorate slowly over time.

The following key features are among those necessary to make the Resource Allocation Logic Framework usable:

- **Flexibility.** The logic framework should be flexible and accommodate different allocation processes and organization structures (e.g., statewide versus district-based allocation), funding constraints, desired and current performance standards, and preservation program taxonomies.
- **Practicality.** The logic framework should be able to link performance expectations with investments for preservation and rely primarily on available, accessible, and reliable data and estimation.
- **User-Friendliness.** The logic framework should depend on optimization and analysis tools and techniques commonly available to state DOTs and allow state DOT staff to easily change and adjust mathematical formulae. It should also be easy to learn and use.

In addition to these key features, the Resource Allocation Logic Framework needs to consider the following:

- Organizational units or members of management who will be making the resource allocation decisions for highway preservation needs
- Appropriate and pertinent strategic objectives or relative importance of preserving specific asset types or executing specific preservation activities to agency goals
- Constraints and committed projects
- Target performance or condition ratings for each asset type or activity
- Target timelines to reach the desired performance targets
- Total funds needed to meet the performance targets (by asset types)
- Legislative mandates and investment guidance that establish funding priorities or set aside specific investments
- Credible estimates of preservation needs to support resource allocation decisions

The successful application of operation research techniques hinges on whether users can practically implement the framework immediately or in the reasonable future. It is critical to clearly specify the data or to estimate support needed for the logic framework:

- What data is needed to execute the allocation logic?
- Is the data readily available in most state DOTs?
- What is the required data quality?
- What tools or software packages may be needed to support the analysis process?

3.2.1 Output Expectations for the Allocation Framework

The Resource Allocation Logic Framework should enable users and decisionmakers to identify the optimal investment mix in highway preservation and maintenance to ensure the following:

- Statewide goals and objectives effectively influence the allocations
- Highway assets/activities are funded to progress toward achieving expected performance/condition ratings within funding constraints
- Difference is minimized between targeted time to achieve rating targets and expected actual time to achieve rating targets
- End-of-allocation-cycle rating results are predicted

3.3 Key Considerations

The Resource Allocation Logic Framework should be for general resource allocation solutions, that is, there should be no restricted order (top-down or bottom-up) on how it can be applied. Our literature research shows that agencies often use either the region-centric or asset-centric models to allocate resources, usually in a top-down or bottom-up process. This model is intended to support both approaches. Agencies would be able to use this model repetitively for resource allocation solutions at different organizational or program levels. Although the general form of the objective function should remain the same, agencies are likely to impose different constraints to best suit their needs at each level.

The second key point here is that the logic model should support computational solutions in any direction. That is, public agencies should be able to solve for allocations needed based on performance objectives and constraints; conversely, agencies should be able to solve for performance objectives and timelines that are achievable given funding constraints and adjustments. There may also be the need to test sensitivities of specific input factors, assumptions, and priorities, or to experiment with alternative performance/condition targets.

3.3.1 Linking Allocation to Preservation Needs and Targets

The allocation solution is intended to be driven fundamentally by existing preservation investment needs. For any identified grouping of assets or activities,[4] preservation needs over an allocation cycle are a function of the expected *average deterioration* in performance or condition of an asset/activity grouping (AAG), plus the needs associated with any targeted improvement in the performance or condition of the grouping. The following are examples:

- If an average of number of units of an AAG inventory is expected to deteriorate below a minimum performance or condition standard during an allocation cycle, that will determine for that cycle how many *units* of that AAG will need restoration to the as-new (or near-new) standards set for preservation projects
- If the average performance/condition rating of an AAG is *above or below* a targeted performance/condition rating for that AAG, that will help determine how many *fewer or additional units* of that AAG will need restoration to the as-new (or almost-as-new) standards for completed preservation projects to meet the target
- Given the number of units in an AAG that require preservation projects, application of the average AAG *unit cost* for preservation projects will provide a reasonable indication of the preservation investment need for that AAG

Linking investment to needs and results targets requires that for each AAG, actual data or credible estimates are needed, including inventory, average deterioration rate, average performance/condition rating, and average unit costs. These will all be treated more extensively in subsequent chapters, as will the need to accommodate AAGs for which such data is not presently available.

3.3.2 Optimized Resource Allocation

The research and experiences of interviewees clearly indicate that optimizing preservation allocation across asset groupings is a difficult challenge, particularly when or if preservation needs cannot be determined and quantified in normalized terms (e.g., ratings and dollar investments needed). In most cases, program priorities, level of urgency, and tolerable rate of change (e.g., dislocation[5] issues) cannot be factored into the allocation framework in a quantifiable way.

The results are familiar. Initial allocations are typically estimated based on various asset group-specific technical models, engineering judgments, field assessments, and so forth. These

[4] At a known average level of performance or condition.
[5] *Dislocation* refers to the effects of rapid and significant changes in period-to-period allocations that cannot be managed effectively in a practical or cost impact sense for reasons of (as examples) contractual obligations, service commitments and work-in-process, limits of staffing flexibility, lead times for project initiation, and so forth.

are usually combined and adjusted based on top-down programmatic decisions and funding decisions and readjusted based on overall funding limits—often late in the allocation process. The result tends to be driven by arbitrary decisions and tradeoffs. Investment result expectations are indeterminate or, at best, approximations that are difficult to relate later to actual outcomes.

Using a linear programming approach, the solution can begin with computation of quantified needs specific to AAGs that reflect and are derived from performance and condition data, adjusted to available resources in a way that is modulated by AAG ranking, performance targets, and measures of urgency. The computational solver cycles repeatedly until needs and performance goals are met to the greatest extent possible within funding limits.

Developing solutions in this way permits a reasonably accurate depiction of allocation needs for AAG inventories across a state or district jurisdiction. Realistically, use of more precise second-order asset deterioration equations and cost curves would not significantly improve confidence in allocation results, because the computation results are aggregate averages, as are the less precise (somewhat subjective) performance/condition ratings that significantly drive the computations.

A second major feature of the linear programming approach is the ability to compute and simply state performance expectations at the end of each allocation cycle based on the final allocations supported by available funding. This is especially important when funding shortfalls preclude the performance expectations imposed at the outset of the allocation process.

3.3.3 Scope of the Allocation Framework

The research team proposed an allocation framework that can leverage straightforward linear programming techniques to link allocations to results based on estimated or actual average values for inventory, deterioration rate, performance/condition rating, and unit costs. It is assumed for this framework that mandated programs and selected major one-off preservation or rehabilitation projects would be funded as objects of specific plans and programs, with commitments that often extend well beyond typical allocation cycles. Funds for these projects will need to be treated as outside the amounts that would be termed “available” for allocation of preservation resources for the broader “rank and file” inventory of highway system assets.

Within the allocation framework, average deterioration rates and average unit costs for preservation may vary considerably for particular asset types within an asset group. For example, deterioration and unit rehabilitation cost differs considerably between flexible and rigid pavements. The allocation framework and computational model will need to permit these cases to be treated as separate and distinct AAGs.

CHAPTER 4

Resource Allocation Logic Framework Development

This chapter describes the mathematical general computational and optimization approaches employed in the proposed Resource Allocation Logic Framework. To begin with, the basic taxonomy to describe, break down, and roll up allocations will ultimately be user defined as a basic starting point in applying the allocation logic framework. The research team has used several sample elements of such a taxonomy[6] to describe and demonstrate the framework. Examples include bridge structures, pavements, signs, and guardrails. In this report and the demonstration model, we will refer to elements of the preservation program taxonomy with the following terms:

Term	Application	Text Shorthand
Asset/Activity ID	Identifies a grouping of asset inventory/preservation activities with an aggregated data set and allocation	AAID
Asset/Activity Group	Refers to all physical inventory in the state or district with a common AAID	AAG
Asset/Activity Unit	Refers to a typical single unit of measure[7] of an Asset-Inventory Group	AAU

4.1 Computational Logic

Based on the requirements described in the previous chapter, the research team developed a computational solution that will work effectively for all AAGs for which preservation needs determination is adequately supported by necessary data or estimates. For AAGs that are not supported by such data or estimates (usually non-bridge or pavement-related AAGs), alternate methods are employed to approximate preservation needs. Preservation needs estimation is a starting point for the allocation solution, as shown in the following computational sequence overview:

- Total preservation needs for each AAG based on programmatic performance goals
- Preservation needs rolled up to total for all AAGs
- Comparison of total needs to available preservation funds
- If available funding exceeds total preservation needs, make the allocation based on (a) needs to meet stated performance/condition targets and to offset expected deterioration or (b) achieving best performance/condition results with resources available
- If available funding is short of total preservation needs, compute and optimize adjustments to approach performance/condition targets as closely as possible
- Compute expected revised performance results expectations after optimized allocation adjustments

[6] Based on NCHRP research of widely used breakdowns of highway asset types and groupings (discussed later this chapter) as well as on case research that revealed significant variations in the taxonomy used for management of preservation programs.
[7] This report employs sample units of measure such as lane-miles and numbers of bridge decks, but the computation model will permit user definition of these, as well.

A **linear programming** approach is recommended to support resource allocation logic. This approach is advantageous for the following reasons:

- Can be the basis for optimal solutions
- Is commonly used by state DOTs for optimization problems
- Is easy to understand and communicate compared with other optimization techniques
- Is typically user- and data-friendly

Linear programming uses mathematical functions that are available in Excel to solve the resource allocation optimization.

4.2 Solution Components

4.2.1 Decision Variables

The research team identified potential *quantifiable decisions* that can be expected to be made in allocating resources for highway preservation needs. These decisions will be represented as decision variables whose respective values are to be determined. These decision variables represent possible strategies and courses of action that state DOTs and other transportation and public agency managers can take in allocating the highway preservation resources. Examples of these decision variables are the amount of allocated funds to individual asset categories (i.e., dollar amount of allocated funds to an AAG). It is also possible that users will identify other kinds of decision variables for incorporation into the model, such as funding priorities for specific AAGs or specific asset preservation strategies. Certain AAGs could, for example, be designated specifically for light or heavy preservation treatment.

Decision variables are expected to guide the highway preservation resource allocation process and include all relevant characteristics such as policy, organizational, programmatic, and performance that are expected to influence the resource allocation process (relevant research on multi-criteria decisionmaking is found in Reference 7). These may change given state DOT priorities for any given period. Figure 4-1 lists examples of decision variables.

4.2.2 Objective Functions

The purpose of an objective function is to measure the composite effects of the decision variables. Developing a clear, detailed, and quantifiable objective function is a fundamental element

Figure 4-1. Decision variables for consideration in the resource allocation mathematical model.

of the problem formulation and is essential for ensuring that state DOTs are allocating resources optimally and in a manner consistent with state policies, goals, and objectives. From this perspective, the objective function can be quite specific, focusing on certain aspects of highway preservation. At the same time, to be successful, the application of operations research can seek solutions that are optimal for the overall organization rather than suboptimal solutions that are best for only one component.

Given the nature of highway preservation resource allocation, decisionmakers may be expected to develop more than one objective function. Adding more than one objective to an optimization problem adds complexity. For example, if a state's goals are to minimize the life-cycle cost of all asset categories and maximize overall safety benefits from investments in maintenance and rehabilitation, potential conflicts could transpire. In such an event, state DOTs are advised to consider tradeoffs and to combine the two objectives into one, loosening the requirements for each objective.

An objective function in the Resource Allocation Logic Framework is used to determine optimal adjustments to computed preservation investment needs, optimized for a specific results objective. These adjustments to computed investment needs are necessitated by the unlikely case that funds available equal funds needed.

Examples of potential definitions for objective functions include the following:

- Maximize service life expectancy for the foreseeable future; in the allocation context, this translates into maximizing performance/condition ratings for all AAGs in as short a period as practical
- Maximize the performance/condition ratings of one or more AAGs while holding current performance condition ratings for other AAGs; this translates to maximizing the performance/condition rating results for the selected AAGs at the end of the allocation cycle
- Maximize benefits expressed as the sum performance/condition ratings for all AAGs; stated another way, all AAGs progress equally in terms of performance condition, given available funds
- Minimize the differences in percentage progress for each AAG, from initial performance/condition rating to target performance condition rating, expected at the end of the allocation cycle; this translates into all AAGs moving toward performance objectives at rates proportional to their respective performance gaps
- Minimize the difference between desired cycle[8] time (set for each AAG) and the expected actual cycle time (after allocation adjustment) to achieve performance targets for each AAG; if funds available are less than allocations needed, the time to reach performance targets will extend beyond the desired cycle times[9] input by the framework user for each AAG

The research team applied the last objective function to test the Resource Allocation Logic Framework computational model: *Invest in maintenance and preservation projects so as to minimize the deviation between the desired and actual timelines to achieve recommended performance/condition targets.*

Minimize:

$$\sum \textit{Differences for all AAGs between desired time and actual time to achieve performance targets}$$

Readers will see that the use of this objective function works well to test all features of the computational approach. Desired and actual time cycles are also an excellent surrogate for rate of progress toward performance objectives, and they offer ways to set priorities. The other pos-

[8] Allocation cycle.

[9] A key presumption here is that small improvements are possible in a single cycle, but significant changes in average performance/condition rating for an entire AAG inventory will require multiple cycles.

sible objective functions can be tested reasonably well by manipulation of various input values and small adjustments in Excel model equations.

4.2.3 Constraints

The purpose of the constraints is to define the "limits" or "boundaries" of certain aspects that agencies must conform to when they try to maximize overall network performance. The constraints can be broadly classified as policy, organizational, programmatic, or performance in nature. Figure 4-2 lists sample constraints for resource allocation.

From a practical point of view, the constraints include possible restraints or restrictions that DOT managers face in preservation resource allocation. The following are examples:

- Funding constraints on the total preservation program
- Funding constraints on what should or should not be spent on specific AAGs
- Any legislation or mandates directing specific highway preservation activities
- Required interdependencies with investment in other programs
- Limits on the time horizon because of the useful life expectations of specific AAGs

Examples of common predetermined constraints that can be applied within the Resource Allocation Logic Framework include:

- **Total Funding Constraint.** The summation of resources to be allocated should not exceed the funding available for preservation.
- **Minimum Funding Constraint.** The resources allocated to certain asset groups should meet or exceed specific minimum funding amounts or funds needed to meet or exceed minimum performance thresholds.
- **Appropriation Constraint.** The allocated resources must conform to appropriations that are predetermined or mandated by state legislation or agencies for specific programs or asset-preservation objectives.
- **Work-in-Process Constraint.** The allocated resources must account for projects that have been committed to, where interruption or reduction of funding is not in the best interest of the state or network users.
- **Life-Cycle Constraint.** The allocated resources should in some way account for the continued performance or the condition of assets in their near-term life cycle.

Deferred maintenance/preservation from prior periods is sometimes treated as a constraint in deciding allocations, meaning that funds would need to be reserved to "pay back" on deferred needs. In the needs-based computation proposed here, deferred needs would show up in current performance/condition ratings.

Policy	Organizational	Programmatic	Performance
• Legislative mandates on highway preservation	• Minimum funding requirement by region or district • Minimum funding requirement by function • "Fixed" commitments	• Total funds available for preservation • Funding constraints on minimum and maximum funds available for individual preservation AAGs	• Minimal acceptable or targeted level of service; usually mandated • Minimal acceptable safety considerations

Figure 4-2. Sample constraints for resource allocation.

The research team considered how the computational model would take into account resource allocation impact on the future asset preservation life-cycle costs (LCC). This presents difficulties, mainly because resource allocation is typically a "static" process bounded by the current-year funding constraints, while the life-cycle view is on medium- and long-range timelines.

The research team suggests that LCC considerations be addressed or accommodated in several ways in the logic framework:

- In asset management practices, LCC analysis typically addresses optimal intervention tactics to improve asset performance through replacement, repair, preservation projects, or maintenance. Preservation practices and policies would be influenced by LCC findings. For example, pavements can be addressed frequently by light overlay tactics to extend time between more costly surface rehabilitation. Or certain pavement groupings may benefit most from one of these strategies alone, with attendant specific effects on unit cost estimates. The computation could consider multiple AAGs to account for these variations, each with a unique set of inventory, deterioration, condition, and unit cost data in support.
- "Needs" could be determined either as current cycle needs only or include projected needs over a specified future time horizon. In practice, by determining total need and timeline to achieve performance/condition targets, the needs typically extend over a longer time span than the usual allocation cycle.
- To the extent desired, agencies could apply this model to develop a first cut on resource allocation for a range of years (e.g., the next 5 years). Further resource allocation can then be refined year by year. The key point here is that to take into account life-cycle considerations, the yearly resource allocation process would be performed in the context of both current and future needs over longer allocation cycles.

The constraints to be considered are $\sum X_{ij} \leq P_{ij}$ where P_{ij} is the minimum/maximum value to be allocated for a given combination of AAG and preservation needs.

4.3 Data Needs

The data needs for the allocation solution, along with the role played in the computational logic by each data set, are shown in Table 4-1. The first column lists the different user data elements; the second column identifies the terminology used to define the data type (i.e., AAG, AAU). Columns 3, 4, and 5 identify whether the particular data element is used to estimate

Table 4-1. Key data inputs for allocating resources for preservation.

User Data Requirements	Apply To	Role in the Model		
		Need	Optimize	Constraint
AAG taxonomy	AAG	N	O	C
AAG inventory	AAG	N	–	C
AAG units of measure	AAG	N	O	–
AAG ranking and allowable adjustment	AAG	–	O	–
Average unit costs to restore AAUs	AAG	N	–	–
Ideal performance/condition rating	AAU	N	–	–
Current average performance/condition rating	AAG	N	O	C
Target average performance/condition ratings	AAG	N	O	–
Timelines for target rating achievement	AAG	N	–	C
Available total funding for preservation	Total	N	O	C

Table 4-2. Key data inputs for allocating resources for preservation.

User Data Requirements	Apply To	Sensitivity of Result to the Variable Need
AAG inventory	AAG	**High**
AAG units of measure	AAG	**Low**
AAG ranking and allowable adjustment	AAG	**Low**
Average unit costs to restore AAUs	AAG	**High**
Ideal performance/condition rating	**AAU**	**Low**
Current average performance/condition rating	AAG	**High**
Target average performance/condition ratings	AAG	**High**
Timelines for target rating achievement	AAG	**Medium**
Available total funding for preservation	Total	**High**

resource needs, optimize allocation, or calculate constraints for allocating resources, respectively. A value of *N* in the third column (Need) indicates that the particular data element is used in the logic framework to estimate resource need. A value of "O*h*" in column 4 indicates that the data is used in optimization procedure, and a value of *C* in the Constraint column indicates that the data is used to determine lower and upper bounds (constraints) for allocating resources.

The key data inputs used for allocating resources all have an impact on the allocation results. However, the final results are more sensitive to a few input values as compared with the others. Table 4-2 flags the sensitivity of the different variables as High, Medium, and Low.

Table 4-3 summarizes the availability of key allocation inputs in state DOT data management systems.

4.3.1 Asset Activity Groups and Inventory

The AAGs that served as examples for developing the allocation solution were chosen as a result of an extensive literature review and discussions and interviews with panel members and state DOT agencies. State DOTs and other transportation agencies typically manage 11 asset groups that require preservation activities:

- Bridges
- Pavement
- Drainage
- Culverts
- Signal systems
- Signs and marking

Table 4-3. Key data inputs for allocating resources for preservation.

Key Data Elements for Needs-Based Allocation	Bridge and Pavement Assets	Non-Bridge/Pavement Assets
Inventory data for AAGs	Most	Many, for some assets
Performance/condition data for AAGs	Most	Many survey some assets
Average deterioration rates for AAG inventories	Many	Few
Average unit costs to restore a single asset unit (AAU) to condition standard	Many	Few
Historical data on work done and expenditure by AAGs	Most	Most

Table 4-4. Typical asset groups and asset types.

Asset Group	Assets	
Drainage	• Cross pipes • Box culverts • Paved ditches • Unpaved ditches • Entrance pipes • Underdrains	• Edge drains • Storm drain drop inlets • Curb and gutter • Sidewalk and ramps • Stormwater management ponds
Roadside	• Grass • Debris and roadkill • Litter • Landscaping	• Brush • Concrete barriers • Sound barriers • Slopes • Fence
Traffic	• Signals • Signs • Highway lighting • Pavement messages • Pavement markings • Pavement markers • Guardrail	• Traffic detector loops • Impact attenuators • Truck ramps • Overhead signs • Object markers and delineators • Glare foils
Pavement	• Paved lanes – asphalt • Paved lanes – concrete	• Paved shoulders • Unpaved shoulders
Bridges	• Overall bridge • Deck • Joints • Paint	• Substructure • Structural culverts • Retaining walls • Channel and channel protection • Superstructure

Source: Review of Virginia Department of Transportation's Administration of the Interstate Asset Management Contract, Joint Legislative Audit and Review Commission of the Virginia General Assembly.

- Guardrails
- Safety structures
- Lighting
- Roadside
- Landscaping

Table 4-4 shows a sample asset management taxonomy used by Virginia DOT.

There are two things to bear in mind on the topic of AAGs:

- The allocation logic framework will be applicable for any realistic set of highway AAGs.
- Performance/condition rating indicators to represent an AAG can be assessed and set for specific elements or asset types within an asset group (e.g., bridge deck rating) as an indicator for the entire AAG.

For better precision in estimating average deterioration rates and preservation unit costs, separate AAGs can be used to address wide variations in these factors. For example, rigid and flexible pavements could be handled separately as distinct AAG inventories. The research team notes that the allocation framework is meant to be high level, and its value will reach a point of diminishing return as detail and required effort increase to develop and feed input data for more AAGs.

It is noted that for high-level allocation decisions, it may be useful and simpler to adopt a specific asset type (e.g., bridge decks) as an indicator of preservation needs for an entire asset group.

Most state DOTs maintain detailed asset inventories for bridge and pavement asset groups. Although some states do not maintain any data for NBP assets, many states maintain this data for at least some assets, such as signage, signals, guardrail, and culverts.

Table 4-5. Resource allocation model—performance/condition rating.

Rating Type	Meaning
Ideal	Expected performance/condition rating of a single unit of an AAG (an AAU[10]) when a preservation project is completed
Target	Desired average performance/condition rating of an entire AAG inventory
Current	Current actual average performance/condition rating of an entire AAG inventory

Because we are determining high-level statewide and districtwide estimates to set overall allocations (and not work planning or project selection), coming up with best estimates of the required data will be sufficient. If the asset inventory information is not available for NBP assets, the data can be synthesized using a variety of means to get a rough estimate of the asset inventory and conditions. For example, to get the asset inventory, agencies may survey samples of asset counts in areas with different road densities (by classification) and use that information to build the systemwide estimates of assets and conditions. For instance, linear quantity could be surveyed or sampled and prorated to support the estimation of guardrail quantities.

4.3.2 Performance/Condition Ratings

Most state DOTs maintain detailed asset condition data for bridge and pavement asset types. NBP asset condition assessment can be determined by trained survey teams applying condition standards and conducting district surveys every 1 or 2 years to assess conditions. Simple measures such as pass/fail on key roadside assets can be used to assess conditions when no detailed procedures are in place. Definitions of the performance condition ratings used in the allocation solution are shown in Table 4-5.

By way of illustration, an example of performance ratings used by the Virginia DOT is presented in Table 4-6.

4.3.3 Deterioration Rates

The asset deterioration rates and unit costs can be determined for bridges and pavement reasonably well, because most states use the historical expenditure, condition data, and asset inventory data. However, estimating the unit costs and deterioration rates for NBP assets is a bit more challenging because of a lack of detailed condition and inventory information. NBP asset deterioration rates can be determined by engineering estimation of useful service life with (or without) long-term data on work done to check and correlate. In general, the deterioration rate would be the number of units (e.g., miles, feet, count) divided by expected life. For instance, an asset type with a 20-year expected life would be expected to have its inventory deteriorate to below a set condition standard at 5 percent per year (average). Deterioration rates can also be estimated based on the asset age and known or estimated asset decay rates in particular regions or under known wear-and-tear conditions. An example is sign retro-reflectivity performance under various climate conditions.

4.3.4 Unit Costs

Unit costs can be determined for bridges and pavement reasonably well in most states using the historical expenditure, condition data, and asset inventory data. However, estimating the

[10] Such as a specific lane-mile of pavement, a bridge deck, or a sign.

Table 4-6. Virginia DOT target asset maintenance and rehabilitation rating schema.

Asset Items	VDOT Target*	Percent of Assets that Passed Annual Evaluations FY 2000 I-95	FY 2000 I-77	FY 2000 I-81	FY 2000 I-381
Shoulders-Hard Surface					
Surface Defects	90	92	100	100	100
Drop Off	90	100	100	99	100
Separation	90	98	100	100	100
Drainage	90	99	100	100	100
Shoulders-Non-Hard Surface					
Drop Off	90	NA	NA	NA	NA
Drainage	90	NA	NA	NA	NA
Roadside					
Grass	90	100	100	100	100
Debris and Road Kill	100	100	100	100	100
Litter	90	100	100	99	100
Landscaping	80	100	NA	NA	NA
Brush and Tree Control	95	98	100	100	100
Concrete Barrier	99	100	100	100	NA
Sound Barrier	95	NA	100	NA	NA
Slopes	90	96	97	100	100
Fence	98	**95**	100	99	**96**
Drainage					
Ditches, Paved	90	90	**84**	**84**	**85**
Ditches, Unpaved	90	96	97	99	100
Pipes	95	**91**	100	98	100
Box Culverts	95	100	100	100	NA
Under/Edge Drains	90	100	94	100	NA
Storm Drains/Drop Inlets	90	98	94	95	100
Curb and Gutter	95	**93**	NA	100	NA
Sidewalks	90	NA	NA	NA	NA

Source: Review of Virginia Department of Transportation's Administration of the Interstate Asset Management Contract, Joint Legislative Audit and Review Commission of the Virginia General Assembly.

unit costs for NBP assets is a bit more challenging because of the lack of detailed condition and inventory information.

Average unit cost to restore to an as-new or nearly new condition standard can be estimated based on quantities restored and material/labor cost estimates or on-average costs of projects divided by units (e.g., miles, feet, count) done. Published material/labor cost indices can be used to address near-term escalation.

It is noted that several types of treatments can be used to preserve an asset (e.g., thin overlay or chip seal in pavements) depending on the condition and available resources. However, the cost of treatments can vary significantly among available options. Similarly, the deterioration rates and unit costs can vary significantly based on the asset type or category (e.g., asphalt vs. concrete vs. bituminous surface treatment pavement). To account for these major differences, the user needs to define each asset as a different AAG with a different unit cost and deterioration rate assumption. For example, asphalt and concrete pavement types can be defined as two different AAGs to capture the variation in unit costs.

4.3.5 Priority-Setting and Ranking

Priority-setting and ranking of AAGs in the preservation context represent an organization's strategic direction and emphasis in resource allocation as indicated here:

- From the operations research point of view, the priorities and ranking are used as the "balancing" factors to integrate multiple competing objectives into a practical application of a "collective" representation of factors influencing allocation results.
- AAG priorities and ranks can be determined by agencies from many perspectives. They can be linked to policy, organization, programmatic mandates, asset LCC, or network performance goals. Two (of many) examples of the logic processes that can influence priority-setting and ranking are:
  - An agency can use engineering tools to calculate LCCs for individual asset types, groups, and programs. By comparing these LCCs, the agency can obtain an objective view of the relative importance or criticality of preserving specific AAGs based on long-term cost, which contributes to the determination of priorities.
  - An agency can analyze customer service requests for recent years to rank the AAGs and specific performance objectives or programs in terms of their importance to customers (or in the example shown in Chapter 5, asset leverage on program objectives). This ranking influences the optimization solution. Priority-setting and ranking is not necessarily based on engineering or math; rather, it is strategic and addresses questions like, "What service or objective should be our emphasis this cycle?"
- Agency consensus on AAG preservation priority influences, but does not of itself drive allocation results a great deal, unless there is a large mismatch between resources needed and resources available. First and foremost, preservation needs drive the distribution of resources across AAGs. Priorities are incorporated into the computational model in several ways:
  - AAG allocation needs are influenced strongly by performance/condition targets and the user-set desired time to reach the targets (urgency of the need). For an AAG, the preservation need in an allocation cycle is controlled by [cost of deterioration during the cycle] + [cost of performance improvement needed ÷ desired years to achieve this]. All other things being equal, a 2-year desired timeline for one AAG reflects twice the improvement urgency of a 4-year desired timeline for another AAG.
  - Users rank AAGs sequentially. They can be 1, 2, 3, 4, etc., or they can be 1, 1, 2, 3, 4, 4, etc. The allocation model will not depend on the "true" or "absolute" values of these rankings. What will affect the outcome of the allocation model are the relative ranks among AAGs.
  - Next, assuming that AAG allocation needs have to be reduced because of a shortfall[11] in available funding, users set adjustment limits commensurate with each rank assigned to an AAG. Doing so results in low-priority AAGs taking a bigger percentage "hit" than high-priority AAGs.

[11] If there is no shortfall, no adjustment priority is needed. Either the process is complete, or performance goals driving needs would be re-evaluated (see also Section 4.1).

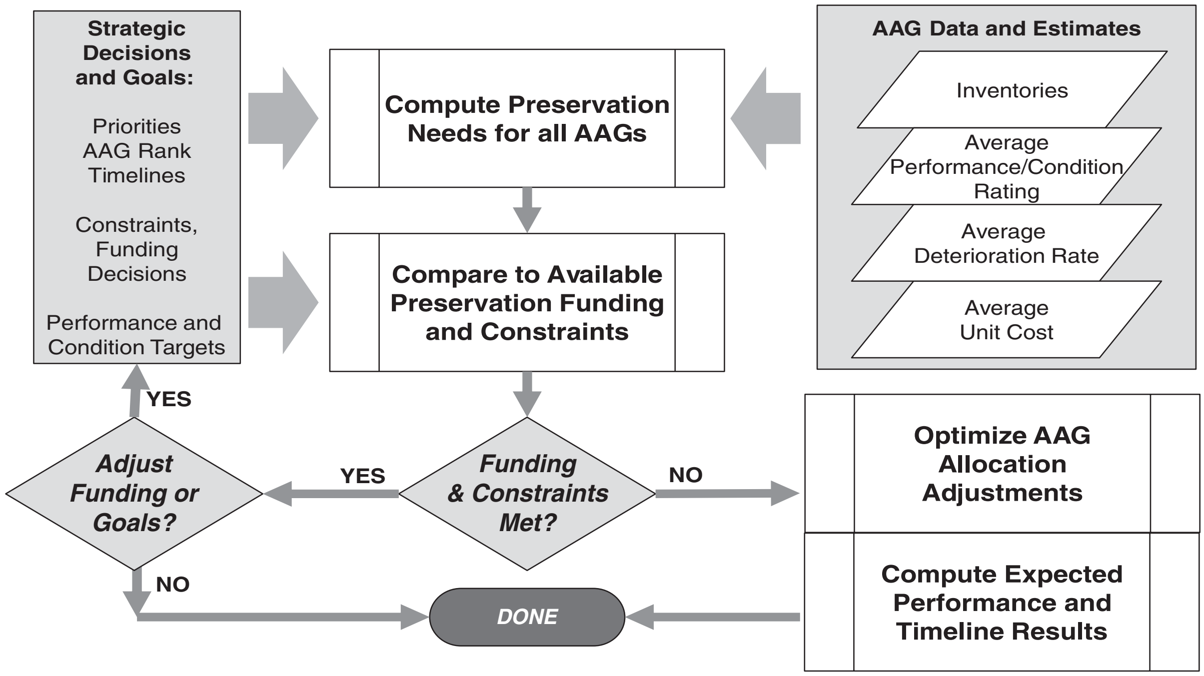

Figure 4-3. Allocation logic overview.

4.3.6 Historical Data

Most state agencies maintain a detailed log of the historical expenditures. The data is readily available for bridges and pavement, in particular. However, assembling the data accurately for NBP assets in some situations might be a bit more difficult, as the preservation and maintenance expenditures for NBP assets are sometimes rolled into major road or bridge project works and not tracked individually.

4.4 Allocation Logic

The ultimate goal of the Resource Allocation Logic Framework and supporting mathematical model is to determine the optimal investment allocations by AAG for specific allocation cycles and specific regions or districts given statewide goals and objectives, available funding constraints, and performance thresholds (see Figure 4-3). Other valuable outputs from the resource allocation model include realistic performance/condition expectations (both conditions and timelines to achieve targets) by AAG after allocations are adjusted to conform to funding limitations and other strategic variables.

Once the strategic inputs and targeted performance/condition (left side of the diagram), and the data inputs (top right side of the diagram) are introduced, the computations and objective function optimize and compute allocations to match available resources, as well as achievable performance results that are accountable to the investments (unshaded blocks). If the performance and timeline results are unacceptable to decisionmakers, adjustments to AAG performance goals or to the overall funding commitment can be made, resulting in new allocation and performance results.

CHAPTER 5

Case Studies and Workshop Findings

With a strategic framework defined to guide resource allocation decisions, the research team developed an Excel model to demonstrate the logic framework and the optimization logic. The team populated a sample case application based on plausible data that was adapted from the project research and previous experience. This demonstration of the solution model was initially displayed in a walk-through and test with the NCHRP Project 14-21 panel and was later refined as an initial logic framework. The logic framework and demonstration model were then applied and tested in the context of two real state DOT preservation resource allocation environments, providing two actual case studies.

After lessons learned from the case studies were factored into the allocation logic and demonstration model, a workshop was held with the panel, key managers from the two DOTs that supported the case studies, and other SMEs. The workshop objective was to review the allocation logic framework and provide comments and suggestions on improvements that would enhance the broader usability and adoption potential across the transportation agency community.

5.1 Case Studies

The case studies enabled the research team to test the Resource Allocation Logic Framework in situations using different terms and taxonomies for preservation activities and with different approaches to the process, logic, and data used for resource allocation.

Two state DOTs were viable and willing candidates (Washington State DOT and Nevada DOT) for the real-world resource allocation case studies. Each employed established allocation practices following different approaches. Washington State DOT uses a centralized preservation resource allocation approach, whereas Nevada DOT uses more of a hybrid district-specific allocation approach. The research team also discovered wide variations in the taxonomies, scope of preservation work addressed, methods for estimating resource needs, and processes for allocation adjustment decisionmaking. These varied considerably from the more generic processes and taxonomies encountered in previous research by the research team and by NCHRP. A general conclusion by the research team was that the allocation logic framework would need to allow wide latitude for variations in terminology and definitions of assets and preservation activities as well as for variations in the data that can reasonably be available to support quantification of preservation needs for NBP[12] assets and activities.

[12]Refers to assets and activities other than bridge- or pavement-related (Non-Bridge/Pavement assets/activities).

The research team conducted a number of detailed telephone discussions with representatives from these two agencies and gathered information about the following:

- Overall processes used to allocate preservation and maintenance funds across different asset groupings
- Scope of the preservation and maintenance program and the asset groupings covered
- General taxonomy of assets and activities used in a preservation context
- Approach for assessing the performance or condition of assets
- Units of measure used to define inventory for different asset groups
- Rating standards and approaches to assess performance or condition
- Inventory data for bridge, pavement, and other asset groups addressed by the preservation programs
- Information on how the expenditures and accomplishments (by asset groups) are tracked and recorded
- Capabilities to determine unit costs from historical data

Both Washington State DOT and Nevada DOT shared extensive information during the discussions and also provided relevant documentation and data. Key findings from the case studies include the following:

- In general, assets are considered to be under the preservation program by both Washington State and Nevada DOT. However, taxonomy of assets was found to be different between the states.
- Both of the agencies have excellent condition and inventory data for pavements and bridges.
- Data for other NBP assets is very scarce (e.g., signs, guardrails, barriers, rest areas)
  - While historical expenditure data on NBP assets was generally available, little specific data was available on condition and inventory for NBP asset groups.
  - Both the agencies are working toward building a database to improve monitoring of condition and inventory of NBP asset groups.
- It is difficult to accurately track expenses on NBP assets, because the costs are embedded as a part of major projects.
- Washington State uses formula-based allocation for NBP assets, and the allocation percentage is based on a percentage of pavement preservation projects. The percentage used for allocating funds for NBP assets is monitored and calibrated using analysis expenditure trends for NBP-related preservation work connected to pavement projects.
- Unit costs and deterioration rates can be reasonably determined for bridges and pavements.

The research team greatly benefited from the data gathered, and the framework was modified as needed based on the findings from the two case studies. The research team has the impression that both agencies saw merit in a straightforward solution to balancing allocations based on need, especially for testing and assessment of results and performance expectations after allocation adjustments have been necessary to address funding shortfalls. The concept can be implemented for bridge- and pavement-related preservation activity, but lack of data for most NBP-related activities is a hindrance at present. However, it is reasonable that a sufficient estimating basis can be developed over time to support preservation needs assessment for activities related to NBP assets. The research team recognized that the allocation solution should be flexible enough to accommodate an initial lack of NBP data but should provide for the NBP data as it (and if it can be) developed.

5.2 Workshop Findings

Upon completion of the case studies, the research team conducted a 1-day workshop in Washington, DC, to present the case studies, to indicate modifications to the solution model, and to gather comments and reactions from 15 practitioners, including the NCHRP Project 14-21 panel.

The research team and workshop participants defined and shared resource allocation issues and challenges, discussed the findings from case studies, reviewed the revised Resource Allocation Logic Framework and assessed the practicality of the solution. The research team conducted a live demonstration of the Excel model and conducted interactive model testing, where the participants were provided an opportunity to observe "test" scenarios. The live demonstration session was then followed with open discussion to receive inputs on the usability of the logic, data, and other issues.

The workshop participants identified the refinements needed to the framework and demonstration model. These have been subsequently implemented by the research team and are reflected in this report and logic framework. The key changes and improvements include the following:

1. **Simplified Terminology and Acronyms.** The original model used terms, such as Performance/Condition/Life (PCL) standards and Performance/Condition/Rating (PCR), to describe the performance condition rating of the assets. As these terms may be confusing or difficult to define across different agencies and asset types, the research team simplified and built in flexibility for user-defined terms to identify the key input variables.
2. **Easier Navigation of the Demonstration Model.** The ease of use of the model was improved, making it easier (a) to navigate by using fewer input tabs and (b) to enter the data needed. In particular, the research team simplified the inputs needed for setting up allocation weights. Additional features were implemented to protect the formula cells in the Excel spreadsheet model.
3. **Scalability and Adaptability to Variations in Terms and Scope.** The scalability and adaptability of the model was enhanced so that the users can enter up to 15 AAGs and up to 15 districts. All AAGs and terms for them are defined by the user.
4. **Improved Summary Tables.** The model was updated to provide summary output tables for easy reading of results. The enhanced model summarizes the final allocation across different asset types and also estimates the expected rating result post-allocation. Tables show the allocation results; comparisons between current, target, and expected (after allocation adjustment) rating results; and comparisons between desired time and actual time to reach target rating. A feature to export the results to a new Excel workbook was also implemented, so that users can save the model results for future reference.
5. **Flexible Taxonomy.** The model now allows users the flexibility to set up asset/activity taxonomies, units of measure for each AAG, and basis for rating. The new tool is flexible enough to allow users to set up multiple groupings of asset/activities, such as flexible pavements and rigid pavements, to accommodate significant variations in deterioration rates, unit costs, or asset inventories. For example, the user can now treat asphalt overlay and chip seal as separate AAGs.
6. **Alternate Needs Computation and Optimization Depending on Data.** There are added features in the model to address situations where data is available for only some of the AAGs. The user can provide needed data inputs to any number of the NBP groupings, and the model will compute preservation needs for those groupings. If necessary data is not available for a particular AAG, preservation needs can be computed based on historical allocations and escalation or as a percentage of the needs for a related asset. For example, guardrail preservation could be treated as a percent of pavement preservation, based on historical patterns.
7. **Optimizing Allocations When Funding Does Not Cover Deterioration During the Cycle.** The model was also updated, so that in situations where available funds are less than sufficient to prevent an overall decline in asset condition, the allocation can still be performed to minimize impact and to compute the overall performance/condition result expected at the end of cycle. This is considered a key feature for decisionmaking on the overall funding for preservation, because it will clarify the performance impact of investment of scarce funds in programs other than preservation.

The case analyses and workshop resulted in significant improvement in the user friendliness and adaptability of the computational model as well as the ability of the logic framework to provide rational outcomes in a wider variety of plausible allocation scenarios. The computational model is described in Chapter 6.

CHAPTER 6

Resource Allocation Logic Framework

After formulating the mathematical model for the resource allocation problem, the research team developed a tool to derive solutions using the logic model. The tool demonstrates the capabilities of the logic model, based on plausible assumptions and examples of data sets and input decisions in a hypothetical state DOT setting. The data sets, inputs, and decisions are based on actual case experience, scaled for clarity and simplicity in the demonstration.

The Excel-based solution model and optimization approach is grounded on plausible asset inventories, average AAG performance/condition ratings, average AAG deterioration rates, and average AAG unit costs. The model is intended to provide a basis for testing the concept and for building a simple logic-based system, expanded to encompass a full asset inventory if desired. It can be easily adapted for whatever district/jurisdictional structure exists in the enterprise.

6.1 Logic Process

The particular solution derived and described in this report is a computational process that can provide multiple input-output examples. Many process variations and outputs can be demonstrated—using varied assumptions, inputs, and priority and ranking approaches. The impact of policy guidelines, constraints on funding, performance/condition targets, and timeline goals can be seen and assessed easily. The many variations and output effects of adjusting inputs, assumptions, and priorities can be demonstrated in real time in working sessions using the Excel model that has been developed.

The logic framework and computational model is described in this section based on one static input-output example. The team has provided summary tables from several alternative cases in Section 6.4. While the framework can be expanded to full-scale use, the example herein addresses a subset of asset types and districts—sufficient to demonstrate a range of quantities, priorities, preservation needs, and overall impact on total allocation.

6.2 Logic Framework and Demonstration Model

The logic framework is structured to operate on specific AAGs for which inventories and performance/condition ratings can be reasonably determined and understood—and on basic jurisdictions (e.g., districts) within a state highway management enterprise. Inventories, performance/condition factors, computations, and results can be rolled up to AAG totals and to statewide results.

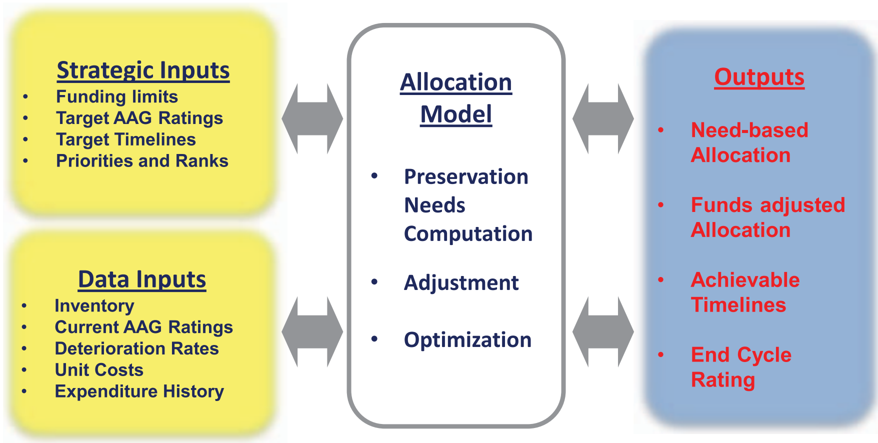

Figure 6-1. Resource allocation model—an overview.

The logic framework involves the following major components:

- **Adjustable Strategic Inputs.** These are determined by policies, program objectives, overall performance/condition expectations, best practices, and available resources and constraints.
- **Data and Estimate Inputs.** These reflect AAG inventory, actual performance/condition ratings, average unit cost experience, and jurisdictional or statewide asset deterioration factors.
- **Outputs/Results.** These include unconstrained[13] need, total annual allocation need, based on performance/condition targets and expected deterioration, funds availability-adjusted allocations, and achievable improvement timelines to reach target ratings after funds availability adjustments. The output also shows the predicted performance/condition rating that can be achieved at the end of the allocation cycle (annual, in the example).
- **Computational Functions.** This includes calculation of optimal results based on strategic input adjustments and on assessment of the sensitivities of various estimates and assumptions underlying the data inputs.

Figure 6-1 is a high-level view of the Excel model for demonstration of the logic framework. In this figure and in subsequent figures in the report, user input cells are displayed with light gray shading, and cells containing computation results are shown in darker gray shading. In the companion demonstration model available on the NCHRP Project 14-21 web page at www.trb.org, the user input cells are shaded yellow and the computation results are shaded blue.

It is important to note that the model was developed to demonstrate the full logic framework, but it is not intended to be prescriptive. Some key observations follow about the demonstration model presented in this report:

1. The allocation solution is primarily designed to address situations where (a) available preservation funding is less than estimated or computed overall preservation needs and (b) asset performance or condition ratings for specific AAGs are below desired targets. Where the opposite is the case, we assume the allocation challenge is met by simply estimating the preservation needs for each asset group and jurisdiction and funding the need—or possibly by re-assessing the rating targets and priorities for a more aggressive preservation program.
2. The allocation solution and model are not intended to have granularity below the District/AAG level; rather the solution is intended to provide a logical total preservation funding

[13]Total resources needed to restore the units of an AAG to ideal performance/condition rating (i.e., the rating of units at completion of preservation projects). This can be considered as-new or nearly as-new, depending on the standards set by the agency for preservation work.

envelope for an AAG within a jurisdiction—either district or state. Neither selection of specific projects nor preservation tactics are intended to derive from this logic model. These are considered technical decisions within the work planning process. The model gives emphasis to the computed total annual preservation needs of AAGs in each district based on inventory, existing shortfall to targeted performance/condition ratings, deterioration rates, unit costs, and desired timelines to achieve target ratings. In fact, annual preservation needs can be estimated and determined in many different ways and for different time periods, yet the basic optimization approach can still be applied.

3. The reader will see that the example model uses a hypothetical prioritization and ranking approach to modulate the limits to which allocations can be adjusted for each AAG and to solve for the optimum adjustments by (a) balancing the ratio of allocated amount versus expected deterioration for each asset type or (b) minimizing the impact on the desired timeline to achieve target ratings for each AAG. While these appear to be logical bases for adjustment, other logic can easily be built in and applied.
4. There are solution options for users to treat specific AAGs that lack key data or estimates to compute and optimize allocation needs in the way intended by the framework. These will produce reasonable approximations of need and may suffice if the investment is relatively small. Users will also be able to experiment with reasonable estimates of the data and factors needed for those AAGs and determine that approximations are sufficient for allocation purposes.
5. The predicted end-of-cycle performance/condition rating results for each AAG (after funds-available adjustments), when compared with desired targets, is useful to assess the effects of funding shortfalls on preservation of the road network. This will help to calibrate stakeholder expectations and high-level decisionmaking on funding in subsequent cycles.

The objective of the allocation model is to assist in allocation of needed and appropriate preservation funding resources for each asset type and for each responsible district or jurisdiction. Planning, selection, and execution of specific preservation projects are subsequent activities performed by central or district authorities based on the allocations approved. *The allocation model is not a work-planning or project-selection tool.*

6.2.1 Basic Assumptions and Definitions for the Illustrative Allocation Model

The basic assumptions and definitions for the example Resource Allocation case are laid out in the Excel workbook for ready reference and shown in Table 6-1. The definitions and

Table 6-1. Resource allocation case assumptions.

1	The Resource Allocation Logic Framework can be used to allocate the available Preservation and Maintenance funds across different user defined Asset Activity-IDs
2	Up to 15 Districts and 15 Asset Activity-IDs can be set by the user
3	For Region-wide Allocation, the user should treat the entire region as a "Single" District and provide the data inputs
4	For full application of the Resource Allocation Logic Framework, the following data elements are needed for each of the Asset-Activity ID specified: (1) Asset Inventory Data (2) Condition Data (3) Deterioration Rates (4) Unit Costs (5) Historical Expenditures. Linear Optimization Program is used to allocate the resources to different asset types to minimize the deviation between the expected time to achieve rating and the desired time. The user can set policy objectives by setting relative weights/ranks for each asset type or the desired time to target rating
5	The user can identify which of the five data elements identified above are available. If either the Inventory, Condition Data, Deterioration Rates or Unit Costs are not input for a particular Asset-Activity ID, the allocation for the particular asset is determined by prorating historical allocations and cost escalation factors
6	The user can choose to allocate the resources for Non Bridge/Pavement assets as a percentage of funds allocated for Pavement Asset IDs
7	The Resource Allocation Logic Framework should be Run by clicking the "Run Model" button in the Run Model Worksheet. The Final Result can be exported to a new workbook by clicking the "Export Results" button

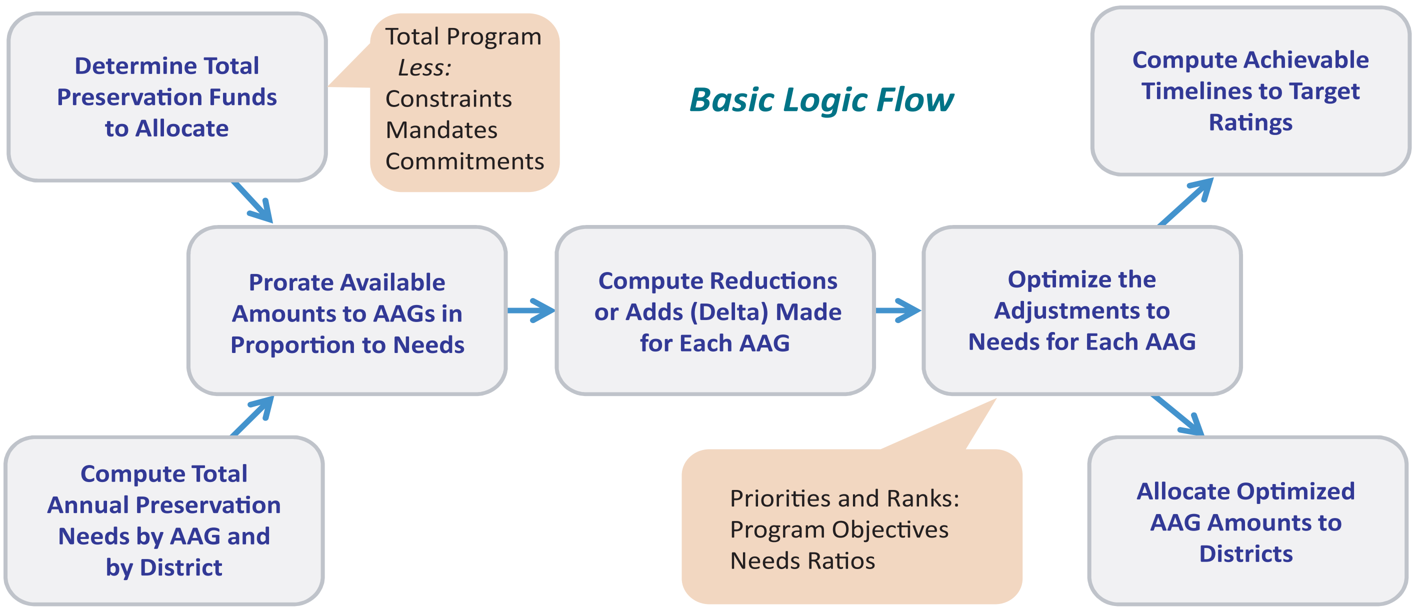

Figure 6-2. Resource allocation model—logic flow.

assumptions of the case inputs, computations, and output results are described in subsequent sections.

The basic flow of the computational operations in the model can easily be followed, as users progress through the input tabs and computation tables and summaries. The basic flow of the computations is shown in Figure 6-2.

The Excel demonstration model workbook incorporates multiple tabs as follows:

Tab 1: 1-Resource Allocation Logic Framework (Introduction Page)
Tab 2: 2-Overview
Tab 3: 3-Basic Inputs
Tab 4: 4-Strategy Inputs
Tab 5: 5-Data Inputs
Tab 6: 6-Needs Estimation
Tab 7: 7-Run Model
Tab 8: 8-Calculations

Tabs 3, 4, and 5 contain the input and control operations; the rest of the tabs are information, displays of intermediate computations, and results. The results are displayed on Tab 7, which also contains the Run Solver and Export Data buttons.

6.2.2 Context and Inputs for the Illustrative Allocation Case

The first step in using the Resource Allocation Logic Framework is to define the AAGs, units of measure, and availability of data or estimates needed for each AAG. The user can specifically identify if the following data elements are available for each AAG:

- Asset Inventory Data
- Condition Rating Data
- Deterioration Rate
- Unit Cost Data.

Table 6-2 shows sample inputs for AAIDs, units of measure, and data/estimate availability.

Table 6-2. AAGs, units of measure, and data/estimate availability (Tab. 3-1).

		Are Data or Reasonable Estimates Available for the Solution Framework? (See note below table)			
Asset-Activity Group (AAG)	**Units of Measure**	**Inventory**	**Condition Rating**	**Deterioration Rate**	**Unit Cost**
Bridges	Bridge Decks	Yes	Yes	Yes	Yes
Pavements	Lane Miles	Yes	Yes	Yes	Yes
Signs	# of Signs	Yes	Yes	Yes	Yes
Highway Lighting	# of Lights	Yes	Yes	Yes	Yes
Guardrail	Miles of Guardrail	Yes	Yes	Yes	Yes
Weigh Stations	# of Stations	Yes	Yes	Yes	Yes
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-

NOTE: If any of the four data elements is not available for an AAG, the preservation needs for that particular AAG will be estimated based on (a) historical expenditures and escalation or (b) as a user-set percentage of the preservation needs of another AAG, such as pavements.

6.2.3 Funding Constraint Inputs

The key assumption here is that NSDOT[14] has determined a total funding amount available for the entire Preservation Program (i.e., distinct from Maintenance, Expansion, Traffic), and that external constraints on the use of the funds can be quantified and summed up, including such items as pre-committed major projects, specific statewide campaigns, and major one-off projects. The research team recognizes that the amount of available funds can be a "moving target" as resource allocations are adjusted between programs and as revenue projections fluctuate. The allocation model will permit immediate recalculation of optimal allocations as such changes occur.

The initial input for the NSDOT example case is shown in Table 6-3.

For this example, the $66 million constraint reflects several hypothetical major projects in process that carry multiyear funding commitments, including this year: a $43 million bridge replacement/rehabilitation, two major repaving projects totaling $18 million, and a $5 million drainage ditch reconstruct campaign. These are assumed to span two districts in the example.

6.2.4 Allocation Method

By default, the Resource Allocation Logic Framework assumes that the input data elements are available to apply a needs-based allocation process. However, in situations where some data elements (see Table 6-2) may not be available, or in situations where the agency routinely allocates funds for NBP AAGs as a percentage of pavement AAGs, the user has an option to allocate resources for some assets by setting the Use Percent Allocation for Some Assets flag to Yes, as shown in Table 6-4.

The user can also set the relative rank of AAGs, by setting the Use Relative AAG Ranks flag to Yes. This establishes a scale of user-predefined limits on the extent of the adjustment that can be made to preservation needs of each AAG.

[14]New State DOT, the case agency name used for the Excel model.

Table 6-3. Preservation and maintenance funds availability data (Tab. 4-1).

Total Preservation funds	$281,000,000
Adjustments for directed programs	$66,000,000
Preservation funds to be allocated	$215,000,000

Table 6-4. Allocation method and ranking (Tab. 4-2).

Use Percent Allocation for Some AAGs	*No*
Use Relative AAG Ranks	Yes

6.2.5 Strategic Inputs

After setting the Allocation Method, the next step is to set the strategic inputs for allocating resources by each AAID. Table 6-5 shows the different input values to be provided by the user.

The table receives important strategic inputs from the users of the allocation framework. These have significant effects on allocation outcomes, and equally important, they strongly affect the resulting predicted performance of AAGs at the end of the allocation cycle. Users can experiment with variations on these inputs to determine their leverage on outcomes. The inputs are as follows:

- **Ideal Rating.** This represents the rating of a single inventory unit of an AAG that has been restored to new or as-new performance, presumably at completion of a preservation project. This rating, when considered hypothetically in comparison with the actual average ratings of an AAG, allows determination of total unconstrained preservation need for the AAG. The unconstrained need is typically a very large number that has little absolute meaning by itself, but it is of value in considering cycle-to-cycle preservation strategies. When compared with unconstrained need calculated the same way from prior years, decisionmakers can assess whether overall AAGs are gaining or losing in health and performance. Over time, this information can be correlated with preservation investments being made as a valuable guide for funding decisions going forward.
- **Target Rating.** This indicates the average performance/condition rating of an AAG that the agency is committed to achieve. Combined with the average current rating of an AAG, unit costs, and inventory population, this drives the amount of investment needed to advance to the desired performance/condition level. When added to the investment needed to offset normal deterioration of an AAG inventory, this can represent a large preservation need, and in most cases, AAGs cannot achieve sufficient performance gains in a single cycle to meet such targets. This leads us to the next input.

Table 6-5. Strategic inputs for allocating preservation resources (Tab. 4-3).

Asset-Activity Group (AAG)	Units of Measure	Ideal Rating	Target Rating	Time (Years) for Target Rating	Relative AAG Rank	Needs based Allocation	% Allocation Basis	Allocation Percentage	Escalation in Expenditure**
Bridges	Bridge Decks	100%	80%	2	2	Yes	No		5%
Pavements	Lane Miles	100%	80%	2	1	Yes	Yes		5%
Signs	# of Signs	100%	100%	8	4	Yes	No		5%
Highway Lighting	# of Lights	100%	85%	4	6	Yes	No		5%
Guardrail	Miles of Guardrail	100%	80%	4	2	Yes	No		5%
Weigh Stations	# of Stations	100%	80%	4	5	Yes	No		5%
-	-								
-	-								
-	-								

* Used only when Percent Based Allocation Flag is set as "Yes"

*** Used when Inventory, Condition, Deterioration Rate or Unit Cost data are not available*

Table 6-6. AAG rank and deviation limits (Tab. 4-4).

Relative AAG Rank	Deviation Limit*
1	100%
2	110%
3	120%
4	130%
5	140%
6	150%
7	
14	
15	

* Allowed Deviation from Pro-rata allocation adjustment

- **Target Time (in Years or Cycles) to Reach Target Rating.** This value indicates the desired number of allocation cycles (years, in this case) to reach the targeted rating for an AAG, assuming that current average ratings are below the targets. This has a couple of functions in the model. First, the time target divides the "performance improvement" portion of the preservation need into a cycle-by-cycle amount. Second, it is an indicator of the strategic priority (or level of urgency) vested in each AAG by the user. And third, it forms the basis for an objective function that moderates funding-driven adjustments to each AAG, so that the difference can be minimized between the desired timelines and the timelines after adjustment.
- **Relative AAG Rank.** This is a user input that can be 1-2-3-4-5-etc. or 1-1-2-3-4-4-etc. Combined with the "deviation limit" in Table 6-6, this ranking reflects the extent to which the user will allow each AAG to be "hit" by negative adjustments to preservation needs due to funding limits. It is another way that strategic inputs can influence the overall optimization.
- **Needs-Based Allocation.** This column is set to identify the AAGs for which the allocation will be a needs-based computation. Note that the Data Availability flag described in Table 6-2 is set to Yes for the particular AAG if the Needs-Based Allocation flag is set to Yes. If an AAG is set to No in this column, the allocation needs will be computed as a ratio with respect to the AAG(s) flagged with Yes in the next column.
- **% Allocation Basis.** This column designates the AAG or AAGs (example, pavement) that will provide the basis for percentage-based allocations, as preservation needs for the designated basis AAGs are determined.
- **Allocation Percentage.** The user sets the percentage of the basis AAG to apply wherever needs-based allocation is set to No.
- **Escalation in Expenditure.** If data is not available for the specific AAG, and percentage allocation is not selected, the allocation is made based on historical expenditure for that AAG, plus the cost escalation factor entered in this column.

6.2.6 Setting Ranks

Table 6-6 requires user inputs to modulate the optimization routine.

The values will be used only if the Use Relative Asset/Activity Ranks flag is set to Yes.

The user-set deviation limit is linked to the AAG ranking, as shown in the previous example. The deviation addressed here is the deviation from the adjustments made for each AAG when calculated preservation need is adjusted to match funding limits. For example, if an across-the-board adjustment of minus 10 percent is made due to funding limitations, that adjustment

Table 6-7. AAG inventory data (Tab. 5-1).

Asset-Activity Group (AAG)	Units of Measure	Total	Regions									
			District 1	District 2	District 3	District 4	District 5	District 6	District 7	District 8	District 9	District 10
Bridges	Bridge Decks	3,500	1,475	885	1,140							
Pavements	Lane Miles	20,750	8,190	5,850	6,710							
Signs	# of Signs	38,100	13,900	11,900	12,300							
Highway Lighting	# of Lights	273,050	176,500	56,750	39,800							
Guardrail	Miles of Guardrail	36,580	16,380	8,590	11,610							
Weigh Stations	# of Stations	113	48	31	34							
-	-											
-	-											
-	-											
TOTAL			216,493	84,006	71,594							

amount will float for each AAG, as the allocation is optimized for best overall performance gain. This table limits the adjustment "float" for the number 1-ranked AAG to a greater extent than for the number 6-ranked AAG. So the lower-ranked AAG is subject to a greater "hit" in some cases (though not every case), depending on how big the funding adjustment is and how much performance gain was targeted for that AAG. Users can experiment with these factors. The research team found the ranks and deviation limits do not have major impact except in extreme funding shortfall cases.

6.2.7 Foundational Data Inputs

Upon setting the strategic inputs, the user needs to provide the AAG inventory, condition, unit costs, and other essential data items. Given inventory data, and having determined strategic program objectives and the key standards, ratings, and timeline targets for performance, other essential data inputs are necessary to determine preservation needs including the following:

- **AAG Inventory Data.** These are the AAG quantities in user-specified units of measure.
- **Current AAG Ratings.** This is the average performance/condition rating of each AAG.
- **AAG Unit Costs.** This is the average cost of restoring a single unit of an AAG to the ideal rating (completed preservation project).
- **AAG Deterioration Rate.** This is the estimated percentage of assets of an asset type or group that is expected to deteriorate below an acceptable level of performance or safety during each cycle.
- **Historical Expenditure Data.** This is the aggregated preservation expenditure for each AAG in prior periods.

All of these performance factors can be measured, computed, or reasonably estimated[15] for the purpose of the model—based on historical data, sample study, engineering analysis, or (if applied across the board) by professional opinion and consensus. The example inputs (current situation) for the NSDOT illustrative case are shown in Tables 6-7 through 6-11:

The average unit cost estimates are based on analyses of known state DOT preservation program costs as well as fact sheets and a number of periodic DOT reports found in our data research—this data is scaled and adjusted for the example NSDOT case. Because of the relative size of the bridge and pavement allocations in typical preservation programs and because the nature of these two

[15] Again, the inputs need not be highly precise, as long as they are reasonably sound estimates, consistently done and applied. The allocation model ultimately leads to an adjustment for available funding; reasonable allocation is the object, not estimation and commitment of funds for projects.

Table 6-8. AAG current condition data (Tab. 5-2).

Asset-Activity Group (AAG)	Units of Measure	Average	Regions									
			District 1	District 2	District 3	District 4	District 5	District 6	District 7	District 8	District 9	District 10
Bridges	Bridge Decks	77.2%	77.2%	76.2%	78.0%							
Pavements	Lane Miles	75.9%	76.1%	75.8%	75.6%							
Signs	# of Signs	92.6%	92.1%	92.9%	92.8%							
Highway Lighting	# of Lights	82.8%	83.0%	82.5%	82.0%							
Guardrail	Miles of Guardrail	75.7%	75.0%	76.0%	76.5%							
Weigh Stations	# of Stations	77.7%	78.0%	76.5%	78.5%							
-	-	-										
-	-	-										
-	-	-										

Table 6-9. AAG unit cost data (Tab. 5-3).

Asset-Activity Group (AAG)	Description	Average	Regions									
			District 1	District 2	District 3	District 4	District 5	District 6	District 7	District 8	District 9	District 10
Bridges	Estimated average cost to improve typical bridge structure to meet Ideal standard	1,100,000	1,100,000	1,100,000	1,100,000							
Pavements	Estimated average cost to improve typical lane mile to meet Ideal standard	120,000	120,000	120,000	120,000							
Signs	Estimated average cost to improve typical sign to meet Ideal standard	2,000	2,000	2,000	2,000							
Highway Lighting	Estimated average cost to improve Highway Lighting to meet Ideal standard	250	250	250	250							
Guardrail	Estimated average cost to improve typical guardrail to meet Ideal standard	1,000	1,000	1,000	1,000							
Weigh Stations	Estimated average cost to improve typical weigh station to meet Ideal standard	50,000	50,000	50,000	50,000							
-		-										
-		-										
-		-										

Table 6-10. AAG deterioration rates data (Tab. 5-4).

Asset-Activity Group (AAG)	Units of Measure	Average	Regions									
			District 1	District 2	District 3	District 4	District 5	District 6	District 7	District 8	District 9	District 10
Bridges	Bridge Decks	1.5%	1.5%	1.5%	1.5%							
Pavements	Lane Miles	5.0%	5.0%	5.0%	5.0%							
Signs	# of Signs	10.0%	10.0%	10.0%	10.0%							
Highway Lighting	# of Lights	4.0%	4.0%	4.0%	4.0%							
Guardrail	Miles of Guardrail	3.0%	3.0%	3.0%	3.0%							
Weigh Stations	# of Stations	2.0%	2.0%	2.0%	2.0%							
-	-	-										
-	-	-										
-	-	-										

Table 6-11. AAG historical expenditure data (Tab. 5-5).

			Regions									
Asset-Activity Group (AAG)	Units of Measure	Total	District 1	District 2	District 3	District 4	District 5	District 6	District 7	District 8	District 9	District 10
Bridges	Bridge Decks	67,998,000	29,854,000	16,889,000	21,255,000							
Pavements	Lane Miles	138,419,000	50,802,000	42,724,000	44,893,000							
Signs	# of Signs	4,395,333	1,627,900	1,348,833	1,418,600							
Highway Lighting	# of Lights	1,595,000	447,500	587,500	560,000							
Guardrail	Miles of Guardrail	1,269,000	442,000	274,000	553,000							
Weigh Stations	# of Stations	195,000	45,000	20,000	130,000							
-	-	-										
-	-	-										
-	-	-										
TOTAL		213,871,333	83,218,400	61,843,333	68,809,600							

** Note that the Historical Expenditure Data entered here is is used to determine the percentage allocation for assets other than Bridge and Pavement assets if percentage based allocation is used*

activities is very different from each other, the research team focused most heavily on realistic estimation of average unit costs and deterioration rates for these two asset groups:

- **Pavements.** Numerous pavement deterioration studies gravitate around 18- to 20-year cycles for major overlay/repaving events, with average costs as low as $100,000 per lane mile; however, costs can run in excess of $130,000 per lane mile, depending on the maintenance regimen in effect. The research team assumed a typical routine maintenance program, with a 20-year cycle, suggesting a deterioration rate of about 5 percent on average. This means that preservation allocations would need to cover at least 5 percent of the inventory each year.
- **Bridges.** Two state DOTs for which we found information appear to address about 1.5 percent of their bridge inventory with significant preservation projects each year. These include such projects as painting, deck rehabilitation, structural reinforcement, scour mitigation, and general rehabilitation of smaller bridge structures. These project costs appear to range between $500,000 and $1.6 million. Larger rehabilitation/replacement projects on major spans range up to $200 million and well beyond, in some cases. We assumed the major bridge replacement/rehabilitation projects on larger bridges would be treated as separate (usually multiyear commitments), and we treated them as commitments that are constraints to determine annual regular preservation funding to be allocated.

Similar estimating can be done for other AAGs, based primarily on historical records of preservation work done and costs. If this data cannot be sampled for analysis, preservation project estimate data might provide a basis for judgment.

The research team adapted the example inventory and expenditure data in proportion to real-world cases.

6.2.8 Computation of Preservation Needs

The first step in the computation process is determination of preservation needs for each AAG.

The Bridge AAG computation is used to illustrate this process, shown in Table 6-12. The table shows the input factors linked from prior tabs and contains the calculation results, assuming the desired timelines to reach target ratings.

Allocation need calculations in the demonstration model are as follows:

$$\text{Unconstrained Need} = [\text{Inventory}] \times ([\text{Ideal Rating}] - [\text{Current Rating}]) \times [\text{Average Unit Cost}]$$
$$= [\text{Inventory}] \times [\text{Deterioration Rate}] \times [\text{Average Unit Cost}]$$

Table 6-12. Calculation of needs.

Asset-Activity Group #1	Total	Districts		
Bridges		District 1	District 2	District 3
Bridge Decks	3,500	1,475	885	1,140
Current Rating	-	77.2%	76.2%	78.0%
Ideal Rating	-	100.0%	100.0%	100.0%
Target Rating	-	80%	80%	80%
Average Unit Cost $	-	1,100,000	1,100,000	1,100,000
Deterioration Rate	-	1.5%	1.5%	1.5%
Unconstrained Need	877,503,000	369,930,000	231,693,000	275,880,000
Ave. Annual Deterioration	57,750,000	24,337,500	14,602,500	18,810,000
Total needed for Target Rating	107,503,000	45,430,000	36,993,000	25,080,000
Desired Time for Target Rating (Years)	-	2	2	2
Annual Allocation needed to meet target Ratings and timelines	111,501,500	47,052,500	33,099,000	31,350,000
Funds needed to improve average current rating by 1%	38,500,000	16,225,000	9,735,000	12,540,000

$$\text{Total Needed for Target Rating} = [\text{Inventory}] \times ([\text{Target Rating}] - [\text{Current Rating}]) \times [\text{Average Unit Cost}]$$

$$\text{Annual Allocation Needed} = [\text{Average Annual Deterioration}] + ([\text{Total Needed for Target Rating}]) \div [\text{ Desired Time for Target Rating}]$$

Table 6-13 shows total and district-based allocation needs by AAGs. The result of Annual Allocation Needed computation for the assets in the model example is shown in the Total column.

Table 6-13. Allocation needs using inventory, current rating, target rating, and timelines.

Allocation Needs based on Asset Inventory, Current Rating, Target Rating and Timelines				
Asset-Activity Group (AAG)	**Total**	**District 1**	**District 2**	**District 3**
Bridges	111,501,500	47,052,500	33,099,000	31,350,000
Pavements	176,121,000	68,304,600	49,842,000	57,974,400
Signs	8,327,150	3,054,525	2,591,225	2,681,400
Highway Lighting	3,114,422	1,985,625	656,172	472,625
Guardrail	1,489,638	696,150	343,600	449,888
Weigh Stations	144,938	60,000	44,563	40,375
-	0	-	-	-
-	0	-	-	-
-	0	-	-	-
	300,698,647	**121,153,400**	**86,576,559**	**92,968,688**

It can be seen that the sum of the Annual Allocation Needed is $300,698,654, which exceeds the total available funding of $215,000,000. This sets the stage for the optimization process (described in the next section), which operates in this model to adjust the individual proration up or down for each of the AAGs or an optimal solution.

Before moving on to the optimization process, we note that the model can demonstrate at least three alternative approaches to narrow the gap between available funds and annual need. These can be applied individually or in combination to yield higher or lower annual needs for an AAG. The alternatives include the following:

- Small downward adjustments in target rating have a significant reduction effect on annual needs.
- Extending desired timelines to reach targets also lowers annual needs results.
- Any reduction in unit costs, possibly based on specific changes in preservation tactics or methods, can reduce annual needs for the specific AAG involved.

6.2.9 Optimization

In this sample optimization approach, we pursued the following strategy:

- At the highest level, we sought to meet both annual needs and desired time for target rating as closely as possible for the assets, given funding constraints (shortfall to needs).
- We moderated the effect of the funding shortfall on specific asset groups by determining limits on upward and downward adjustments based on weighting and ranking factors.
- The weighting and ranking factors are influenced by several user inputs as well as ratios between costs to cover deterioration versus annual needs for each asset type.

The summary of the case example optimization results is shown in Table 6-14 and Figures 6-3 and 6-4.

Table 6-14. Summary allocation results (Tab. 7-1).

		Table 7-1: Summary results - Allocation of Preservation Funds								
Asset-Activity Group (AAG)	**Total**	**District 1**	**District 2**	**District 3**	**District 4**	**District 5**	**District 6**	**District 7**	**District 8**	**District 9**
Bridges	65,688,599	27,719,921	19,499,531	18,469,147	-	-	-	-	-	-
Pavements	137,039,134	53,147,570	38,781,886	45,109,678	-	-	-	-	-	-
Signs	8,035,405	2,947,509	2,500,441	2,587,456	-	-	-	-	-	-
Highway Lighting	2,924,593	1,864,598	616,177	443,818	-	-	-	-	-	-
Guardrail	1,190,236	556,231	274,540	359,465	-	-	-	-	-	-
Weigh Stations	122,033	50,518	37,520	33,994	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
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-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
	215,000,000	**86,286,347**	**61,710,095**	**67,003,558**	**-**	**-**	**-**	**-**	**-**	**-**

(continued on next page)

Table 6-14. (Continued).

Asset-Activity Group (AAG)									
Asset-Activity Group (AAG)	*Difference between Desired and Estimated Time to reach Target Rating*			*Difference between Current and Historical Allocation*					
	Desired Time	Estimated Time	Difference (Desired - Target)	Average Historical Allocation	Difference (Current - Historical)	Total Allocation *less* Deterioration Need	Target Rating	Current Rating	Expected Rating Result
Bridges	2	14	12.0	67,998,000	(2,309,401)	7,938,599	80.00%	77.21%	77.41%
Pavements	2	14	12.0	138,419,000	(1,379,866)	12,539,134	80.00%	75.85%	76.36%
Signs	8	20	12.0	4,395,333	3,640,072	415,405	100.00%	92.58%	93.12%
Highway Lighting	4	16	12.0	1,595,000	1,329,593	194,093	85.00%	82.75%	83.03%
Guardrail	4	16	12.0	1,269,000	(78,764)	92,836	80.00%	75.71%	75.96%
Weigh Stations	4	16	12.0	195,000	(72,967)	9,033	80.00%	77.74%	77.90%
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
				213,871,333	1,128,667	**21,189,100**			

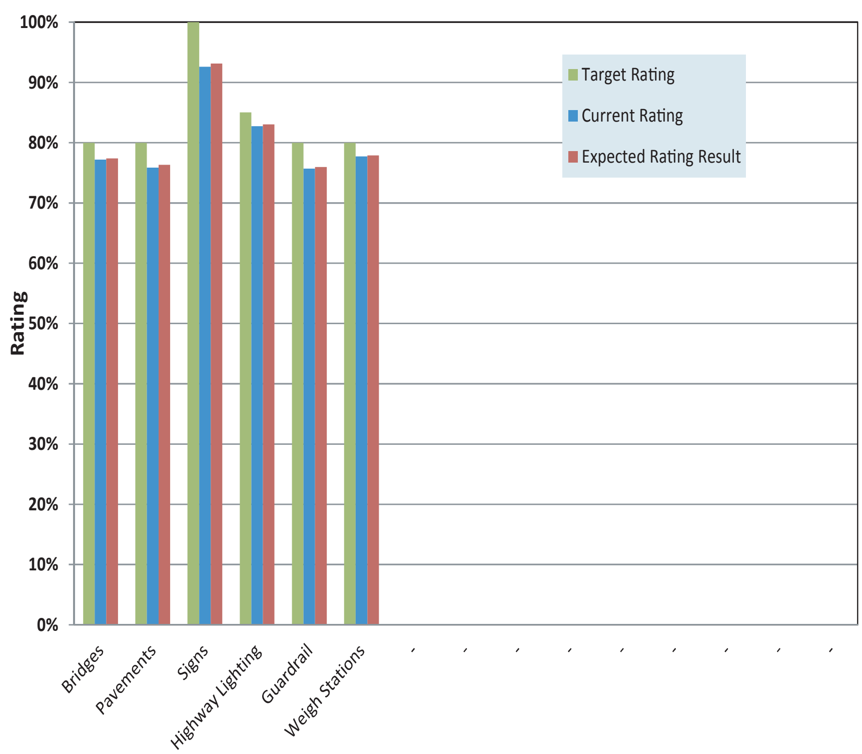

Figure 6-3. Comparison of target rating, current rating, and expected rating result.

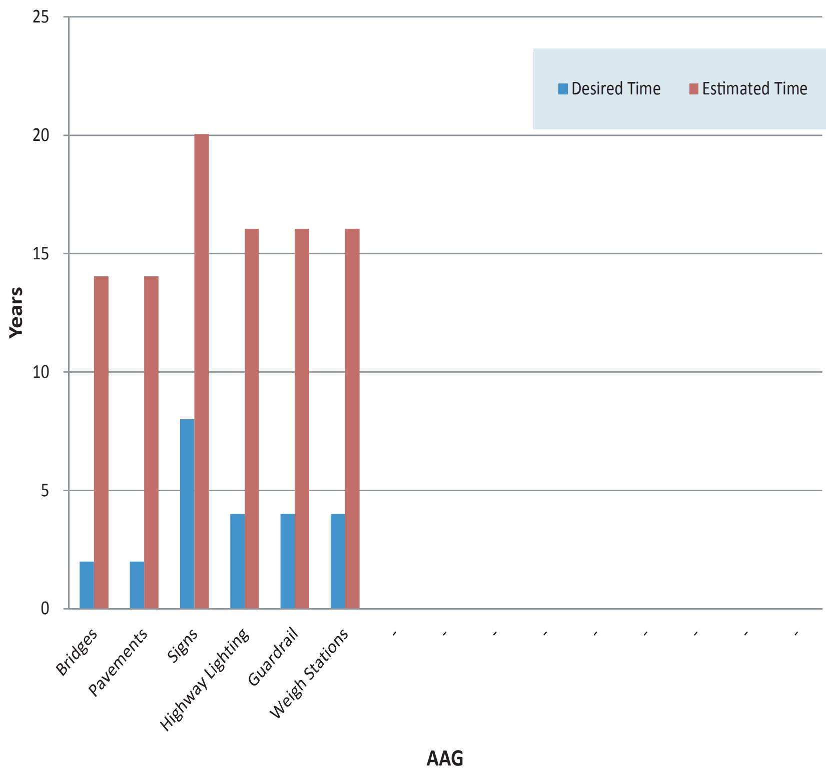

Figure 6-4. Comparison of desired time and estimated time to reach target rating.

6.3 Setup of Additional Case Examples

This section provides examples of how to set up key parameters in the Excel model for different case studies.

Case Example 1: Allocate the total funds for the AAGs based on needs.

Step 1. In the **3-Basic Inputs** tab, Table 3-1 (in the model), set the Data Availability flags to Yes for the AAGs.

		Are Data or Reasonable Estimates Available for the Solution Framework?			
Asset-Activity Group (AAG)	**Units of Measure**	**Inventory**	**Condition Rating**	**Deterioration Rate**	**Unit Cost**
Bridges	Bridge Decks	Yes	Yes	Yes	Yes
Pavements	Lane Miles	Yes	Yes	Yes	Yes
Signs	# of Signs	Yes	Yes	Yes	Yes
Highway Lighting	# of Lights	Yes	Yes	Yes	Yes
Guardrail	Miles of Guardrail	Yes	Yes	Yes	Yes
Weigh Stations	# of Stations	Yes	Yes	Yes	Yes

Step 2. In **4-Strategy Inputs** tab, Table 4-2 (in the model), set the Use Percent Allocation for Some Assets to No.

Use Percent Allocation for Some AAGs	***No***
Use Relative AAG Ranks	**Yes**

Step 3. In **5-Data Inputs** tab, enter values in the five tables for **ALL** AAGs.

Step 4. Run the optimization model by selecting the **Run Model** button in the **7-Run Model** tab.

Results will be seen in the **7-Run Model** tab.

Step 5. Press the **Export Results** button to save the output results in a new workbook. Save the new workbook for future reference (if needed).

Case Example 2: Allocate the total funds based on needs for AAGs with data, but use historical expenditure information and escalation for AAGs with missing data.

Step 1. In **3-Basic Inputs** tab, Table 3-1 (in the model), set the Data Availability flags to Yes for the AAGs that need to be allocated using needs and set the data flag to No for assets that should be allocated based on historical expenditure and associated escalation rates. Setting No in any one of the four columns will allow historical data to be used for determining resources for the particular asset. In the example below, resources for highway lighting and weigh stations will be determined based on historical data, and the other allocations will be determined based on needs.

		Are Data or Reasonable Estimates Available for the Solution Framework?			
Asset-Activity Group (AAG)	**Units of Measure**	**Inventory**	**Condition Rating**	**Deterioration Rate**	**Unit Cost**
Bridges	Bridge Decks	Yes	Yes	Yes	Yes
Pavements	Lane Miles	Yes	Yes	Yes	Yes
Signs	# of Signs	Yes	Yes	Yes	Yes
Highway Lighting	# of Lights	Yes	No	Yes	Yes
Guardrail	Miles of Guardrail	Yes	Yes	Yes	Yes
Weigh Stations	# of Stations	Yes	Yes	No	Yes

Step 2. In the **4-Strategy Inputs** tab, Table 4-2 (in the model), set the Use Percent Allocation for Some Assets to No.

Use Percent Allocation for Some AAGs	***No***
Use Relative AAG Ranks	**Yes**

Step 3. In the **4-Strategy Inputs** tab, Table 4-3 (in the model), enter the escalation factor for the AAGs that do not have the necessary data (in this case, for Highway Lighting and Weigh Stations).

Asset-Activity Group (AAG)	Units of Measure	Ideal Rating	Target Rating	Time (Years) for Target Rating	Relative AAG Rank	Needs based Allocation	% Allocation Basis	Allocation Percentage	Escalation in Expenditure**
Bridges	Bridge Decks	100%	80%	2	2	Yes	No		5%
Pavements	Lane Miles	100%	80%	2	1	Yes	Yes		5%
Signs	# of Signs	100%	100%	8	4	Yes	No		5%
Highway Lighting	# of Lights	100%	85%	4	6	Yes	No		5%
Guardrail	Miles of Guardrail	100%	80%	4	2	Yes	No		5%
Weigh Stations	# of Stations	100%	80%	4	5	Yes	No		5%
-	-								
-	-								
-	-								

* Used only when Percent Based Allocation Flag is set as "Yes"

*** Used when Inventory, Condition, Deterioration Rate or Unit Cost data are not available*

Step 4. In the **5-Data Inputs** tab, input values in the five tables for the assets for which a needs-based allocation is to be made.

Step 5. Run the optimization model by selecting the **Run Model** button in the **7-Run Model** tab. Results will be presented in the **7-Run Model** tab.

Step 6. Press the **Export Results** button to save the output results in a new workbook. Save the new workbook for future reference (if needed).

Case Example 3: Allocate the funds based on needs for some AAGs and percentage-based for other AAGs. For example, use needs-based allocation for Bridges, Pavements, Highway Lighting, and Weigh Stations and use percentage-based allocation for Signs and Guardrail (based on percentage of Pavements allocation).

Step 1. In the **3-Basic Inputs** tab, Table 3-1 (in the model), set the Data Availability flags to Yes for the AAGs with needs to be allocated using needs (Bridge, Pavement, Highway Lighting, and Weigh Stations).

		Are Data or Reasonable Estimates Available for the Solution Framework?			
Asset-Activity Group (AAG)	**Units of Measure**	**Inventory**	**Condition Rating**	**Deterioration Rate**	**Unit Cost**
Bridges	Bridge Decks	Yes	Yes	Yes	Yes
Pavements	Lane Miles	Yes	Yes	Yes	Yes
Signs	# of Signs	No	No	No	No
Highway Lighting	# of Lights	Yes	Yes	Yes	Yes
Guardrail	Miles of Guardrail	Yes	No	Yes	No
Weigh Stations	# of Stations	Yes	Yes	Yes	Yes

Step 2. In the **4-Strategy Inputs** tab, Table 4-2 (in the model), set the Use Percent Allocation for Some Assets to Yes.

Use Percent Allocation for Some AAGs	***Yes***
Use Relative AAG Ranks	**Yes**

Step 3. In the **4-Strategy Inputs** tab, Table 4-3 (in the model), set the Needs-Based Allocation flag to Yes for Bridges, Pavements, Highway Lighting, and Weigh Stations and set the Needs-Based Allocation flag to No for Signs and Guardrail. Set the Percentage Allocation Basis flag to Yes for Pavements (to allocate as a percentage of Pavements), and input the allocation percentage (as a percentage of Pavement funds) in the Allocation Percentage column.

Asset-Activity Group (AAG)	Units of Measure	Ideal Rating	Target Rating	Time (Years) for Target Rating	Relative Asset-Activity Rank	Needs based Allocation	% Allocation Basis	Allocation Percentage	Escalation in Expenditure**
Bridges	Bridge Decks	100%	80%	2	2	Yes	No		5%
Pavements	Lane Miles	100%	80%	2	1	Yes	Yes		5%
Signs	# of Signs	100%	100%	8	4	No	No	2.5%	5%
Highway Lighting	# of Lights	100%	85%	4	6	Yes	No		5%
Guardrail	Miles of Guardrail	100%	80%	4	2	No	No	2.5%	5%
Weigh Stations	# of Stations	100%	80%	4	5	Yes	No		5%
-	-								
-	-								
-	-								

Step 4. In the **5-Data Inputs** tab, input values in the five tables for the assets for which Needs-Based Allocation is to be made.

Step 5. Run the optimization model by selecting the **Run Model** button in **7-Run Model** tab. Results will be presented in the **7-Run Model** tab.

Step 6. Press the **Export Results** button to save the output results in a new workbook. Save the new workbook for future reference (if needed).

6.4 Results from Sample Runs

6.4.1 Scenario 1: Base Case (Fully Needs-Based Allocation)

Table 7-1: Summary results - Allocation of Preservation Funds

Asset-Activity Group (AAG)	Total	District 1	District 2	District 3	District 4	District 5	District 6	District 7	District 8	District 9
Bridges	65,688,599	27,719,921	19,499,531	18,469,147	-	-	-	-	-	-
Pavements	137,039,134	53,147,570	38,781,886	45,109,678	-	-	-	-	-	-
Signs	8,035,405	2,947,509	2,500,441	2,587,456	-	-	-	-	-	-
Highway Lighting	2,924,593	1,864,598	616,177	443,818	-	-	-	-	-	-
Guardrail	1,190,236	556,231	274,540	359,465	-	-	-	-	-	-
Weigh Stations	122,033	50,518	37,520	33,994	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
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-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
	215,000,000	**86,286,347**	**61,710,095**	**67,003,558**	**-**	**-**	**-**	**-**	**-**	**-**

Asset-Activity Group (AAG)									
	Difference between Desired and Estimated Time to reach Target Rating			*Difference between Current and Historical Allocation*					
Asset-Activity Group (AAG)	Desired Time	Estimated Time	Difference (Desired - Target)	Average Historical Allocation	Difference (Current - Historical)	Total Allocation *less* Deterioration Need	Target Rating	Current Rating	Expected Rating Result
Bridges	2	14	12.0	67,998,000	(2,309,401)	7,938,599	80.00%	77.21%	77.41%
Pavements	2	14	12.0	138,419,000	(1,379,866)	12,539,134	80.00%	75.85%	76.36%
Signs	8	20	12.0	4,395,333	3,640,072	415,405	100.00%	92.58%	93.12%
Highway Lighting	4	16	12.0	1,595,000	1,329,593	194,093	85.00%	82.75%	83.03%
Guardrail	4	16	12.0	1,269,000	(78,764)	92,836	80.00%	75.71%	75.96%
Weigh Stations	4	16	12.0	195,000	(72,967)	9,033	80.00%	77.74%	77.90%
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
				213,871,333	1,128,667	**21,189,100**			

Note: The Total Allocation less Deterioration Need column indicates an excess amount over the amount needed to cover deterioration costs. This is the amount that is used for net improvement in condition/performance rating.

6.4.2 Scenario 2: Constrained Case (Fully Needs-Based Allocation)

This is the same as the base case, but the Adjustments to Directed Program in Tab 4-1 is increased to 91,000 from 66,000 (in base case). This results in a deficiency of funds as compared with the annual deterioration.

Table 7-1: Summary results - Allocation of Preservation Funds

Asset-Activity Group (AAG)	Total	District 1	District 2	District 3	District 4	District 5	District 6	District 7	District 8	District 9
Bridges	56,614,463	23,890,728	16,805,891	15,917,843	-	-	-	-	-	-
Pavements	122,051,959	47,335,129	34,540,536	40,176,294	-	-	-	-	-	-
Signs	7,470,168	2,740,171	2,324,551	2,405,446	-	-	-	-	-	-
Highway Lighting	2,676,810	1,706,622	563,972	406,216	-	-	-	-	-	-
Guardrail	1,075,822	502,762	248,149	324,910	-	-	-	-	-	-
Weigh Stations	110,778	45,859	34,060	30,859	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
	190,000,000	**76,221,271**	**54,517,160**	**59,261,569**	**-**	**-**	**-**	**-**	**-**	**-**

Asset-Activity Group (AAG)	*Asset-Activity Group (AAG)*								
	Difference between Desired and Estimated Time to reach Target Rating			*Difference between Current and Historical Allocation*					
	Desired Time	Estimated Time	Difference (Desired - Target)	Average Historical Allocation	Difference (Current - Historical)	Total Allocation *less* Deterioration Need	Target Rating	Current Rating	Expected Rating Result
Bridges	2	NA	-	67,998,000	(11,383,537)	(1,135,537)	80.00%	77.21%	77.18%
Pavements	2	NA	-	138,419,000	(16,367,041)	(2,448,041)	80.00%	75.85%	75.76%
Signs	8	NA	-	4,395,333	3,074,835	(149,832)	100.00%	92.58%	92.38%
Highway Lighting	4	NA	-	1,595,000	1,081,810	(53,690)	85.00%	82.75%	82.67%
Guardrail	4	NA	-	1,269,000	(193,178)	(21,578)	80.00%	75.71%	75.65%
Weigh Stations	4	NA	-	195,000	(84,222)	(2,222)	80.00%	77.74%	77.70%
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
				213,871,333	(23,871,333)	**(3,810,900)**			

Note: The Total Allocation less Deterioration Need column indicates an excess amount over the amount needed to cover deterioration costs. This is the amount that is used for net improvement in condition/performance rating.

Result Observation: This run demonstrates the impact of changing the total funds available for preservation. As a result of increasing the Adjustments to Directed Program, the funds available for allocation reduce from $215 million in baseline to $190 million. As a result of the reduction, the total fund available for preservation is less than the total needs to cover deterioration costs (as indicated by negative numbers in the Total Allocation less Deterioration Need column). A value of NA (Not Applicable) in the Estimated Time columns indicates that with current funding levels, the target rating cannot be achieved.

6.4.3 Scenario 3: Percentage-Based Allocation

This is the same as the base case, but it uses percentage-based allocation for Signs and Guardrails. The allocation for Signs and Guardrail is based on a percentage of Pavements preservation funds. The allocation percentages are set by the user to be 2.5 percent.

Table 7-1: Summary results - Allocation of Preservation Funds

Asset-Activity Group (AAG)	Total	District 1	District 2	District 3	District 4	District 5	District 6	District 7	District 8	District 9
Bridges	66,574,056	28,093,575	19,762,377	18,718,104	-	-	-	-	-	-
Pavements	138,437,860	53,690,035	39,177,723	45,570,102	-	-	-	-	-	-
Signs	3,460,947	1,269,528	1,076,970	1,114,449	-	-	-	-	-	-
Highway Lighting	2,943,289	1,876,518	620,116	446,655	-	-	-	-	-	-
Guardrail	3,460,947	1,617,399	798,302	1,045,245	-	-	-	-	-	-
Weigh Stations	122,903	50,878	37,788	34,237	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
	215,000,000	**86,597,932**	**61,473,277**	**66,928,791**	**-**	**-**	**-**	**-**	**-**	**-**

Asset-Activity Group (AAG)									
	Difference between Desired and Estimated Time to reach Target Rating			***Difference between Current and Historical Allocation***					
Asset-Activity Group (AAG)	**Desired Time**	**Estimated Time**	**Difference (Desired - Target)**	**Average Historical Allocation**	**Difference (Current - Historical)**	**Total Allocation *less* Deterioration Need**	**Target Rating**	**Current Rating**	**Expected Rating Result**
Bridges	2	13	10.6	67,998,000	(1,423,944)	8,824,056	80.00%	77.21%	77.44%
Pavements	2	13	10.6	138,419,000	18,860	13,937,860	80.00%	75.85%	76.41%
Signs	8	NA	-	4,395,333	(934,387)	(4,159,053)	100.00%	92.58%	87.12%
Highway Lighting	4	15	10.6	1,595,000	1,348,289	212,789	85.00%	82.75%	83.06%
Guardrail	4	1	(3.4)	1,269,000	2,191,947	2,363,547	80.00%	75.71%	82.17%
Weigh Stations	4	15	10.6	195,000	(72,097)	9,903	80.00%	77.74%	77.91%
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
				213,871,333	1,128,667	**21,189,100**			

Note: The Total Allocation less Deterioration Need column indicates an excess amount over the amount needed to cover deterioration costs. This is the amount that is used for net improvement in condition/performance rating.

Result Observation: This run demonstrates the impact of using percentage allocation for a few assets instead of *fully* optimized allocation. As a result of using percentage-based allocation for Signs and Guardrail, the allocation for guardrail increases more than the baseline (optimal) allocation whereas the allocation for Signs ends up being less than the optimal allocation.

6.4.4 Scenario 4: Change in Desired Time to Reach Target Rating

This is the same as the base case, except the desired time to reach target rating for Signs is reduced to 4 years from 8 years (in the base case).

Table 7-1: Summary results - Allocation of Preservation Funds

Asset-Activity Group (AAG)	Total	District 1	District 2	District 3	District 4	District 5	District 6	District 7	District 8	District 9
Bridges	65,633,319	27,696,594	19,483,121	18,453,604	-	-	-	-	-	-
Pavements	136,952,030	53,113,789	38,757,235	45,081,005	-	-	-	-	-	-
Signs	8,179,595	3,014,100	2,537,320	2,628,176	-	-	-	-	-	-
Highway Lighting	2,923,409	1,863,843	615,928	443,638	-	-	-	-	-	-
Guardrail	1,189,670	555,966	274,409	359,294	-	-	-	-	-	-
Weigh Stations	121,978	50,495	37,503	33,979	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
	215,000,000	**86,294,787**	**61,705,516**	**66,999,696**	**-**	**-**	**-**	**-**	**-**	**-**

Asset-Activity Group (AAG)									
Asset-Activity Group (AAG)	*Difference between Desired and Estimated Time to reach Target Rating*			*Difference between Current and Historical Allocation*					
	Desired Time	Estimated Time	Difference (Desired - Target)	Average Historical Allocation	Difference (Current - Historical)	Total Allocation *less* Deterioration Need	Target Rating	Current Rating	Expected Rating Result
Bridges	2	14	12.1	67,998,000	(2,364,681)	7,883,319	80.00%	77.21%	77.41%
Pavements	2	14	12.1	138,419,000	(1,466,970)	12,452,030	80.00%	75.85%	76.35%
Signs	4	16	12.1	4,395,333	3,784,262	559,595	100.00%	92.58%	93.31%
Highway Lighting	4	16	12.1	1,595,000	1,328,409	192,909	85.00%	82.75%	83.03%
Guardrail	4	16	12.1	1,269,000	(79,330)	92,270	80.00%	75.71%	75.96%
Weigh Stations	4	16	12.1	195,000	(73,022)	8,978	80.00%	77.74%	77.90%
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
				213,871,333	1,128,667	**21,189,100**			

Note: The Total Allocation less Deterioration Need column indicates an excess amount over the amount needed to cover deterioration costs. This is the amount that is used for net improvement in condition/performance rating.

Result Observation: This run demonstrates the impact of changing the Target Years. As a result of decreasing the number of years to reach target rating for signs (from 8 to 4 years), the optimal allocation for signs increases from $8,085,405 in baseline to $8,179,595. This results in a corresponding decrease in allocation for other assets.

CHAPTER 7

Conclusion

The Resource Allocation Logic Framework is fundamentally based on needs. Optimization applies to the adjustments of needed allocations to match available funds.

A needs-based determination of allocation resources means that it is necessary to connect preservation investments directly to expected performance/condition results and to enable correction of expected performance/condition outcomes commensurate with any positive or negative allocation adjustments.

Connecting investments to results requires reasonably reliable data *or estimates* on AAG-specific inventories, average performance/condition, average deterioration, and average preservation unit costs.

When available funding exceeds preservation needs, optimization is used to distribute allocation for best results. When available funding is short of the aggregated preservation needs, the optimization is used to minimize the negative effects of the shortfall on program assets and activities. This usually results in extension of the time required to reach some or all stated performance/condition goals or targets.

Some additional conclusions are highlighted as follows:

1. Based on literature review and interviews, each state DOT has unique practices, definitions, account structure, and taxonomies for the allocation of funds to preservation. There is no one-size-fits-all solution.
2. Inventory, performance/condition, deterioration, and preservation unit cost data availability for NBP assets is very scarce among DOTs, making it challenging to apply a complete analytical approach for allocating resources, without significant estimating and judgment.
3. Agencies track performance metrics and asset inventory in unique ways, so the framework is flexible for a wide range of definitions of both asset-activity groupings and performance standards.
4. Good historical expenditure data is needed to estimate unit costs and deterioration rates.
5. In a severely constrained situation, optimization is still useful to minimize damage to the net asset condition.
6. Deterioration is a very strong driver of preservation need. Where deterioration-based preservation need exceeds funding allocations for any particular AAG, performance improvement is not possible; rather performance can be expected to regress. In these cases, optimized allocation of available funds would seek to minimize this regression across AAGs.
7. The nonlinear aspects of asset deterioration can be reasonably represented as first-order (straight line) equations when aggregated as average rates across entire AAG inventories.
8. The allocation framework does not explicitly incorporate life-cycle cost analysis (LCCA). LCCA is important for determination of preservation strategies, which drives unit costs for

preservation projects. The rate at which asset inventories need to be addressed in an established year-to-year program also drives the deteriorate rates in the logic model. The resource allocation logic focuses on making the best use of available resources in a particular allocation cycle.

The Excel-based demonstration model was developed to validate the logic framework using real or plausible estimates of required data based on two DOT case examples and a composite of data collected from other DOTs. It is not market software. While the model is very flexible and applies straightforward logic, adaptation to other cases requires meeting significant data[16] requirements, as well as familiarity with Excel modeling, and application of linear programming solutions.

Several suggestions are included for activities to support and enhance adoption of the Resource Allocation Logic Framework including the following:

1. **Average Deterioration Rates.** Research is suggested to support improved methods for determining or estimating average deterioration rates for various AAGs. This is a very important factor in the allocation logic framework. Ideally, a high-level average rate is needed for each designated AAG and can be based on specific preservation strategies for that AAG or, as in the case for reflective signs, may be simply based on estimated reflectivity declines under various conditions. As an example, the preservation strategies for pavement may include a portion of the inventory expected to need light overlay treatment each year, and another portion that can be expected to receive full surface rehabilitation each year. This can be addressed in the framework as two separate pavement-related AAGs, each with appropriate inventory, unit cost, performance/condition information, and deterioration rates reflecting the expected time cycles for each grouping. Levels of stress (e.g., vehicle/truck traffic, climate) may also be used to calibrate deterioration estimates.
2. **Asset Inventory and Condition Management.** The actual availability of reasonably reliable asset inventory data (for NBP assets) appeared considerably less common via the interview process than suggested by literature. The process of collection and management of full actual inventory and condition data is an expensive proposition, in relation to the total preservation budgets for NBP assets. Compilation of practical NBP inventory and condition assessment and management approaches (in use by DOTs) would be useful and helpful to potential users of the allocation logic framework, both for enhanced resource allocation and for other asset management purposes. The inventory and condition assessment approaches could include sampling, mapping analysis, and aerial surveys.
3. **Objective Functions for Optimizing Resource Allocation.** Section 4.2.2 lists a number of example objective functions that may be appropriate for the linear optimization, depending on the priorities and particular preservation concerns of DOTs using the logic framework. Using any of these objective functions requires some dexterity with the Excel model computation formulae. It makes sense that preferred optimization strategies (and therefore objective functions) would vary considerably across multiple DOTs. Prospective users of the allocation logic framework would benefit from the exercise of developing the right object functions and collecting ideas and preferences from multiple peer agencies. Collection of this intellectual capital would likely be best done via a focus-group/brainstorming approach with multiple practitioners. A simplified version of the logic model (a few AAGs and example data) will be useful in collecting and checking proposed objective functions.
4. **Added Case Applications for Logic Framework.** Additional case applications would support, build, and communicate confidence among prospective adopters of the Resource Allocation Logic Framework. This will provide experience and lessons learned across a wider

[16]Actual or estimated.

variety of DOTs' allocation processes and characteristics, which range over a wide spectrum from basic "seat-of-the-pants" methods based on history and internal negotiations to much more sophisticated performance-based approaches supported by up-to-date management systems and analytic support.

5. **Methodology to Facilitate Initial Adoption of the Resource Allocation Logic Framework.** Preservation resource allocation processes are well-established in most cases, and the research team assumes that transition to a new approach will require familiarization, validation, and calibration before deployment as a core component of agencies' preservation resource allocation. The team envisions that an adopting DOT will want to populate a full version of the framework with the actual AAG taxonomy and real-time estimates or facts on inventory, unit costs, performance status, deterioration, and so forth. It will likely run and calibrate the allocation results in parallel with the normal allocation process. Through this approach over one or two allocation cycles, agencies should be able to validate the logic, and increase dependence on it.
6. **Development and Sponsorship of Practitioner Training.** Training support is likely to be needed at both strategic and modeler/operator levels for effective assessment, adoption, and implementation of the Resource Allocation Logic Framework. Training would be useful for (1) strategic input estimation and development of objective functions and (2) populating and manipulating the Excel model and Solver for various objective functions. The research team believes that the combination of this and the other suggestions on this list will be important to building acceptance and deployment of the allocation framework.
7. **Application of the Framework to Other Resource Allocation Areas.** Since the model can be adapted to virtually any taxonomy and is fundamentally based on performance-based investment needs, the model can support any application with a quantifiable inventory, performance ratings that can be normalized, and known average cost factors to link investment to results. It may be useful to explore application of the logic more broadly to maintenance and infrastructure improvement programs.

APPENDIX A

Literature Review Summary

This section presents brief summaries of the five reports that were reviewed in detail to collect information on the process and principles used to allocate resources to meet highway asset preservation needs.

NCHRP Project 20-74 "Developing an Asset-Management Framework for the Interstate Highway System" (*NCHRP Report 632*) (*6*)

The objective of NCHRP Project 20-74 was to develop a practical framework for applying asset management principles and practices to managing Interstate Highway Systems (IHS) investments. The framework developed through the project is intended to provide a basis for making decisions across asset classes in an integrated manner and from a systemwide perspective about operation and maintenance as well as new construction and reconstruction.

Summary of Information Presented in this Report: The information presented in this report provides a good understanding of the state-of-the-practice in asset management, framework for managing interstate highway assets, asset categories and asset types, the analytical tools, and the performance measures for making resource allocation decisions.

The summary of key information presented in this report is as follows:

- Asset management process that incorporates the issues of significance to managing IHS
- Guidance for implementing IHS Asset Management Framework and a demonstration of the application of IHS Asset Management Framework
- Grouping of different highway asset types into four major asset categories, namely Roads, Structures, Safety Features, and Facilities
- Recommended core and additional performance measures by different performance categories, such as Preservation, Mobility, Safety, and Environment
- Enumeration of all the analytical tools commonly used in the industry and the context to the analytical tools, such as business rules, analysis data, analysis parameters, and core asset data

The approach to defining performance measures is also available.

***NCHRP Synthesis of Highway Practice 371: Managing Selected Transportation Assets: Signals, Lighting, Signs, Pavement Markings, Culverts, and Sidewalks* (*8*)**

The objectives of this synthesis were to gain a better understanding of the state-of-the-practice for managing transportation infrastructure assets other than pavements and bridges, to identify best practices, and to document gaps in existing knowledge and needs for further research. The study focused primarily on six types of "selected" assets:

- Traffic signals, including structural components
- Lighting, including structural components

- Signs, both ground-mounted (or roadside) and overhead, including structural components
- Pavement lane striping and other markings
- Drainage culverts and pipes (but not bridges)
- Sidewalks, including the walkway itself, curbs, and corners on urban roads and streets (corner curbs, and curb cuts and ramps, if present)

This synthesis examined several key aspects of asset management related to the six selected infrastructure assets, including primary sources of technical guidance for management; basic approaches to budgeting for and conducting preservation, operation, and maintenance; organizational responsibilities for ongoing maintenance; measurement of asset condition and performance, including methods and frequencies of data collection; estimates of service lives (or deterioration models) for key components of the selected assets; and major gaps in knowledge that impede better asset management, with suggestions for future research. These data were gathered through a review of U.S. and international literature and a survey of state, provincial, county, and city transportation agencies in the United States and Canada.

Summary of Findings: The information gathered provides a good understanding of the challenges and issues related to managing non-bridge and non-pavement asset types, data availability, and guidelines to evaluate conditions of these assets. From an organizational, institutional, and procedural view, non-bridge and non-pavement assets present challenges in management, coordination, and data compilation. From an engineering and technical standpoint, selected assets comprise a number of components and materials, serve in many different environments, and are subject to many different types of deterioration. As such, developing the models that adequately explain these deterioration mechanisms and that can predict service lives for the complete range of possible conditions is a major challenge.

NCHRP 20-68: U.S. Domestic Scan Program: Best Practices in Asset Management (*4*)

The objective of this study was to identify best-case examples of the application of asset management principles and practice in U.S. transportation agencies. Six state DOTs (Florida, Michigan, Minnesota, Ohio, Oregon, and Utah) were interviewed as a part of this study. The report presented the findings of this study under the following categories: decisionmaking process, asset management approach, management and data systems, results of system preservation strategy, and lessons learned.

Summary of Findings

- All state DOTs interviewed use a Preserve First Policy and have implemented a performance-based asset management system.
- State DOTs use specific performance categories (e.g., safety, performance conditions, customer satisfaction, mobility) to make resource allocation decisions.
- Investment decisions are made to meet performance targets.
- Mostly private contractors are used to perform maintenance activities.
- Bridge and pavement management systems are more advanced than other maintenance management systems.

A Flexible Framework for Sustainable Multi-Objective Cross-Asset Infrastructure Management (*9*)

Detailed literature review revealed that there are very few reports that describe or present an analytical approach or framework that focuses on cross-asset management. Most asset management systems only allow for a stove-piped analysis for any asset (e.g., pavement, bridge). However, the cross-asset management provides a unified approach for managing different types of assets in an integrated process. In this approach, instead of considering individual asset types independently, several types of assets are managed simultaneously. Based on the overall strategic level policies and asset values, resources are allocated across different asset types, such as roadways, electrical facilities, and water-distribution facilities. The resources allocated to each asset category are then distributed within each asset class.

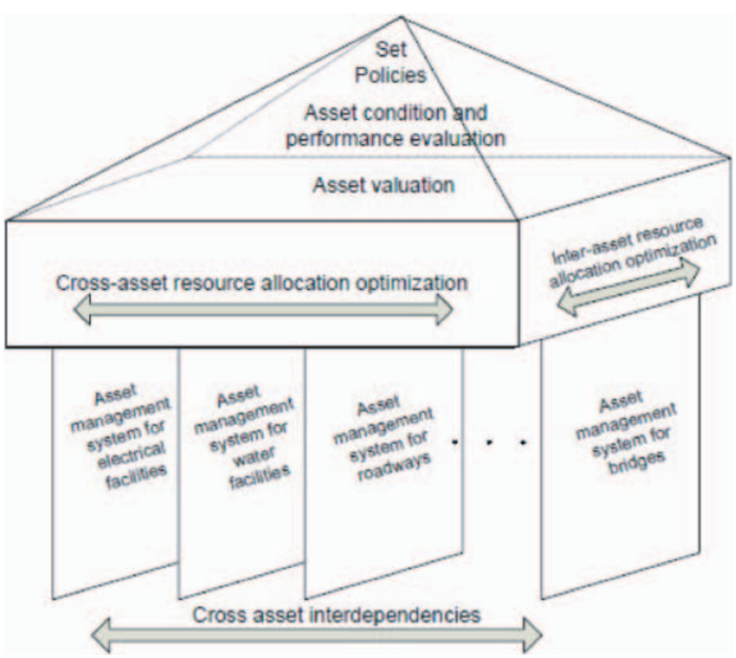
At the strategic level, cross-asset management can be described as a process with the following four major steps: (1) setting strategic policies and objectives, (2) evaluation of performance measures and indicators, (3) combining the indicators for each domain and developing and index for each domain, and (4) optimizing the allocation of resources for maximizing the achievement of the various goals within the available constraints.

Overview of Resource Allocation and Utilization in Asset Management (Dehghanisanij and Flintsch 2004) (9)

Cross-asset resource allocation involves identifying and measuring performance indicators for each aspect (e.g., safety, mobility, preservation). These aspects can then be integrated to develop a combined performance indicator for each asset. Optimization techniques can be used to allocate available resources based on defined objective functions and performance targets.

Summary of Findings: This research paper presents the current practice in different steps of the cross-asset management process and presents the challenges in developing a cross-asset management framework. The key findings from this study include the following:

- Asset management in the context of multi-objective and multi-constraint domains is getting more attention from both decisionmakers and engineers.
- Goals and policies are being increasingly linked to performance measures.
- To simplify the decisionmaking process, different measures and indicators with different scales associated with different assets are increasingly merged into combined indices.
- Limitations in human, funding, and natural resources and an increasing trend toward considering multiple objectives are reshaping asset management.
- Application of soft computing and optimization techniques capable of simultaneously considering multiple objectives and constraints has shown great potential to enhance the process.
- The integration of more effective performance measures and multi-objective, cross-asset optimization techniques should allow a more efficient use of the available resources.



***NCHRP Report 551: Performance Measures and Targets for Transportation Asset Management* (*1*)**

This report was published in 2006. The primary objectives of this project were to investigate performance measures suitable for use in an asset management approach that effectively address resource allocation in transportation facility preservation, operation, improvement, and expansion and develop a framework for establishing performance measures and setting targets for use in asset management practice.

This study provides information on the following key topics:

- **Current State-of-the-Practice.** Presents the current state-of-the-practice with respect to performance measurement as it relates to asset management. The state-of-the-practice was determined by conducting a literature interview and interviews with several transportation agencies.
- **Criteria for Selecting Performance Measures for Asset Management.** Presents the criteria for selecting performance measures useful for an asset management approach. The asset management self-assessment tool was used to derive guidelines for identifying and using performance measures in an asset management context.
- **Performance Measures Design Considerations for Use in Asset Management.** Provides an in depth discussion of important considerations in designing and using performance measures and setting performance targets in support of asset management.
- **Recommended Framework for Incorporating Performance Measures in the Asset Management Practice.** Presents the recommended framework for identifying, designing, and using performance measures for asset management and for setting performance targets.

Key findings of this report are as follows:

- A number of state DOTs collect and manage performance measures in four major categories: Preservation, Mobility and Accessibility, Operations and Maintenance, and Safety.
- Agencies understand the importance of program delivery measures in achieving the results intended during resource allocation and in strengthening the credibility of the agency for communicating both resource allocation recommendations and program delivery accomplishments.

Information Relevant to the Research Allocation Project: The report presents several examples of commonly used performance measures by different categories. This information served as a useful input for this study. The guidance for integrating performance measures into asset management practice also served as a useful input.

APPENDIX B

State DOT Interview Guide Book

Business Context (or) Decisionmaking Process

1. Can you provide an overview of your state departments of transportation (DOT) organization structure? What role does the asset management division play? What is your role in the organization?
2. Which department or division within your highway organization is responsible for preservation maintenance of highway assets?

Understanding of Fund Allocation at a Higher Level

1. Can you provide us an overview of the fund allocation process within your highway department (refer to Figure B-1)? In particular, start with the overall highway budget and describe the sequence in which the highway funds trickle down, keeping in mind the following items:

   In general, what is the process adopted to allocate money across the following:

   a. Emergency programs, legislative mandates, zero-tolerance programs, staff billets and salary requirements, and constrained long-range plans
   b. Different investment types (Preservation Maintenance, Operations, Expansion)
   c. Different districts or regions within the state
   d. Can you think of any other factors that influence fund allocation at a high level before we talk specifics about asset preservation maintenance?
1. *NCHRP Web-Only Document 41 (*10*)* (NCHRP Project 20-24 [11]) defines three investment types or programs (Preservation Maintenance, Operations, and Expansion). Does your state DOT use similar categories?
2. Are the resource allocation decisions across different investment types made at the state level or at the district or regional level (refer to Figure B-2)?

Understanding of Asset Preservation Budget Estimation and Resource Allocation in Detail

1. How does your state DOT define asset preservation maintenance? For example, what activities are typically funded under the umbrella "asset preservation maintenance"?
2. How is the preservation maintenance budget estimated? What role does historical data play?
3. What kind of constraints does the DOT face in allocating preservation maintenance resources (e.g., budget constraints, performance targets, service levels, customer demands, environmental requirements, risks and liabilities)?
4. What is the process for allocating asset preservation maintenance dollars to different asset types like bridges, pavements, drainage systems, signage, or lighting?

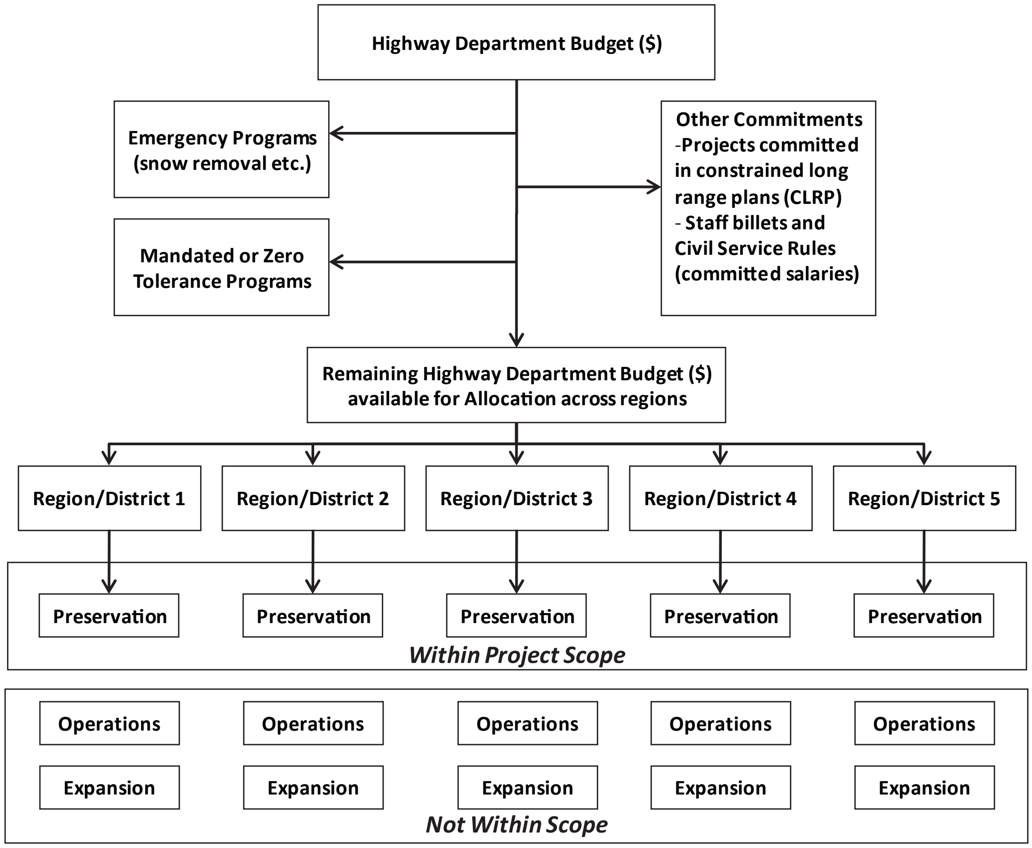


Figure B-1. A Sample Resource Allocation Logic Framework.

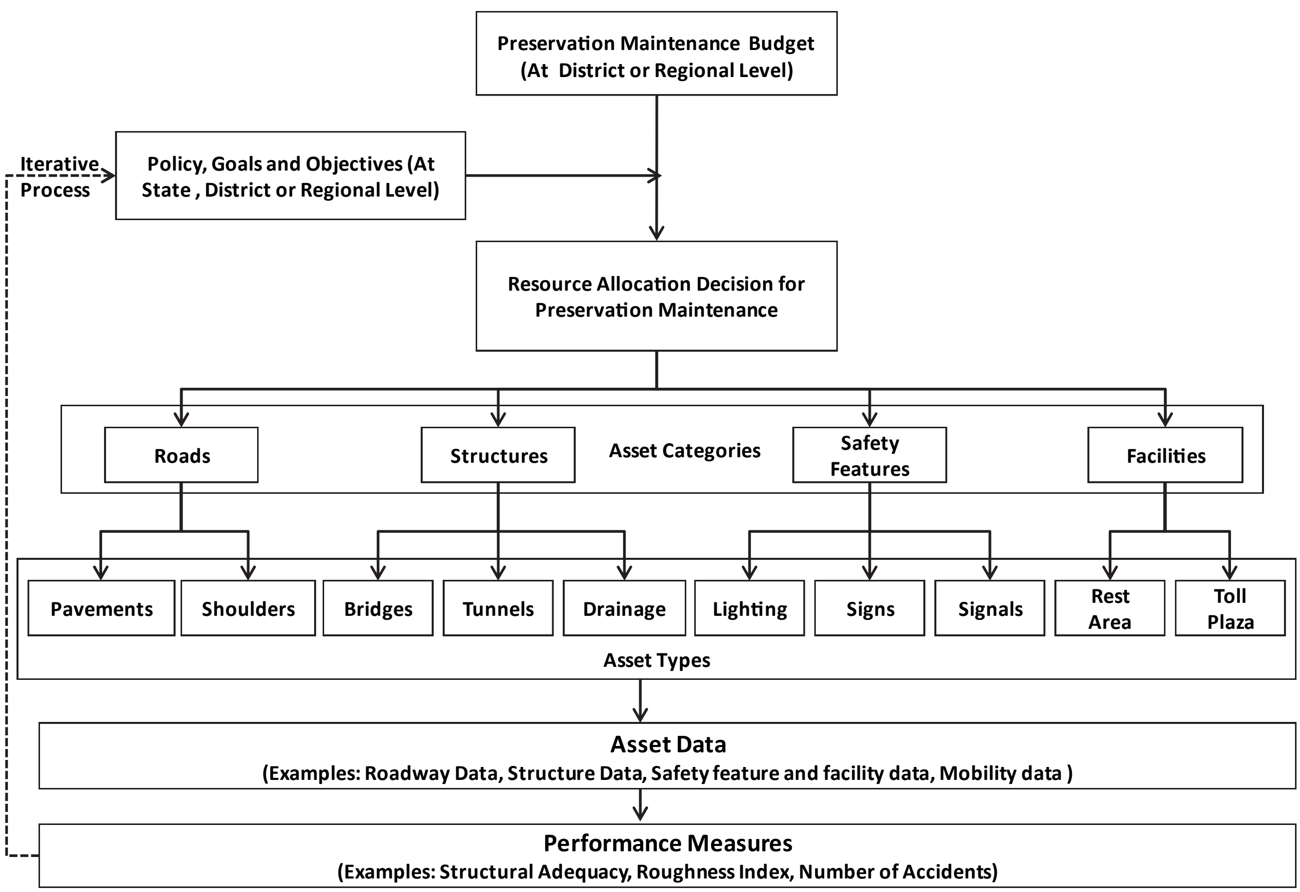


Figure B-2. A Sample Decisionmaking Process for Resource Allocation Across Different Asset Categories.

1. How do you then determine the funds to be allocated to individual assets within a given asset type? Is a different process adopted for each asset type?
2. How do policies and performance goals impact the resource allocation decisionmaking process? Are policies set typically at the state level or at the district level?
3. What is the period/evaluation cycle employed for making resource allocation decisions (annual, biannual, 2 years, 5 years)?
4. In the resource allocation decision process, can you think of any issues if we adopt the categorization of assets based on a recently conducted study, *NCHRP Report 632* (refer to Figure B-3)?
   a. Can you confirm if the assets listed in this slide represent the universe of assets that are in your state highways and local roads?
   b. If we adopt the same asset categorization, would we be missing any important asset types?
   c. After bridges and pavements, in your opinion, list four or five asset types/categories with the highest maintenance and replacement costs?

Data requirements (understand what asset data is used by state DOTs to allocate preservation maintenance dollars):

1. What are the different asset data systems (e.g., Bridge Management System [BMS], Pavement Management System [PMS]) that your state DOT has?
   a. What types of data systems are available for the non-bridge and non-pavement assets?
2. Take each asset data system (e.g., BMS, PMS) and tell us what data is typically captured?
   a. Inventory
   b. Condition
   c. Usage
   d. What else?
3. How frequently is the data collected in each asset data system? Is it a complete inventory or a survey of a representative sample?
4. Can we get a list of performance measures (e.g., structural adequacy, roughness index, number of accidents) that are used commonly by your state for allocating resources?
5. How do you gather the performance measures? Does the agency attempt to set uniform or comparable measures across different asset types?
6. How is the feedback among resource allocation decisions, data collection efforts, system performance, and agencies' policy and goals established or ensured?

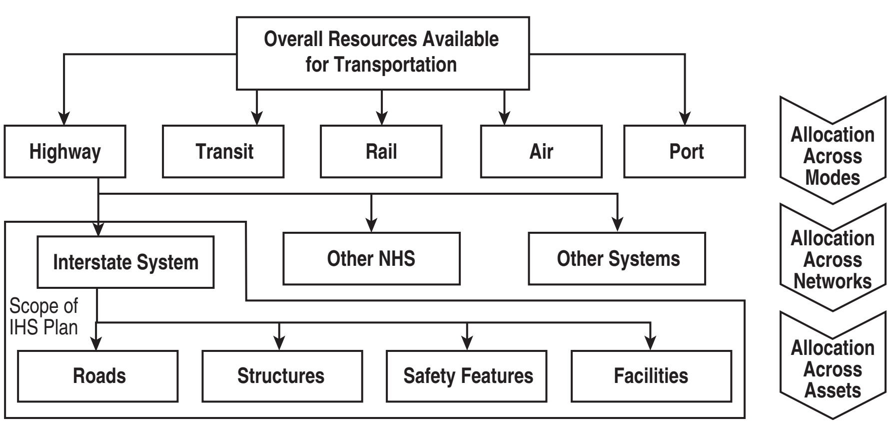


Figure B-3. Example Framework from NCHRP Report 632: An Asset Management Framework for the Interstate Highway System.

Analytical or Optimization Techniques:

1. What analytical tools are used for allocating resources for preservation maintenance? Are the tools asset specific or an integrated tool using data for different asset types?
2. What specific tools are used for sub-allocating funds available for preservation maintenance across different asset categories and to different assets within an asset category?
3. Are the analytical tools used to perform scenario or sensitivity analysis to determine optimal/best solutions?
4. Are operations research techniques used for analysis? If so, what objective functions are considered? What constraints are used?
5. What steps are taken to ensure validity of the tools or adopted approach?

Outputs and Reporting:

6. Are documents that describe the agencies' asset management practice, maintenance management programs, and preservation resource allocation practices readily available?
7. What outputs are typically generated using models or tools used for making resource allocation decisions? How are the outputs from the resource allocation process presented?
8. How is the preservation maintenance resource allocation success reported?

APPENDIX C

References

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5. Cambridge Systematics, Inc. *NCHRP Web-Only Document 154: Target-Setting Methods and Data Management to Support Performance-Based Resource Allocation by Transportation Agencies, Volume III: Case Studies,* Transportation Research Board of the National Academies, Washington, DC, 2010.
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7. Zongzhi Li and Kumares C. Sinha, Purdue University, Methodology for Multi-Criteria Decisionmaking in Highway Asset Management. Presented at the 83rd Annual Meeting of the Transportation Research Board, Washington, DC, 2004.
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APPENDIX D

Acronyms

AAG	Asset/Activity Grouping
AAID	Asset/Activity Identification
AAU	Asset/Activity Unit
BMS	Bridge Management Systems
BPETG	Bridge Preservation Expert Task Group
DOT	Department of Transportation
FARS	Fatality Analysis Reporting System
FHWA	Federal Highway Administration
GIS	Geographic Information System
HERS	Highway Economic Requirements System
HPMS	Highway Performance Management System
HSIP	Highway Safety Improvement Program
HSIS	Highway Safety Information System
IHS	Interstate Highway System
IRI	International Roughness Index
ISTEA	Intermodal Surface Transportation Equity Act
ITS	Intelligent Transportation System
LCC	Life-Cycle Cost
LOS	Level of Service
MOOS	Multi-Objective Optimization System
MRP	Maintenance Rating Program
NBI	National Bridge Inventory
NBP	Non-Bridge/Pavement
NCHRP	National Cooperative Highway Research Program
PCL	Performance/Condition/Life
PMS	Pavement Management System
ROI	Return on Investment
SME	Subject Matter Expert
SWOT	Strengths, Weaknesses, Opportunities, Threats/Risks

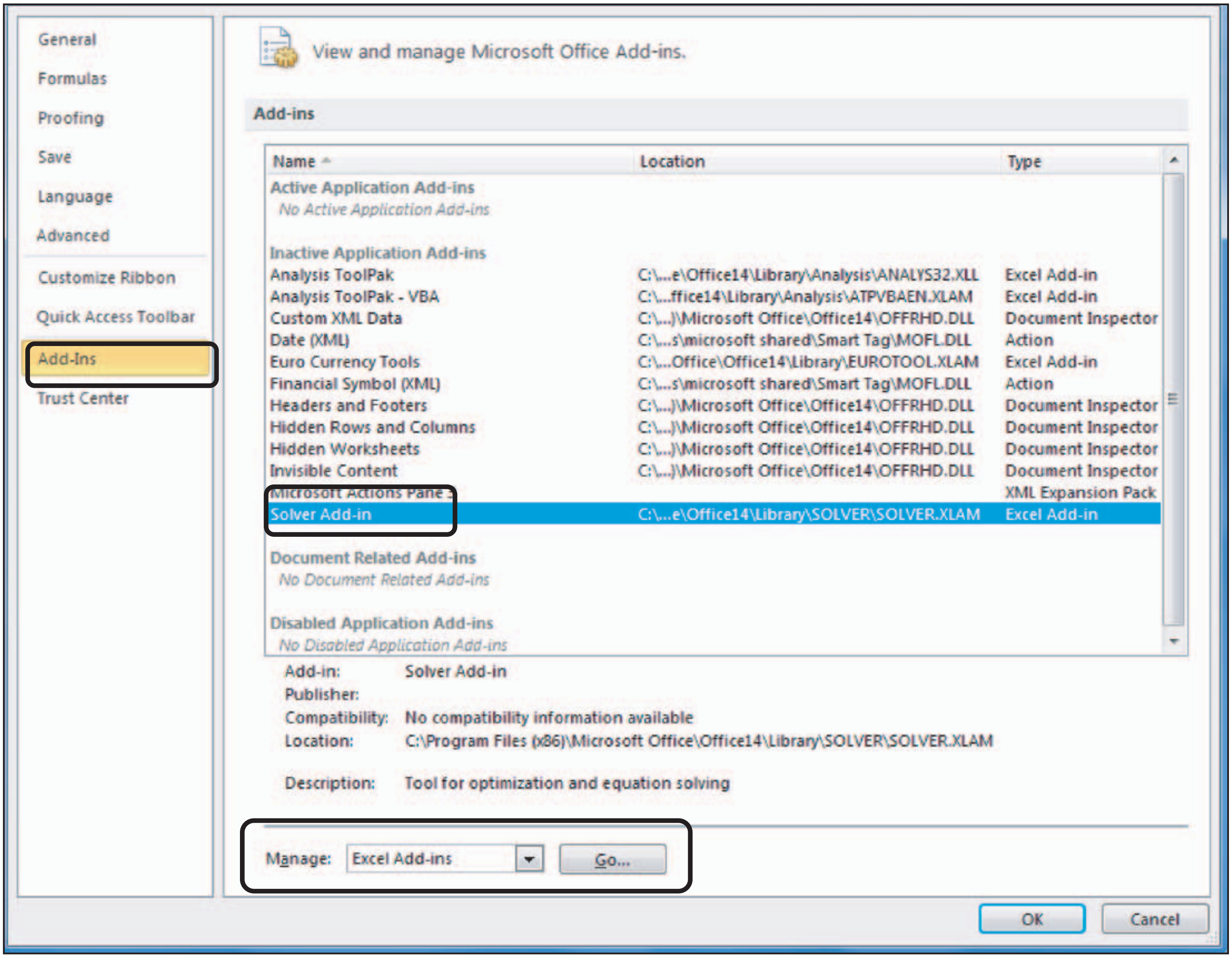
APPENDIX E

Instructions to Activate Solver in Excel Program

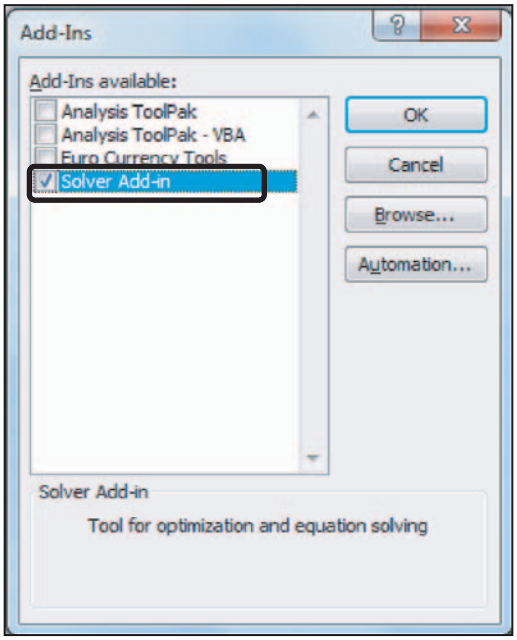
To run the Linear Optimization Procedure in the Excel model developed to implement the Resource Allocation Logic Framework, the user needs to activate the Solver add-in available in Excel, if the Solver add-in in Excel has not been activated before. Instructions for adding/activating the Solver add-in are provided as follows.

Instructions for Adding and Activating the Solver Add-In for Excel 2010:

1. Click the File tab, click Options, and then click the Add-Ins category.
2. To add Solver Add-in, select Solver Add-in in the Inactive Application Add-ins options.
3. In the Manage box, click Excel Add-ins, and then click Go.



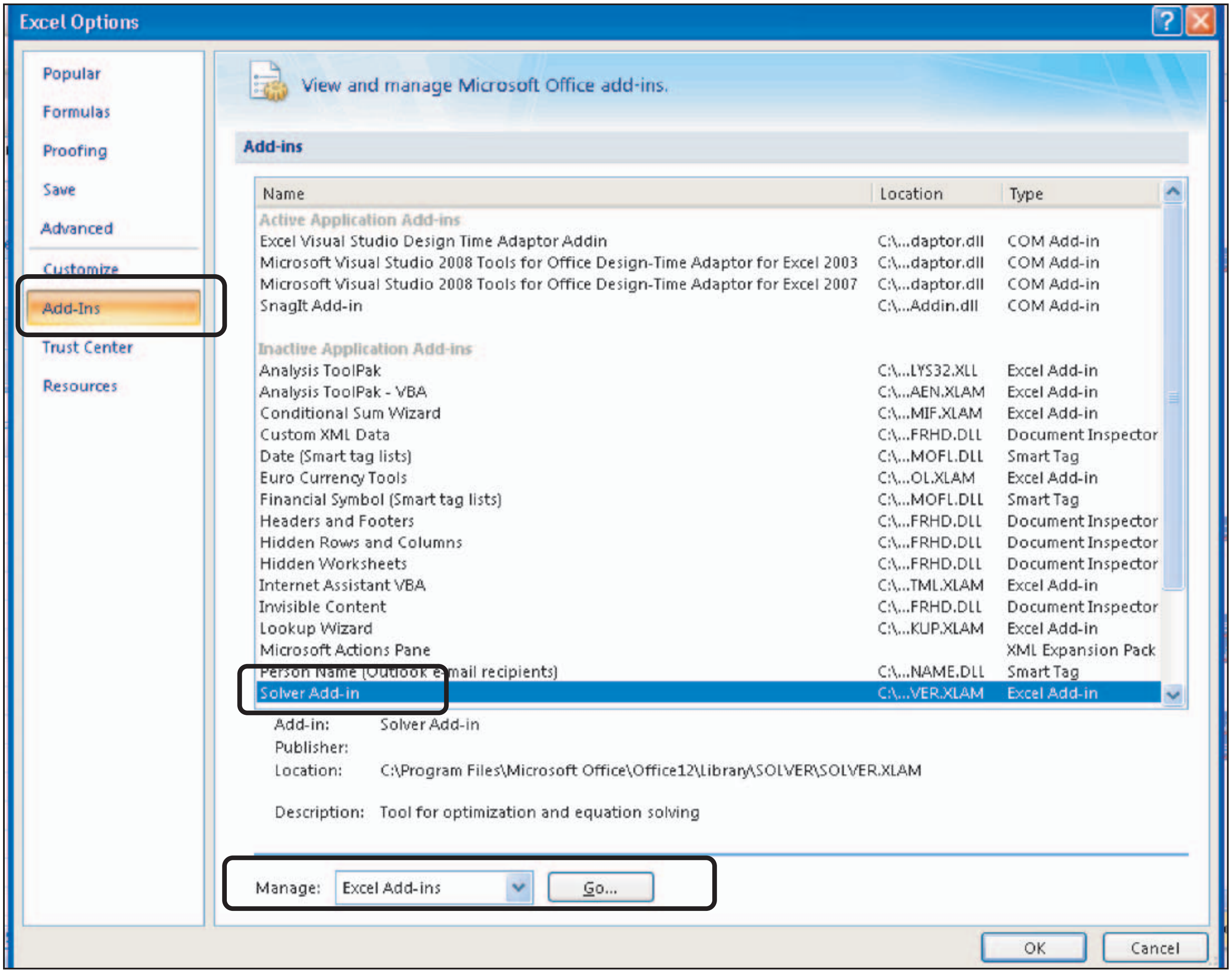
4. The Add-Ins dialog box appears. In the Add-Ins Available box, select the check box next to Solver Add-in that you want to activate, and then click OK.



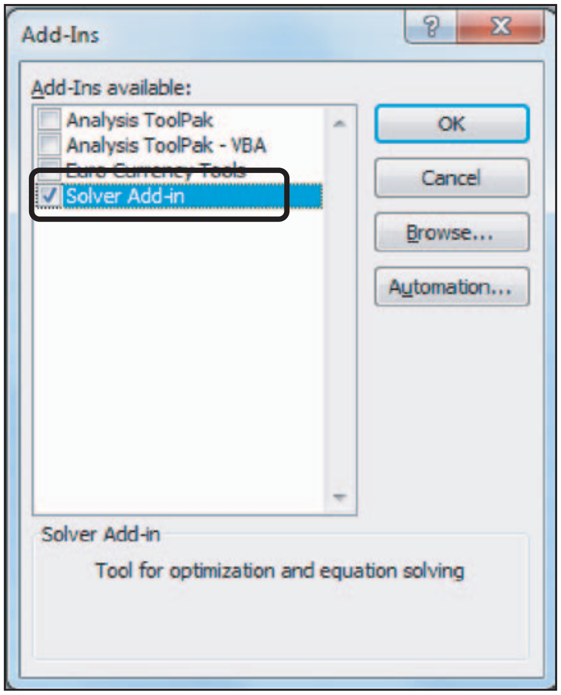
5. Close Excel and reopen the Excel Program.

Instructions for Adding and Activating Solver Add-In for Excel 2007:

1. Click the File tab, click Excel Options.
2. Click the Add-Ins category.
3. To add the Solver Add-in, select Solver Add-in in the Inactive Application Add-ins options.
4. In the Manage box, click Excel Add-ins, and then click Go.



5. The Add-Ins dialog box appears. In the Add-Ins Available box, select the check box next to Solver Add-in that you want to activate, and then click OK.
6. Close Excel and reopen the Excel Program.



Instructions for Installing Excel Solver Add-in for Mac:

Starting with Excel 2011 Service Pack 1 (Version 14.1.0), Solver is bundled with Microsoft Excel for Mac. To enable Solver, click **Tools** then **Add-ins.** Within the **Add-in** box, check **Solver.xlam** then hit **OK.**

If you are running Excel 2008 in Mac, download Solver for free from Frontline Systems and then use Solver with Excel 2008.

- Visit the Frontline Systems website, and then follow the instructions on the download page.
- After you have downloaded and installed Solver, open the workbook that contains your Solver model.
- Enable macros.

Abbreviations and acronyms used without definitions in TRB publications:

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
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