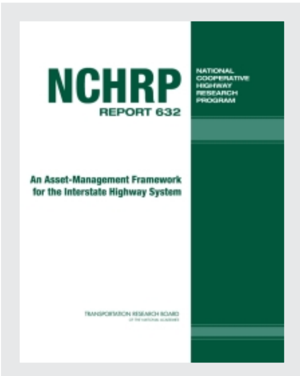


An Asset-Management Framework for the Interstate Highway System

DETAILS

71 pages | | PAPERBACK
ISBN 978-0-309-11775-3 | DOI 10.17226/14233

AUTHORS

Transportation Research Board

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP REPORT 632

An Asset-Management Framework for the Interstate Highway System

CAMBRIDGE SYSTEMATICS, INC.
Cambridge, MA

WITH

APPLIED RESEARCH ASSOCIATES, INC.
Champaign, IL

ARORA AND ASSOCIATES
Robbinsdale, MN

KLS ENGINEERING
Sterling, VA

PB CONSULT, INC.
Baltimore, MD

Louis Lambert
Laingsburg, MI

Subject Area
Planning and Administration

Research sponsored by the American Association of State Highway and Transportation Officials
in cooperation with the Federal Highway Administration

TRANSPORTATION RESEARCH BOARD

WASHINGTON, D.C.
2009
www.TRB.org

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Academies was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state and local governmental agencies, universities, and industry; its relationship to the National Research Council is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and the Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

NCHRP REPORT 632

Project 20-74
ISSN 0077-5614
ISBN: 978-0-309-11775-3
Library of Congress Control Number 2009902288

NOTICE

The project that is the subject of this report was a part of the National Cooperative Highway Research Program conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council. Such approval reflects the Governing Board's judgment that the program concerned is of national importance and appropriate with respect to both the purposes and resources of the National Research Council.

The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the American Association of State Highway and Transportation Officials, or the Federal Highway Administration, U.S. Department of Transportation.

Each report is reviewed and accepted for publication by the technical committee according to procedures established and monitored by the Transportation Research Board Executive Committee and the Governing Board of the National Research Council.

The Transportation Research Board of the National Academies, the National Research Council, the Federal Highway Administration, the American Association of State Highway and Transportation Officials, and the individual states participating in the National Cooperative Highway Research Program do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

Published reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from:

Transportation Research Board
Business Office
500 Fifth Street, NW
Washington, DC 20001

and can be ordered through the Internet at:

http://www.national-academies.org/trb/bookstore

Printed in the United States of America

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

The **National Academy of Sciences** is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. On the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Ralph J. Cicerone is president of the National Academy of Sciences.

The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Charles M. Vest is president of the National Academy of Engineering.

The **Institute of Medicine** was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, on its own initiative, to identify issues of medical care, research, and education. Dr. Harvey V. Fineberg is president of the Institute of Medicine.

The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both the Academies and the Institute of Medicine. Dr. Ralph J. Cicerone and Dr. Charles M. Vest are chair and vice chair, respectively, of the National Research Council.

The **Transportation Research Board** is one of six major divisions of the National Research Council. The mission of the Transportation Research Board is to provide leadership in transportation innovation and progress through research and information exchange, conducted within a setting that is objective, interdisciplinary, and multimodal. The Board's varied activities annually engage about 7,000 engineers, scientists, and other transportation researchers and practitioners from the public and private sectors and academia, all of whom contribute their expertise in the public interest. The program is supported by state transportation departments, federal agencies including the component administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation. **www.TRB.org**

www.national-academies.org

C O O P E R A T I V E   R E S E A R C H   P R O G R A M S

CRP STAFF FOR NCHRP REPORT 632

Christopher W. Jenks, *Director, Cooperative Research Programs*
Crawford F. Jencks, *Deputy Director, Cooperative Research Programs*
Andrew C. Lemer, *Senior Program Officer*
Eileen P. Delaney, *Director of Publications*
Margaret B. Hagood, *Editor*

NCHRP PROJECT 20-74 PANEL
Field of Special Projects

Kirk T. Steudle, *Michigan DOT, Lansing, MI* (Chair)
Carl Chase, Jr., *South Carolina DOT, Columbia, SC*
Tremain V. Downey, *California DOT, Sacramento, CA*
Wendy L. Gagnier, *PBS&J, Orlando, FL*
Shiv K. Gupta, *Wisconsin DOT, Madison, WI*
William M. McEntee, *Road Commission for Oakland County (MI), Waterford, MI*
Sue McNeil, *University of Delaware, Newark, DE*
Tammy B. Sims, *Texas DOT, Austin, TX*
Jeffrey H. Smith, *Maryland State Highway Administration, Baltimore, MD*
Shirley J. Ybarra, *Reason Foundation, Washington, DC*
Francine Shaw-Whitson, *FHWA Liaison*
Thomas Palmerlee, *TRB Liaison*

FOREWORD

By Andrew C. Lemer
Staff Officer
Transportation Research Board

This report presents a practical framework for applying asset-management principles and practices to managing Interstate Highway System (IHS) investments. The IHS is a national asset; as a system it serves a very large share of the nation's highway transportation demand, disproportionate to the system's share of the nation's highway mileage. A major challenge in managing this asset lies in developing usable management principles and strategies that can be accepted and applied by the varied government agencies that share responsibility for the IHS. These principles and strategies draw on the growing body of experience in transportation asset management, but are intended to respond to the unique challenge of the IHS. The report describes the scope of the challenge and presents specific asset-management practices that may be adapted to IHS management. This work will be useful to state government officials and others responsible for preparing, administering, and executing management plans for highway networks that include elements on the IHS and other systems of national significance.

The United States has made significant investments in its transportation infrastructure and, as this infrastructure is used and exposed to natural environmental forces, it ages and deteriorates. Responsible agencies expend time, effort, and money to preserve and maintain the infrastructure to ensure that it will support consistent, reliable, and safe transportation services and produce economic benefits.

One of the nation's most significant investments in transportation infrastructure is the Dwight D. Eisenhower System of Interstate and Defense Highways, often referred to simply as the Interstate Highway System. The IHS, initiated more than 50 years ago, is vital to the nation's economy and is a critical contributor to global production and distribution systems. Investments in the system are managed by the state departments of transportation (DOTs) and a variety of other associated agencies responsible for specific Interstate facilities. To ensure that the benefits of the IHS continue for future generations, these agencies must preserve, operate, maintain, and augment its assets.

The principles and practices of transportation asset management constitute a framework for making decisions about planning, programming, design, construction, maintenance, and operation of roadways, bridges, tunnels, and other transportation facilities. These principles and practices have been developed in recent years and applied in the United States and other countries to protect and ensure high returns on investment in transportation infrastructure assets. Interpretation and application of these principles and practices may vary among the responsible agencies in appropriate responses to the specific asset portfolios, institutional settings, funding, and priorities affecting each particular agency. These assets nevertheless serve national purposes and their management should reflect an appropriate balance between state and national interests.

To assist agencies in applying sound asset-management principles and practices for the IHS, AASHTO requested NCHRP to undertake Project 20-74, "Developing an Asset-Management Framework for the Interstate Highway System." This report is the final product of that research.

The objective of this research project was to develop a practical framework for applying asset-management principles and practices to managing IHS investments. The framework is designed to be applicable to existing facilities and those that may be developed in the future; to provide the bases for making decisions across asset classes in an integrated manner and from a systemwide perspective, to address operation and maintenance as well as new construction and reconstruction; and to be easy to implement, cost-effective, and sufficiently beneficial to be attractive for adoption by transportation officials and agencies nationwide.

A research team led by Cambridge Systematics, Inc., Cambridge, Massachusetts, conducted the research. The project entailed first identifying asset performance indicators appropriate for use in understanding the condition and performance of IHS assets and suitable as the bases for making a broad range of asset-management decisions. Such indicators must support decision makers' understanding of the impacts of their management decisions on asset performance as it affects mobility, capacity, safety, and other aspects of highway system performance. The research team gave particular attention to specific mechanisms for incorporating risks of system failure in an asset-management framework and how risk may be considered systematically as an influence on asset-management decision making. Such risks include, for example, loss of system continuity due to failure of a critical asset, acceleration of reconstruction requirements caused by insufficient maintenance funding, or increased safety hazard associated with reduced asset performance.

The report describes data needed to support IHS asset-management decisions, how current data inventories may be employed, gaps in currently collected data that should be filled to enable effective application of asset-management principles and practices to the IHS, and cost-effective data-collection schemes. The report also considers available decision-support tools that can be used in applying asset-management principles and practices for the IHS and the adequacy of these tools to support a practical asset-management framework. The research included testing the management framework using a data set assembled from several states to represent the variety of design and operating conditions within the IHS nationwide.

The research also entailed consideration of indicators of the measurable system benefits that DOTs and others could use to evaluate their IHS application of asset-management principles and practices and of the obstacles and costs likely to be encountered in implementing the asset-management framework. The report describes the rationale for agencies responsible for IHS asset management to adopt and use the framework.

C O N T E N T S

SUMMARY

An Asset-Management Framework for the Interstate Highway System

The objective of NCHRP Project 20-74 is to develop a practical framework for applying asset-management principles and practices to managing Interstate Highway System (IHS) investments.

It is impossible to overstate the importance of the IHS to global, national, regional, and local area movements of people and goods. On a global scale, the competitiveness of the United States in international trade and the need to surmount the challenges of moving goods over long distances has benefited immensely from this far-reaching network of roads that for a generation had no equal. On a national scale, the IHS has transformed the nation, enabling coast-to-coast travel and trade in a matter of days instead of weeks. On a regional level, the IHS has facilitated economic integration and accessibility within numerous multistate corridors, as evidenced by the growing number of voluntary interstate corridor coalitions of states and metropolitan areas that have sprung to life over the past 15 years. On a more local level, in literally hundreds of urbanized areas around the country, networks of beltways and radial highways serve as the surface transportation backbone of metropolitan regions. The NCHRP 20-74 effort is intended to supplement other work on the past and future of the IHS with tools and approaches for better managing the system in the present.

Part of the challenge of managing the IHS lies in developing cost-effective investment strategies mutually agreed upon by agency staff and external stakeholders for managing the various assets on the system. The assets need to be managed collectively by asset type, as well as by segment, by corridor, by region, and for the system in its entirety. The challenges only will grow greater as the system ages, and there are further increases in passenger and freight traffic.

Transportation asset management is a developing field that provides a set of tools and techniques for managing infrastructure assets. Asset management is, at its core, a set of guiding principles and best practice methods for making informed transportation resource allocation decisions, and for improving the accountability for these decisions. Asset management principles and processes apply to all types of investments in transportation infrastructure assets. Conceptually asset management is not limited to a preservation focus, but considers the full range of potential investments, as well as factors related to safety, operations, environmental management, corridor management, and project/program delivery.

In applying asset management to the HIS, one must first ask what, if anything, is unique about the IHS that demands a targeted approach. The answer to this most fundamental question is that the IHS is uniquely important because it represents the most critical set of highway assets in the United States. Keeping its portion of the IHS in operation is a critical concern for every IHS owner, and asset management promises an approach for helping accomplish this objective. Applying asset management to IHS assets is not an objective unto itself, but a means for achieving a larger, national goal, that of helping keep the IHS network in operation using the most effective means. This objective is in one respect very targeted, in that it applies to a single portion of the U.S. transportation network. In another respect, the objective is quite broad, as it implies

consideration of the full range of factors that might impact operation of the IHS, and introduces the concept of a national interest in IHS asset performance. This approach provides a consistent asset management framework and, therefore performance expectations for the IHS, by leveraging existing agency-to-agency institutions and relationships in managing the connection points of the system.

The basic strategy recommended for integrating decision making for IHS assets with the broader decision-making scope is for each IHS owner to develop an Interstate Asset Management Plan on a periodic basis. The plan should summarize conditions of IHS assets, establish performance measures for those assets considering available funds, and describe the plan for future investments in the IHS. The plan, once developed, will help support the agency's ongoing resource allocation process for its IHS network across investment categories and decision-making horizons. It also should provide consistent information about the system that can be shared among the many agencies managing the network. A recommended outline for an Interstate Asset Management Plan is presented in Chapter 2.

Previous work on transportation asset management is readily transferable to the present study, but developing an asset management framework tailored to the IHS requires extending previous work on transportation asset management, focusing on selected areas. These include:

- Defining how to better incorporate assessment of the risks of system failure into an asset management framework. Chapter 3 recommends a risk management approach for the IHS.
- Providing guidance for handling all IHS assets, particularly assets besides pavements and bridges. Chapter 4 details available data and tools for IHS assets and provides guidance for what data to collect and analyses to perform for the full set of IHS assets.
- Recommending a set of measures tailored for use in reporting and facilitating discussion of IHS performance both within an agency, to system users, industry partners, regionally, and nationally. Chapter 5 details the recommended approach to performance management for IHS assets and includes recommendations on what performance measures to include in an Interstate Asset Management Plan.

Chapter 6 of this report provides guidance on implementing an asset management approach for the IHS. The approach to implementing asset management will depend up the basic motivation for implementation, the focus area of the effort, the approach taken to leading the effort, and the set of internal and external stakeholders involved in implementation. An Interstate Asset Management Framework may focus on areas that vary according to function (preservation, mobility, safety, and environment), or level within the organization (policy level issues, program and project prioritization issues, management and operational issues), or any combination of these.

Each and every agency and entity responsible for a portion of the IHS must reach its own conclusions, for its own reasons, on whether and how to undertake all or parts of the Interstate Asset Management Framework. Motivating factors will vary, as will areas of emphasis, specific approaches, sources of leadership, background expertise, and organizational characteristics. What does not vary is the simple fact that the potential consequences of deterioration or disruption to the nation's most important arteries will be severe in terms of impacts upon the economic well being and quality of lives of our citizens. By taking advantage of best practices in asset management and risk management, system owners and operators can most effectively identify and combat the effects of deteriorating infrastructure, minimize costly system disruptions, and ensure that our national highway system continues to serve as an engine for helping drive our economy forward.

CHAPTER 1

Introduction

1.1 Research Objectives

The objective of NCHRP Project 20-74 is to develop a practical framework for applying asset-management principles and practices to managing IHS investments. The framework developed through the project is intended to:

- Be holistic, applicable to existing facilities and those that may be developed in the future;
- Provide the 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; and
- Be easy to implement, cost-effective, and sufficiently beneficial to be attractive for adoption by transportation officials and agencies nationwide.

The IHS is the backbone of the nation's transportation system, essential nationwide for providing mobility and crucial to the United States maintaining its economic competitiveness. A number of efforts are currently underway to assess the state of the IHS and the future of the system. The objective of the current effort is to supplement other work on the past and future of the IHS with tools and approaches for better managing the system in the present.

1.2 Criticality of the Interstate Highway System

It is impossible to overstate the importance of the IHS to global, national, regional, and local area movements of people and goods. On a global scale, the competitiveness of the United States in international trade and the need to surmount the challenges of moving goods over long distances has benefited immensely from this far-reaching network of roads that for a generation had no equal. Moving forward, with the looming economic power houses of China and India building similar networks as they emulate our success and close their internal mobility gaps, effective management of the IHS will be more important than ever before if the United States is to remain competitive in the world economy.

On a national scale, the IHS has transformed the nation, enabling coast-to-coast travel and trade in a matter of days instead of weeks. Approximately 20 percent of all road travel by automobiles, trucks, and buses occurs on the one percent of miles represented by the IHS. On a regional level, the IHS has facilitated economic integration and accessibility within numerous multistate corridors, as evidenced by the growing number of voluntary interstate corridor coalitions of states and metropolitan areas that have sprung to life over the past 15 years. On a more local level, in literally hundreds of urbanized areas around the country, networks of beltways and radial highways serve as the surface transportation backbone of metropolitan regions.

Despite the undeniable significance of the IHS as a physical, economic, and social asset at all geographic levels from the globe to the beltway, there is no generally accepted framework for managing and operating these assets in a manner that considers the unique needs of the IHS. The absence of such a framework is understandable considering:

- The focus for over four decades on completing the initial system.
- The variation in needs across the system reflecting differences in age and in traffic volumes and patterns, as well as weather and soil conditions, and differences in expectations and priorities of system users and owners.
- Ownership and maintenance responsibilities are dispersed among the 48 contiguous states (plus Hawaii, which has three interstate routes), and therefore it is understandable that different approaches to preserving, operating, and enhancing the system would emerge over the years.
- For many of the entities that own and operate the IHS, this system must fit within the financial and operational paradigms confronting each agency for a much larger system of streets and highways as well as other facilities over which

they have operational responsibilities. This is magnified by the need to spend Federal dollars predominately based on specified spending categories.
- The aversion among states and localities to becoming homogenized under the weight of "one-size-fits-all" legal requirements and technical processes that can fail to consider their individual and unique situations and challenges, and which can encourage superficial and misleading "apples and oranges" comparisons that can easily distort reality.

Notwithstanding these reasons why an asset management framework for the IHS has not emerged, the initiative represented by this project signals an emerging recognition of the need for and potential benefits of establishing such a framework.

The framework presented here is intended to help move consideration of IHS investment decisions away from what is often a patchwork combination of incomplete and inconsistent "factual" information and the even more nebulous array of subjective policy-level and political pressures to a more objective, fact driven, repeatable, performance-based approach. It provides a national vision that can be implemented based on sensitivity to unique state, regional, and local conditions and realities. The framework cannot eliminate the influence of more subjective pressures on investment decisions. However, it can be used to objectively assess and communicate the consequences of actions and decisions driven by factors that are perhaps more subjective and less defensible.

The initial deployment of the IHS to physical standards that are consistent, and with connections that met without fail at mutually agreeable state line crossings, is something of an institutional "miracle"—a miracle perhaps explained by several key factors:

- A compelling need to provide an enhanced level of highway service for the post World War II burgeoning population of cars and trucks.
- A clear vision by a motivated President whose personal experiences in the now famous 1919 cross-country caravan which he led and with the German autobahns he encountered in the closing days of the Second World War provided more than a sufficient basis for his proactive leadership. This vision of the system as critical to the future of the nation's growth and to its defense has served as focus for this great infrastructure construction.
- A too-good-to-turn-down funding mechanism that provided 90/10 funding that was recalculated every two years based upon each state's proportionate requirements in relation to all other states and the national commitment to a "cost to complete" approach to build the system.
- The energy, commitment, and long-term "buy-in" among political stakeholders, as well as among technical-level professionals, that is inherent in undertaking the implementation of a grand plan of action that has never before been done.

By comparison, it is arguable that formulating an Interstate Asset Management Framework that will be widely accepted and embraced in today's setting reflects the need for an even greater miracle, with the technical challenges, though significant, paling in comparison to the institutional. However, with nothing short of the continued economic security and prosperity of the United States on the line, it is imperative that this miracle happen. The chapters of this report describe the framework for managing and operating consistently the assets associated with the IHS in order to help achieve this vision.

1.3 Report Organization

The remainder of this report is organized into the following chapters:

- **Chapter 2** presents the Interstate Asset Management Framework, providing an overview of transportation asset management concepts, detailing how these concepts can be applied to IHS assets, describing where the present effort has focused on developing these concepts further, and outlining the recommended approach to develop an agency's Interstate Asset Management Plan applying the framework.
- **Chapter 3** details an approach to incorporating risk management in the Interstate Asset Management Framework, details the steps in the approach, and discusses institutional responsibilities in implementing risk management.
- **Chapter 4** summarizes readily available data and tools for managing IHS assets, and provides guidance on how existing data and tools can be used to support the Interstate Asset Management Framework.
- **Chapter 5** describes the performance management approach central to the framework. This section recommends a set of performance measures to use in characterizing conditions of an agency's IHS assets and documents the approach used to develop the recommended set of measures.
- **Chapter 6** provides implementation guidance, discussing practical issues in implementing the Interstate Asset Management Framework, potential focus areas for an implementation effort, leadership roles, implementation benefits, and potential challenges.
- **Chapter 7** presents the conclusions of the NCHRP 20-74 research effort.
- **Appendix A** describes the literature review performed, which focuses on recent research on risk management, asset management data and tools, and performance management.
- **Appendix B** describes the pilot application performed as part of the research to test application of the Interstate Asset Management Framework.

CHAPTER 2

Interstate Asset Management Framework

2.1 Asset Management Overview

Part of the challenge of managing the IHS lies in developing cost-effective investment strategies with measurable outcomes that are mutually agreed upon by agency staff and external stakeholders for managing the various assets on the system. Assets need to be managed collectively by asset type, as well as by segment, by corridor, by region, and for the system in its entirety. The challenges only will grow greater as the system ages, and there are more increases in passenger and freight traffic.

A hallmark of the IHS is that it was initially constructed to conform to consistent design standards. However, individual segments of the system now face very different realities resulting from factors such as varying physical condition, age, traffic characteristics, operating environments, weather, design standards, and the diverse approaches to operating and maintaining the system that have been employed at the state level.

Figure 2.1 demonstrates how the variations in condition on the IHS are manifested over a typical corridor based on analysis of data from the Highway Performance Monitoring System (HPMS). The figure plots the Average Daily Traffic (ADT) and pavement condition over one of the cross-country interstate corridors. Variations in ADT are plotted on the vertical axis, while International Roughness Index (IRI) ranges are shown using different colors. As indicated in the figure, there are significant variations in both traffic and pavement condition over the length of the corridor. There are peaks in traffic levels in several areas of the corridor where the highway passes through urban areas, with particularly high levels at approximately 700 miles. Pavement conditions are generally very good (IRI less than 60) or good (IRI between 60 and 95). However, conditions appear to worsen as one progresses through the corridor (right side of the graph), based on the increasing occurrence of sections classified as "acceptable" (values between 95 and 170) or "unacceptable" (IRI greater than 170). Note that IRI is measured and reported somewhat differently from state to state, complicating national comparisons. Also, note that as a measure of roughness of the pavement surface, IRI does not necessarily provide an indication of the condition of the underlying pavement structure or substructure.

Clearly the system owners of different portions of the corridor shown in Figure 2.1 must consider different factors as they determine how best to manage their portion of the IHS, illustrating the fact that there is no "one size fits all" solution to measuring and managing the system. The IHS is of national importance, but management of the system must be based on balancing challenges at the state, corridor, and local levels. An objective approach addressing the needs at these varying geopolitical levels is essential if the vital interests of each are to be considered in a rational way.

Transportation asset management is a developing field that provides a set of tools and techniques for managing infrastructure assets. Asset management is, at its core, a set of guiding principles and best practice methods for making informed transportation resource allocation decisions, and for improving the accountability for these decisions. AASHTO defines asset management as follows (*1*):

> Transportation Asset Management is a strategic and systematic process of operating, maintaining, upgrading, and expanding physical assets effectively throughout their lifecycle. It focuses on business and engineering practices for resource allocation and utilization, with the objective of better decision-making based upon quality information and well defined objectives.

The core principles of asset management have increasingly gained acceptance in the transportation community since they were initially described in the AASHTO Transportation Asset Management Guide (*2*). These principles hold that asset management is:

- **Policy-Driven.** Resource allocation decisions are based on a well-defined and explicitly stated set of policy goals and objectives.

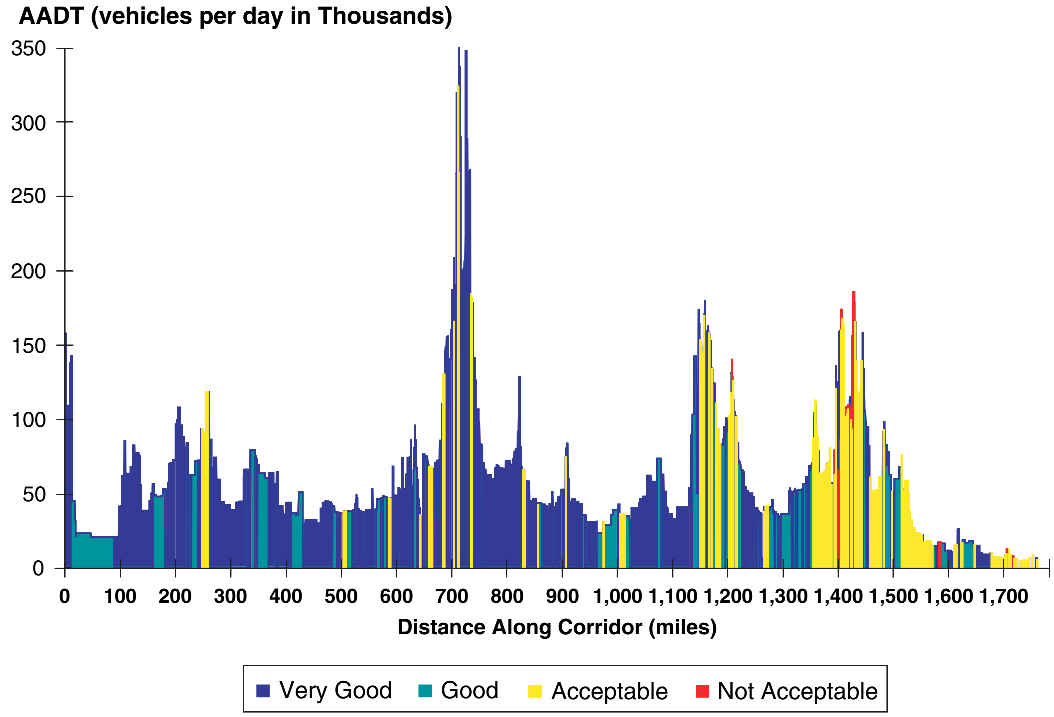


Figure 2.1. Traffic levels and pavement conditions along an interstate corridor.

- **Performance-Based.** Policy objectives are translated into system performance measures that are used for strategic management and tied to the resource allocation process.
- **Reliant on Analysis of Options and Tradeoffs.** Decisions on how to allocate resources within and across different types of investments are based on an analysis of how different allocations will impact the achievement of relevant policy objectives.
- **Focused on Yielding Decisions Based on Quality Information.** The merits of different options with respect to an agency's policy goals are evaluated using credible and current data. Where appropriate, decision support tools are used to provide easy access to needed information, to assist with performance tracking and predictions, and to perform specialized analysis.
- **Reliant on Monitoring to Provide Clear Accountability and Feedback.** Performance results are monitored and reported. Feedback on actual performance may influence agency goals and objectives, as well as resource allocation and utilization decisions in future budget cycles.

Figure 2.2 summarizes the basic asset management process, highlighting issues of particular importance for the IHS at each step of the process. The following paragraphs discuss these steps.

Policy Goals and Objectives. The first step of the process is to establish agency policy goals and objectives. In this step, internal stakeholders across an agency must define its basic goals and objectives, translating these into a set of performance measures and targets. This step must be performed factoring in available information on funding levels and customer expectations, and considering the perspectives of all internal and external stakeholders. Customer expectations are of particular importance for management of the IHS, given the importance and level of use of the system. Customers of the system may be interpreted to include stakeholders in the resource allocation process (e.g., Metropolitan Planning Organizations and other planning partners, Federal agencies, and resource agencies), the traveling public, and private sector freight carriers.

Analysis of Options and Tradeoffs. Once an initial set of goals and objectives has been established, the next step is to analyze options and tradeoffs. In this step, analytical tools are used to systematically analyze the impact of different budget levels for a specific set of assets and activities. Note that this iterative step is both informed by and informs the development of policies, goals, and objectives. As analyses are performed, an agency may realize the need to revisit its goals, objectives, and performance targets. This step establishes the concept of an asset management approach that provides decision-making transparency to the framework development.

Resource Allocation Decisions. Analysis of options and tradeoffs typically results in a target funding level by asset type and/or treatment, and a set of prioritized candidate projects

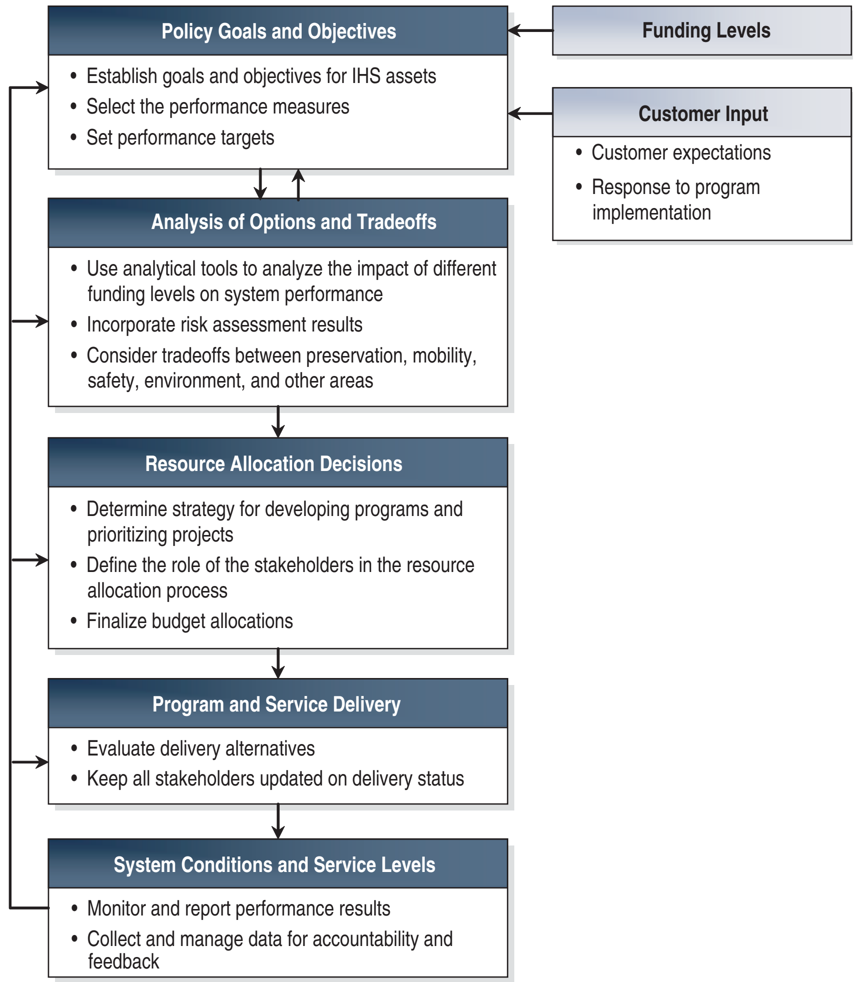


Figure 2.2. Generic asset management process with issues of importance for the IHS.

that can populate fundable programs to renew and extend asset life. The next step is to determine how to allocate resources based on this information, in a manner consistent with an agency's policy goals and objectives and the external stakeholders understanding of the potential implications of these allocation strategies.

Program and Service Delivery. The focus shifts to delivery once resource allocation decisions have been made. There are a number of key issues an agency must consider in this area, including determining the best approach to delivering the program, managing work zones, and communicating the status of the program to industry partners and the public, to provide transparency into an agency's processes and convey important information about ongoing or upcoming construction work that may impact travel decisions.

System Conditions and Service Levels. In conjunction with program delivery, an agency monitors the system conditions and service levels, as indicated in the final step of the figure. Because asset management is data-driven, the process is designed assuming that data collected in this step are inputs to every other step in the process.

The asset management principles and process described apply to all types of investments in transportation infrastructure assets. Conceptually asset management is not limited to a preservation focus, but considers the full range of potential investments, as well as factors related to safety, operations, environmental management, corridor management, and project/program delivery.

2.2 Applying Asset Management to the IHS

The basic transportation asset management principles and process described in this report and detailed in the AASHTO *Guide* are wholly applicable to IHS infrastructure assets. The asset management framework for the IHS necessarily encompasses and builds upon the concepts in the AASHTO *Guide*. However, in applying asset management to the IHS one must first ask what, if anything, is unique about the IHS that demands a targeted approach.

The answer to this most fundamental question is that **the IHS is uniquely important because it represents the most critical set of highway assets in the United States.** Keeping its portion of the IHS in operation is a critical concern for every IHS owner, and asset management promises an approach for helping accomplish this objective. This answer is based on the following key assumptions:

- The IHS typically represents the highest priority network for a transportation agency. High priority can be defined in a number of ways, but by any definition of the term, the IHS is clearly the highway network with the highest priority at the national level. For any given transportation agency, their portion of the IHS is likely a reasonable approximation of their highest priority network. However, it may be that there are additional highway sections not classified as interstates that are critical from a regional or statewide perspective (e.g., nonredundant portions of the network, evacuation routes, and/or other high traffic sections). By the same token there may be some highway segments, though classified as interstates, which do not carry the same level traffic or provide the same degree of connectivity as other segments off of the IHS. Thus, the concepts described in this report should properly be considered as applying to a transportation agency's "highest priority network," with the understanding that this network largely consists of, but may not be identical to, an agency's portion of the IHS.
- Keeping its highest priority network in operation is of fundamental concern for any transportation agency. With the IHS largely complete, and the corresponding shift in focus of U.S. highway owners from building the network to delivering transportation as a service, the immediate challenge transportation agencies face is keeping their most critical assets in operation. The concern for keeping the network in operation is reflected in the emphasis on Intelligent Transportation Systems (ITS) and Vehicle Infrastructure Integration (VII) aimed at using technology to improve network operations and safety. Also, this focus is readily apparent in areas such as snow and ice removal in cold-weather climates. But keeping the network in operation is more than a day-to-day challenge; it is a long-term concern that should be reflected in project development, capital budgeting, long-term planning, and other processes.
- Asset management helps an agency keep its network in operation by improving decision making based on data that provides a quantitative overview of the performance of the system. That is, transportation asset management helps an agency make decisions that are better targeted to achieve agency policy goals and objectives, and that help achieve those goals and objectives in a more cost-effective manner. There is a significant amount of evidence in other industries that a performance-based approach helps improve performance, and an abundance of anecdotal evidence concerning agency successes in applying asset management principles. Nonetheless, the focus on asset management is still a relatively new phenomenon, and must be treated with the assertion that it is of benefit as an assumption until sufficient evidence mounts to prove or disprove it.

Based on the preceding assumptions, applying asset management to IHS assets is not an objective unto itself, but a means for achieving a larger, national goal, that of helping keep the IHS network in operation using the most effective means. This objective is in one respect very targeted, in that it applies to a single portion of the U.S. transportation network. In another respect, the objective is quite broad, as it implies consideration of the full range of factors that might impact operation of the IHS, and introduces the concept of a national interest in IHS asset performance. This approach provides a consistent asset management framework and performance expectations for the IHS by leveraging existing agency-to-agency institutions and relationships in managing the connection points of the system.

Figure 2.3 presents a perspective concerning how IHS asset management decisions relate to the larger resource allocation process. It is intended to put decisions concerning IHS assets into a practical context. As indicated in the figure, agencies typically make a distinction between modes (e.g., highway, transit, rail, ports, aviation) in their resource allocation process. Within the highway mode, an agency must make decisions across network classifications. Network classifications vary from one agency to another, but frequently include the IHS (and/or other high-priority network links), the National Highway System (NHS), and other classifications. Within a network classification an agency must determine how to allocate resources to obtain the best performance and lowest risk (greatest reduction in risk) across all asset types, recognizing any relevant legislative direction or other constraints. The figure depicts this relationship within the IHS network, but the network can be further subdivided by corridor.

In practice the lines between decisions concerning IHS assets and other assets are not so sharply delineated as depicted in the figure. Investments in IHS assets must be balanced with investments in other parts of the network. Also, there are legitimate reasons for establishing policies and evaluating performance for selected asset types across networks. Further, the dimension of time is not illustrated in the figure, though certainly relevant. Practically speaking, certain decisions, such as those concerning capacity expansion projects, are the product of a long-term planning process. Other capital budgeting decisions are made on a year-to-year basis, while maintenance and operations

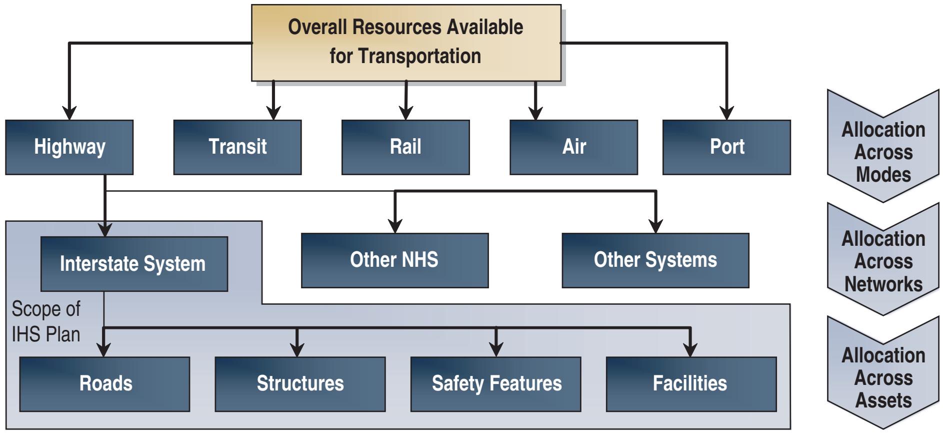


Figure 2.3. Example IHS resource allocation process in context.

decisions are often made with a shorter time horizon and often target existing (not projected) performance and condition issues.

The basic strategy recommended for integrating decision making for IHS assets with the broader decision-making scope presented here is for each IHS owner to develop an Interstate Asset Management Plan on a periodic basis. The plan should summarize conditions of IHS assets, establish performance measures for those assets considering available funds, and describe the plan for future investments in the IHS. The plan, once developed, will help support the agency's ongoing resource allocation process for its IHS network across investment categories and decision-making horizons. It also should provide consistent information about the system that can be shared among the many agencies managing the network. A recommended outline for an Interstate Asset Management Plan is presented in Section 2.4.

2.3 Focus Areas for Interstate Asset Management

Previous work on transportation asset management is readily transferable to the present study, but developing an asset management framework tailored to the IHS requires extending previous work on transportation asset management, focusing in on selected areas. These include:

- Defining how to better incorporate assessment of the risks of system failure into an asset management framework;
- Providing guidance for handling all IHS assets, particularly assets besides pavements and bridges; and
- Recommending a set of measures tailored for use in reporting and facilitating discussion of IHS performance both within an agency, to system users, industry partners, and nationally.

The following sections describe each of these areas further.

Risk Management

Ideally, any decision-making process should take risk into account. As the risks faced in management of the IHS are significant and the potential consequences of risk such as failure of an IHS link can be staggering, incorporating risk assessment into a framework for managing the IHS is a topic of particular importance. Risk management is of importance for managing any transportation system, but is of particular importance for the IHS because of the magnitude of the consequences to society when and if risks to the system are realized.

Tragic events such as the Northridge Earthquake of 1994 starkly illustrate the importance of this topic. When this earthquake struck the Los Angeles area on January 17, 1994, it caused extensive damage to Los Angeles freeways, including the collapse of two bridges on Interstate 10 between downtown Los Angeles and Santa Monica, the collapse of the Interstate 5/Antelope Valley Freeway interchange and a closure of a portion of State Route 118 in the Simi Valley. The transportation-related economic impact of the event has been estimated to be over $1.5 billion (*3*). Similarly tragic consequences arose from the collapse of the Mianus River Bridge on Interstate 95 in Connecticut in 1982, from the damage caused along the Gulf Coast by Hurricane Katrina in 2005 and by Hurricane Ike in 2008, and from the 2007 collapse of the Interstate 35W bridge over the Mississippi River in Minneapolis.

Transportation agencies that own and operate the IHS are well aware of the risks they face as they deliver a service—providing a transportation network—to the public. Further, individual agencies have performed in an exemplary fashion in responding to events such as those described above. However, the existing tools and approaches developed for asset management are of limited value for managing risk. While asset management principles are not inconsistent with the concept of risk assessment, it is true that this has not been an area of significant focus in many asset management implementation efforts. Further, while significant work has been performed on risk assessment for transportation in recent years, there is little guidance available on how to integrate a risk management approach with an agency's asset management-related processes.

Chapter 3 of this document describes an approach to risk assessment for IHS assets that integrates best practices in risk management with the concepts of transportation asset management. The approach is focused on the risks of system failure. In the context of this report, system failure refers to any condition that results in closure of an IHS link to travel for some period of time, as a result of unintentional hazards, intentional threats, natural hazards, or substandard performance. A scenario-based approach is presented for quantifying the risks to a set of IHS assets, including their likelihood, consequences if realized, and available mitigation approaches. Ideally, the quantitative approach presented in this section would be used to perform a comprehensive risk assessment. However, the section describes an alternative threshold approach that an agency can use where sufficient data and resources are lacking to support the recommended approach. The outcome of applying the scenario-based approach is a recommended allocation of resources to mitigating risk based on a determination of how an agency can best minimize the expected economic losses from the risks it perceives to its IHS assets.

If a risk can be managed through other systems and processes without employing the scenario-based approach detailed in Chapter 3, the risk is referred to as a "programmatic" risk. In the case of performance risks, such as substandard design, construction defects, materials defects, and unexpected traffic volumes, these risks are best addressed through existing preservation programs, such as pavement preservation and bridge preservation programs. In theory, asset management systems should help manage these risks, but the reality is that there are gaps that need to be filled to improve systematic capabilities for handling programmatic risk. Chapter 4 describes the existing tools available for managing IHS assets and identifies gaps that should be addressed in their capabilities.

Guidance for the Comprehensive Set of IHS Assets

Each of the individual segments of the IHS is composed of a number of distinct types of infrastructure assets. Table 2.1 details the infrastructure assets associated with the IHS, organized by asset category. Even though rights-of-way, equipment, and people may be viewed as assets using a broader definition of the term, they are not included in the table because they are not part of the built infrastructure.

AASHTO's *Asset Management Guide* emphasizes that the transportation asset management principles and processes apply to all assets, modes, and investment categories. A concern voiced in the *Guide* and in other work on transportation asset management is that agencies should make investment decisions across assets, modes, and investment categories, rather than concentrating decision making within narrowly defined "silos," with each silo focusing on a specific asset and/or type of investment. In spite of this concern, the reality is that significant attention has been devoted to developing systems and approaches for handling two asset types—pavements and bridges—while the data, tools, and approaches for other asset types are typically rudimentary by comparison. This is not an accidental development: pavements and bridges necessarily consume the greatest portion of agencies' preservation expenditures, and the data, tools, and processes have evolved based on this reality.

The current study, with its focus on developing a practical approach for managing all of an agency's assets, but for only the most critical portion of the agency's network, forces the question of how an IHS owner should go about managing "all of those other assets" listed in Table 2.1. Chapter 4 details the data and tools typically available for each asset category and type, focusing on assets other than pavements and bridges that have been the subject of much of the attention in transportation asset management in the past. With regard to other assets beside pavement and bridges, the guidance can be summarized as follows:

- IHS owners should collect inventory and inspection data for IHS pavements and bridges consistent with both Federal reporting requirements and the requirements of pavement and bridge management systems, and they should use these systems to manage pavements and bridges.
- IHS owners should collect inventory and inspection data for all of their IHS structures, including those listed in Table 2.1. Tools and techniques employed for managing bridges should be employed for managing other IHS structures besides bridges. The basic logic for this recommendation is simple: structures can fail catastrophically, and in so doing cause system failure (closure of an IHS link for some period).
- IHS owners should report conditions on other assets, including safety features, based on the degree the assets are "functioning as intended." A maintenance level of service or remaining service life approach is recommended for budgeted future investment needs for these assets.

Performance Measure Reporting for IHS Assets

A cornerstone of transportation asset management is its emphasis on using quality information to make performance-based decisions. Encouraging a performance-based approach is consistent with best practices followed in other industries and the direction of many state transportation departments

Table 2.1. IHS infrastructure assets.

Asset Category	Asset Type
Roads	Pavement
	Shoulders
Structures	Bridges
	Tunnels
	Culverts/drainage structures
	Noise barrier walls
	Retaining walls
	Overhead sign structures
	High mast light poles
Safety Features	Pavement markings/delineators
	Lighting
	Guardrails
	Median barriers
	Impact attenuators
	Signs
	Surveillance and monitoring equipment
	Signal and control equipment
Facilities	Rest areas
	Toll plazas
	Weigh stations
	Maintenance depots
	Pump houses
	Communication facilities

(DOT). The AASHTO *Guide* discusses performance measures for asset management at high level, and *NCHRP Report 551* (*4*) covers this topic in detail.

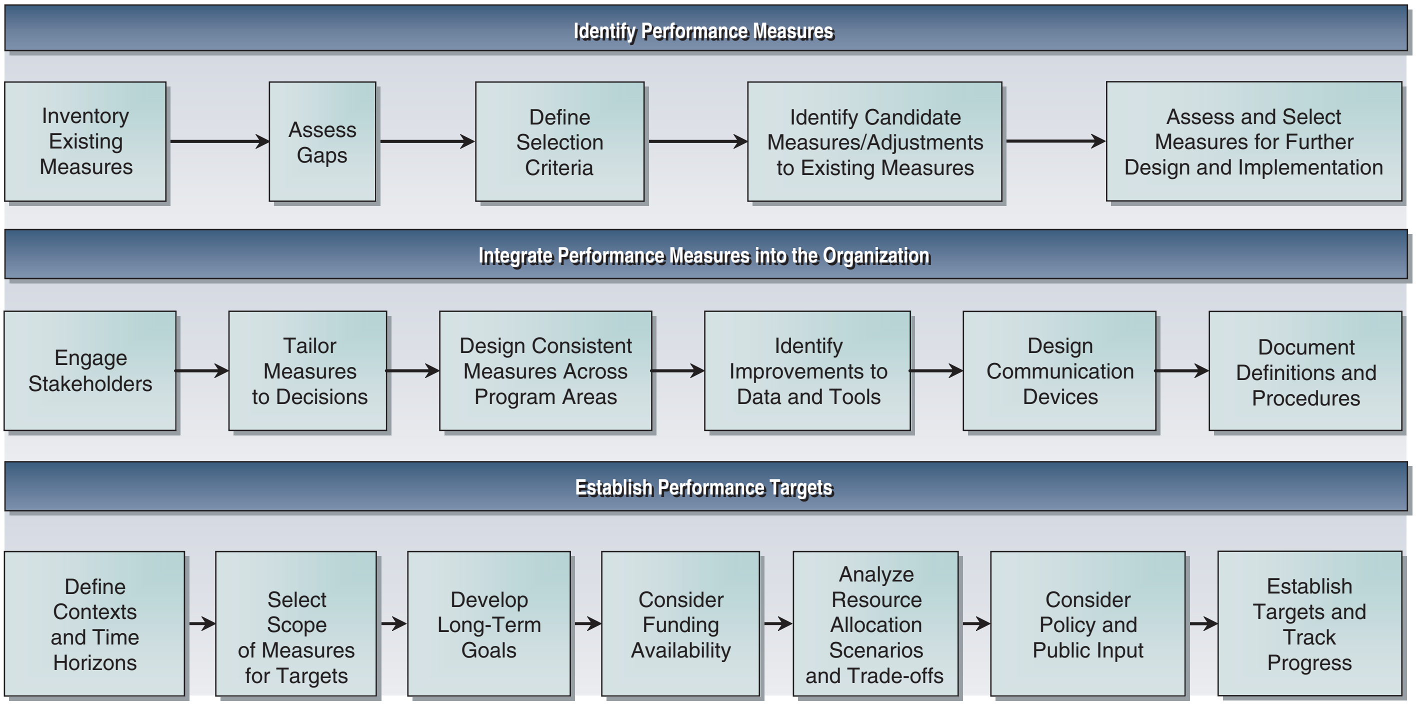
This study adopts the terminology and basic approach for describing performance measures and targets introduced in *NCHRP Report 551.* The approach described in Volume 2 of that report, summarized in Figure 2.4, has been employed to develop a set of performance measures for use in reporting IHS conditions in an Interstate Asset Management Plan. With this approach, performance measures are used to monitor progress towards policy goals and objectives, reflect asset conditions, provide a long-term view of asset life cycles, and track program delivery. Performance targets are specific performance measure values an IHS owner plans to achieve. These are set based on consideration of past trends, predicted future performance, agency funding levels, and other factors.

In developing the set of measures, the research team made a distinction between measures that every IHS owner should be in a position to report today, labeled "core" measures, and additional measures that would be desirable to report for IHS assets if an agency has sufficient data and resources, labeled "comprehensive" measures. Ideally, every IHS owner would report the core measures described here, at a minimum, and plan to collect and report the full set of comprehensive measures in the future.

Chapter 5 details the recommended performance management approach for IHS assets. Table 2.2 summarizes the recommended core measures.

With regard to the Environment category, it is clear that this is an area of great importance, but there are few environmental measures that can be both localized to the IHS, and used to support the asset management process. Also, there is little consistency from one IHS owner to another concerning how environmental data are collected and reported. Thus, rather than recommending a specific set of measures as in the other categories, for the Environment category this report recommends a report card approach, whereby an IHS owner establishes a set of environmental milestones and reports whether they are achieving them on a pass/fail basis. These milestones may include measures of air quality, wetlands restoration, provision of mitigation features such as wildlife crossings and fish passages, and an indication of the extent the IHS owner is satisfying its environmental commitments.

Chapter 5 lists a number of additional comprehensive measures. The comprehensive set includes measures of asset performance for each of the categories listed in Table 2.1.



Source: *NCHRP Report 551*.

Figure 2.4. Setting performance measures and targets.

Table 2.2. Recommended core IHS asset management performance measures.

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 million vehicle miles traveled (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

2.4 Interstate Asset Management Plan Outline

The basic strategy recommended for applying asset management tools and techniques to IHS assets is for each IHS owner to develop an Interstate Asset Management Plan. The plan should summarize conditions of IHS assets, establish performance measures for those assets considering available funds, and describe the plan for future investments in the IHS. The starting point for developing the Interstate Asset Management Plan should be an agency's existing long-range plan (LRP) developed following the Federally mandated LRP development process. The LRP should include policies, goals, and objectives, with specific measures of effectiveness or performance that can be used and/or supplemented for the Interstate Asset Management Plan.

The plan, once developed, will help support the agency's ongoing resource allocation process for its IHS network across investment categories and decision-making horizons. It also should provide consistent information about the system that can be shared among the many agencies managing the network.

The following is a recommended outline for a typical state Interstate Asset Management Plan. As always, some variations will be necessary to address an IHS owner's specific policies, priorities, organization, responsibilities, business processes, and data capabilities, but this prototype can provide the basic building blocks to initiate such a plan. Typically, sections of the plan should include:

1. Significance of the Interstate Highway System;
2. Assets Included in the Plan;
3. Measuring Performance;
4. Past and Present Funding;
5. Risk Assessment;
6. Interstate Investment Strategy; and
7. Updating the Plan.

Section 1.0—Significance of the Interstate Highway System

1. Role of the IHS in our state's economy and quality of life:
   a. Percent of miles;
   b. Percent of traffic;
   c. Access to ports and gateways;
   d. Connectivity with the nation;
   e. Access to regions of the state; and
   f. Importance to economic development goals.
2. The State's Interstate system:
   a. System map; and
   b. System table, with route number, length, average daily traffic, and percent trucks. Include non-IHS, National Highway System routes included in the plan. (For the sake of brevity all references to the IHS include selected NHS routes.)
3. Interstate Routes—Level of Geographic Significance:
   a. Criteria:
      i. National—Serves long corridors on a national scale;
      ii. Multistate—Located in/serves more than one state; and
      iii. State/Metropolitan—Serves relatively limited area within one state.
   b. Table showing results—route number, category (national, multistate, or state/metropolitan), and rationale for designation.

Section 2.0—Assets Included in the Plan

This section documents the types of asset (pavement, shoulders, bridge, etc.) included in the plan. At a minimum, for each asset type, it is recommended that agencies include a basic inventory unit (lane miles, count, etc.) and the value for each unit. Agencies may also decide to break down the inventory information further by level of geographic significance, geographic area (e.g., DOT district), etc. Table 2.1 provides a list of assets that should be included in the plan.

Section 3.0—Measuring Performance

This section defines the performance measures used to assess the effectiveness of IHS investment and maintenance strategies. Table 2.2 provides a list of measures recommended for the plan, and Chapter 5 provides more detailed guidance on selecting measures.

At a minimum, include the value for the measure for the previous year. If the data is available, provide historic trend information for up to 10 years.

Section 4.0—Past and Present Funding

This section provides information in the form of tables and graphs showing trends over time in sources and levels of funding and how these funds have been allocated from various perspectives, including transportation system categories (mode and level of system), corridors and geographic areas, functional categories, asset classes, etc. The compilation, presentation, and interpretation of such information would be customized according to the attributes and issues unique to the particular circumstances of the agency and its IHS responsibilities and challenges. The categories used to report historic funding levels in this section should match the categories used to present the investment strategy in Section 6.0 of the plan.

Section 5.0—Risk Assessment

This section identifies and assesses key issues and challenges including significant vulnerabilities and risks associated with the IHS. It defines deficiencies and provides a factual and objective foundation for the development of IHS policy and performance goals and strategies in such critically important areas as economic development, freight, and personal mobility and safety. Chapter 3 provides guidance on conducting a risk assessment and communicating the results.

Section 6.0—IHS Investment Strategy

This section presents the recommended level and distribution of IHS investments and establishes performance targets for the IHS based on predictive modeling and considering potential investment levels. It should serve as guidance for subsequent programming and project prioritization processes, and provide a basis for monitoring the effectiveness of investment decisions in terms of the defined targets.

Since resources are invariably limited and insufficient to achieve all desired outcomes, the "art" of asset management comes into play when all of the information and analyses are focused on evaluating an array of "what if" investment alternatives that consider vulnerabilities and deficiencies, risks and priorities, goals and performance targets. The questions will entail addressing what is to be gained and what is to be lost by changing investment strategies, such as:

- Between the IHS and non-IHS;
- Among asset types on the IHS;
- Among specific IHS routes;
- At varying investment levels; and/or
- At varying performance levels.

The end result of this tradeoff exercise is an IHS investment strategy organized around the performance measures identified in Section 3.0 of the plan. For each measure, the agency should define the preferred target level and the annual funding required to achieve it.

The investment strategy also may include a list of major projects or initiatives that have been identified throughout the planning and programming process or during the risk assessment.

Section 7.0—Updating the Plan

This section describes the process and timeframe for updating the plan. It is recommended that agencies reassess and update the plan on a defined schedule—perhaps annually but not less often than biennially—based on changing conditions and the effectiveness of previous investments and management strategies.

CHAPTER 3

Risk Management

This section describes an approach for integrating risk management concepts into the process of managing IHS assets. Section 3.1 summarizes the broad concepts of risk management and proposes a categorization of risks facing transportation agencies. Section 3.2 provides a proposed approach to addressing risks in development of an IHS owner's Interstate Asset Management Plan. Section 3.3 addresses the institutional commitment necessary to extend IHS management practices to accommodate risk.

3.1 Overview

Risk management occurs with varying degrees of conscious intent across the full spectrum of human endeavor, in both public and private organizations, and in everyday lives. Although the context and the degree of formality of the process varies, the fundamental elements of risk management are constant. These elements include:

- Establishment of risk tolerances;
- Identification of threats/hazards;
- Assessment of impact or consequence;
- Identification of potential mitigation strategies/countermeasures;
- Development of a mitigation/management plan; and
- Implementation of the plan.

Risks faced by transportation agencies come from a variety of sources, and it is possible to categorize them in a number of different ways. The recommended categorization of risks for IHS assets emerged from the literature review described in Appendix A and through development of the Interstate Asset Management Framework. Figure 3.1 illustrates this categorization. It distinguishes between programmatic risks and nonprogrammatic risks. These are defined as follows:

- **Internal Programmatic Risks.** These are risks that are internalized in the day-to-day business process of a transportation agency. IHS owners face a broad range of internal programmatic risks in every part of their operations, from planning and programming, through project development and delivery, and on to maintenance and operations, and finally system monitoring. For example, inaccurate forecasts of asset deterioration and revenues, inaccurate project cost estimates, and unforeseen ground conditions on construction projects fall into this category. Although the frequency of these risks is high and the impact can be substantial, it is rare that they will cause the closure of a link in the transportation system.
- **External Nonprogrammatic Risks.** These are risks that are addressed outside of a transportation agency's day-to-day business process, either because they are very unlikely, or because they are perceived as external risks over which an agency has little or no control. They tend to relate to the potential for system failure, and may be the result of either the natural environment or human actions. Earthquakes, terrorist attacks, and vehicle/infrastructure collisions that cause the failure of a transportation infrastructure asset fall into this category. Although the frequency of these risks is low, their potential to cause one or more high-priority network links to fail in the event a risk is realized is high. The current study is focused on risk of system failure for IHS assets, which are included in this category.

Given the distinction between programmatic and nonprogrammatic risks, it is not surprising that over the past 20 or more years the focus has been on managing programmatic risks in developing management systems and processes. Much of this work is confined to handling risk at a subprogram level to enable budget optimization for annual project selection or contingency planning (i.e., planning for and dealing with the consequences of materialized threats/hazards). For example, Washington State Department of Transportation developed and uses a Cost Estimate Validation Process (CEVP) to mitigate the risk of inaccurate cost estimates for large and complex

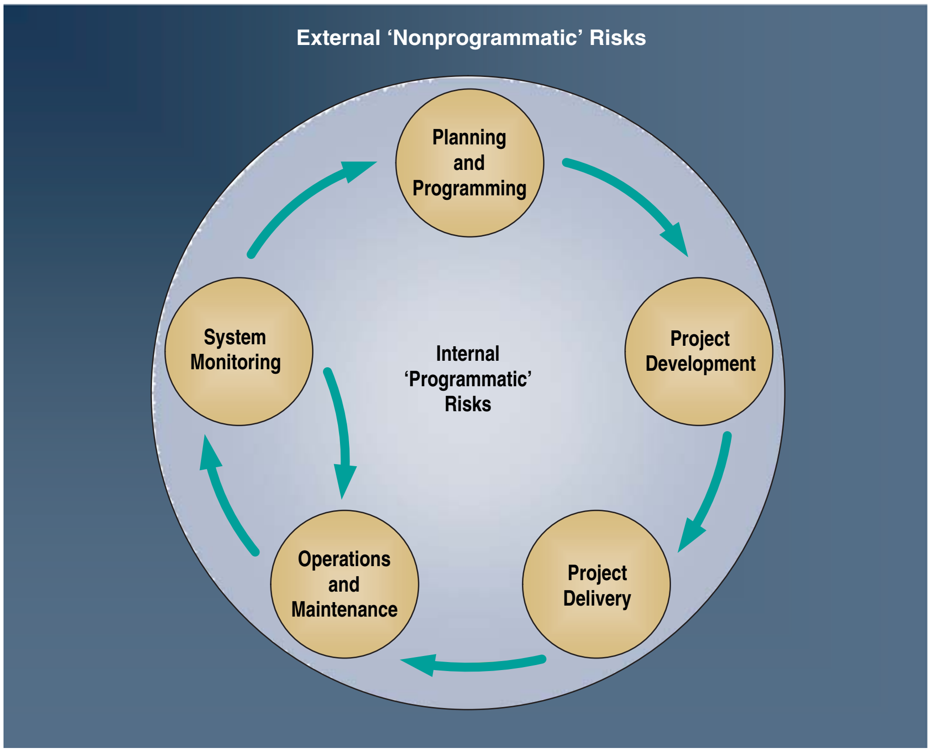


Figure 3.1. Existing transportation agency risk environment.

projects. The CEVP is designed to identify the areas of a project that could be sources of increased costs, assess the likelihood of key risks materializing, and ultimately results in the specification of project cost range as opposed to a point estimate to account for the risks identified. Chapter 4 describes existing management systems and other analytical tools that can be used for managing programmatic risks.

By contrast, the history approaches for addressing external nonprogrammatic risk is considerably shorter. Activity in this area was propelled by the terrorist attacks of September 11, 2001, and again more recently by a number of significant natural disasters. Despite recent focus, development of external risk management activities today lags behind that for internal risks. Appendix A summarizes the literature review conducted as part of this research. The review describes several promising concepts and approaches that have been incorporated into the proposed methodology. Two particularly important resources include the *AASHTO Guide to Highway Vulnerability Assessment (5)* and the report for NCHRP Project 20-59(17) currently in draft format (*6*).

In the context of the aging IHS, where the consequences of the failure of a system link are potentially enormous, it is important that the Interstate Asset Management Framework provides for a robust analysis of risk of system failure. Such an analysis must produce more comprehensive mitigation schemes that take into account the asset/operations interdependencies, and significantly increase agencies' ability to deal with "out-of-the-norm" threats/hazards. At the same time, it must be recognized that the resources required to manage these risks will no doubt compete with those needed to revitalize and renew the aging IHS infrastructure to ensure safe and reliable operations for the coming generations.

3.2 Risk Management for the Interstate Asset Management Framework

This section outlines a proposed approach to augmenting transportation agencies' existing risk management activities with a process that helps assess risks of system failure for IHS assets. IHS owners could perform the risk assessment approach described here for their IHS assets and any other assets on what they define to be on their highest priority network. The result of this approach is a set of priorities for risk mitigation. A description of the assessment and its results should be included in the Interstate Asset Management Plan described in Section 2.0.

In developing the proposed approach the research team has adhered to the following guiding principles:

- The entire IHS (or highest priority network) represents a collection of assets of vital importance to maintaining socioeconomic growth and prosperity. A transportation agency should have an approach to managing programmatic risks for all of its assets. Particularly for the IHS assets it owns, an agency also should consider external, nonprogrammatic risks to these assets that could result in system failure and determine what mitigation actions could best minimize risk.

- In evaluating risk, ideally one would use consequence modeling approaches which compute/impute risk (both materialized and avoided) in financial terms. If possible, one should try to explicitly calculate the likelihood of a risk occurring, the impact of the risk in terms of mobility and safety measures, and the costs of mitigation. When quantitative modeling is not feasible, the most reasonable, but still performance-based, subjective method should be used for assessing risk and prioritizing risk mitigation. Subjective approaches are often required given the lack of necessary data for quantifying costs of a risk in financial terms. For instance, for structures there are many well-known but poorly quantified risks, and there are few models available for calculating the relative likelihood of different risks to structures.
- Ideally risk management should be pursued at the programmatic level within a transportation agency. It is an active function and its membership is drawn from all the stakeholders of interest within the governing agency and its intersecting stakeholder groups.
- Implementing risk management requires involvement of all levels of an organization. A basic requirement is that an organization has an organizational structure for identifying what risks should be managed. Section 3.3 discusses institutional roles and responsibilities further.

The following subsections describe how to determine what risks should be addressed in an Interstate Asset Management Plan, and present a step-by-step approach to risk assessment.

Risks Addressed in the Interstate Asset Management Framework

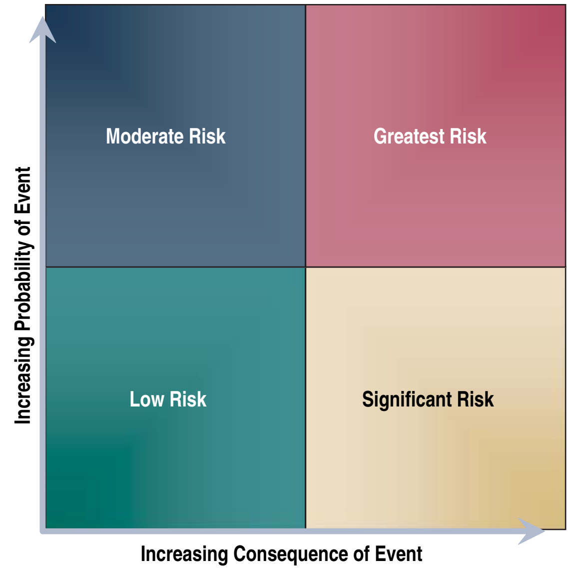
To help identify the categories of risk that should be addressed, one should consider the universe of risk illustrated in Figure 3.2, and derived from the oft-used risk formula:

$$\text{Risk} = (\text{Probability of the occurrence of an event}) \times (\text{Consequence of an event})$$

The vertical axis of Figure 3.2 represents the probability (from low to high) of a particular threat/hazard materializing and the horizontal axis represents the consequence (from low to high) of the materialized threat/hazard. Any threat/hazard can be located in this risk universe.

The proposed approach focuses on the right hand quadrants shaded red and gold. Threats/hazards in these two quadrants have the greatest consequences in terms of:

- Human safety (injury and/or loss of life);
- Property damage; and
- System/mission disruption.



Source: Adapted from the draft NCHRP 20-59(*17*) Report (*6*).

Figure 3.2. Universe of risk for HIS.

This is not to suggest that threats/hazards that fall into the other two quadrants are unimportant. However, it is the experience of the industry that risks with high probability of occurrence (e.g., minor incidents, winter operations, etc.) but that do not reach the threshold for any of the three consequence categories identified above are usually dealt with programmatically.

Consistent with the draft NCHRP 20-59(17) report (*6*), the following taxonomy of threat/hazard types focuses in higher-consequence risks:

- **Unintentional hazards.** Unintentional hazards are usually created by human-induced traffic incidents, due to insufficient skills or experience in design, operation, or enforcement of vehicles.
- **Natural hazards.** Natural hazards include major weather or geological events that might cause significant loss of life, destruction of assets, or long-term interruption of agency mission.
- **Intentional threats.** Intentional hazards include terrorist attacks, crimes, and war. They are less frequent and less predictable and involve active countermeasure evasion by criminals and terrorists.
- **Performance risks.** Risk or underperformance of an asset due to design, materials, and construction defects coupled with lack of accurate condition inspection or forecasting capabilities cause more-than-expected wear and tear on assets or hindrances to operations. They could also be recurring events with reasonable predictability (such as heavy snow fall accumulations, minor traffic incidents, etc.).

Note that performance risks are treated as programmatic risks described previously, and therefore handled in routine asset management and operations planning. Several examples of these lower-consequence risks are listed in Table 3.1. These are grouped into a single category, as the focus of the present study is on risks of system failure. However, this category can be further expanded into a wide variety of different risks that fall within this category.

Risk Assessment Process

The fundamental objective of the proposed risk mitigation process is to provide IHS owners with a practical approach to augmenting their programmatic risk management activities with an approach for addressing risks of system failure for their IHS and any other critical assets. The result of the process is a set of risk mitigation priorities included in the Interstate Asset Management Plan, supplement other types of asset needs, and can be used as an input to the resource allocation process. Figure 3.3 illustrates the risk management philosophy that forms the basis for the proposed approach.

The core elements of the philosophy are:

- It uses scenario-based methods for risk identification;
- It considers IHS and related overall transportation system disruption for consequence analysis where feasible;
- It supports and encourages the use of direct and indirect economic losses resulting from realized threats/hazards as key focal points to drive investment decisions. However, it also provides a well established alternative that can be used in situations where there is insufficient data to perform the calculations, which is quite often the case;
- It considers mitigation measures and their effectiveness as avoided losses in the cost stream; and
- It allows for the consideration of benefit/cost analysis where practical and return on investment metrics to help identify risk mitigation priorities.

Figure 3.4 presents the proposed step-by-step process for performing the risk assessment. The following paragraphs detail the steps in the process.

Table 3.1. Risk types and examples.

Risk Type	Example	Likely Impact/Consequence	Relative Frequency	Influential Characteristics
Unintentional Hazard	• Vehicular crashes • Hazardous materials spill • Oil spill	• Short-term road closure • Loss of life • Potential isolated structural failure	High	Skill, experience, enforcement, operation, etc.
Intentional Threat	• Terrorist attack • Crime • War attack	• Short- or long-term road closure • Loss of life • Potential isolated structural failure	Very low	Access, security, exposure, design features, etc.
Natural Hazards	• Heavy rain • Strong wind • Heavy snow and ice • Earthquake • Hurricanes • Flood • Mud/landslide	• Short- or long-term road closure • Loss of life • Potential structural failure – isolated or corridor-wide	Low	Structure type, location, etc.
Performance	• Substandard design • Construction defects • Materials defects • Unexpected heavy traffic • Incorrect performance models	• Increased agency and user costs • Increased work zone delay • Reduced asset life	High	Skill, experience, design, etc.

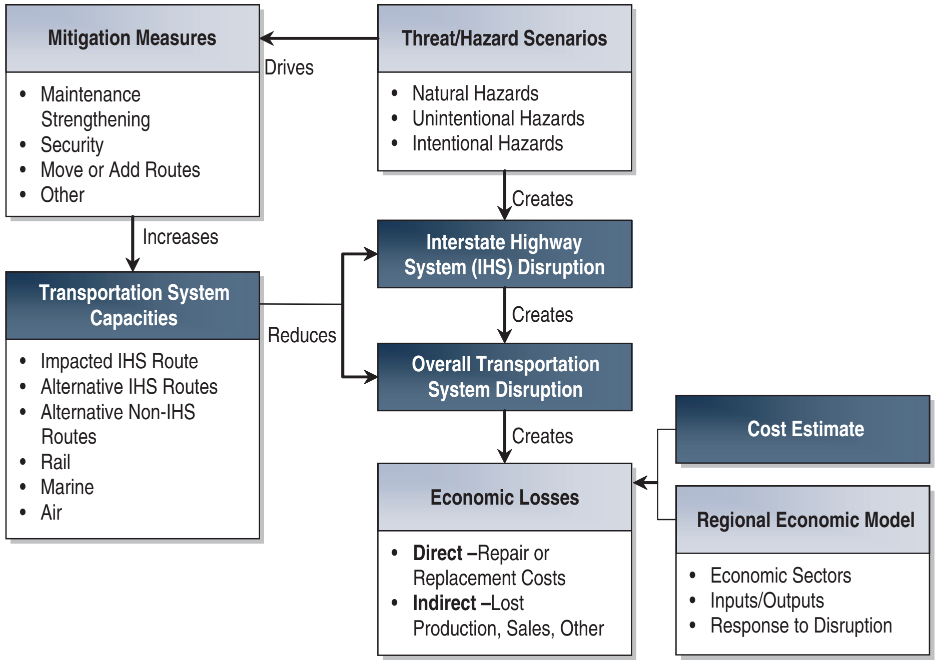


Figure 3.3. Overall risk management philosophy.

Step 1.a. Identify Hazards/Threats. The process begins with the identification of threats and hazards of relevance, as well as their respective magnitudes, probabilities, and spatial distribution across the jurisdictional area based on actuarial data, experience, or judgment. Hazards/threats identified in this step should include, at a minimum, any natural or man-made disasters for which mitigation is feasible that have been encountered on IHS assets in an IHS owner's geographic region. For instance, it is important to consider the potential for hurricane/flood damage in coastal regions prone to flooding. IHS owners on the Pacific Coast and in other seismically active regions should consider potential for damage from earthquakes. IHS owners nationwide should consider potential risks to bridges, particularly bridges that have no reasonable detour available, are fracture critical and/or susceptible to scour.

Step 1.b. Identify Critical Infrastructure Elements. Concurrently with Step 1.a, an IHS owner must make a set of policy-level decisions to identify critical asset groups and individual assets for analysis. Bridges and tunnels should be identified, at a minimum, but an IHS owner may wish to include other asset types, depending on the types of risks identified and available data.

Step 2. Develop Threat/Hazard Scenarios. Combining the results of Steps 1.a and 1.b, the IHS owner should next develop a set of threat/hazard scenarios. Each scenario should have an associated magnitude, probability, and location.

Step 3. Estimate Scenario Consequences. The scenario-based analysis considers each asset or asset grouping (i.e., groups of assets with similar characteristics) and determines the consequences of exposing them to each of the threats or hazards identified. Consequences are measured in terms of safety and mobility metrics, e.g., human safety, property damage, and system/mission disruption.

There are two approaches to performing the consequence analysis. The first, consequence modeling, is more objective and results in the computation/imputation of a financial cost that will result from each scenario under consideration. The consequence modeling approach requires a larger input data set to support the analysis and is more rigorous. In return, it provides a more quantified estimate of consequences for materialized threats/hazards. This provides an economic benefit value, which in conjunction with estimates of countermeasure costs, makes the option of establishing risk mitigation priorities (Step 5) on a benefit/cost basis possible. Moreover, consequence modeling can be used to study the impact of materialized threats/hazards on the disruption of network efficiencies cutting across transportation and other related economic sectors.

The alternative, more subjective approach, uses the consequence threshold technique proposed in the draft NCHRP 20-59(17) report. This approach involves identifying the levels of certain transportation asset characteristics, at and above which the agency should consider taking action specifically to mitigate one or more catastrophic risks. Examples of the types

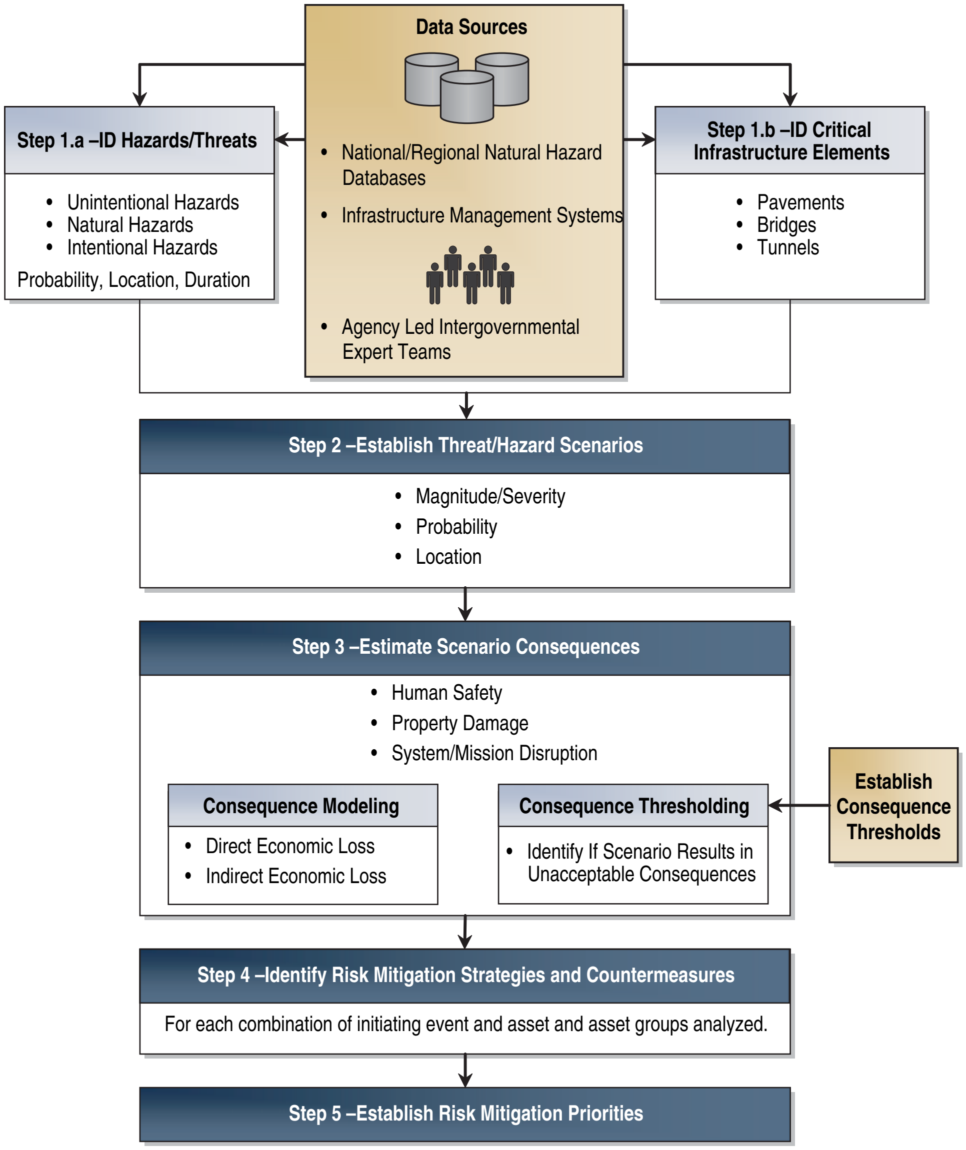


Figure 3.4. Risk Assessment Process for the Interstate Asset Management Framework.

of characteristics that must be considered in each of the three areas are:

- **Human Safety—**Numbers of people killed or injured by a particular event;
- **Property Damage—**Replacement cost of the asset(s) destroyed; and
- **System/Mission Disruption—**The product of ADT, percent trucks, detour distance and duration of outage.

These values must be estimated or calculated for each of the critical assets or groups of assets identified in Step 1.b to see which ones should be the focus of Step 4, during which risk mitigation strategies and countermeasures will be identified.

Appendix A describes several example applications of the consequence modeling approach. An example of the consequence threshold approach (also referred to as "thresholding") is the New York State Department of Transportation's Bridge Vulnerability Rating described in Appendix B of NCHRP Report 590 (*7*). This process, developed during the 1990s, determines each structure's vulnerability by combining the likelihood and consequences associated with different events, and uses the vulnerability rating as the basis for prioritization.

Step 4. Identify Risk Mitigation Strategies and Countermeasures. The next step in the process is the identification of effective risk mitigation strategies or countermeasures for each combination of initiating event (i.e., threat/hazard of a certain magnitude) and the analyzed asset or asset group. This, again, is a policy decision based on experience and judgment and can be codified in predefined countermeasure matrices. Once effective countermeasures are identified and estimates of costs developed, they need to be packaged to maximize cost efficiency and reduce impact on mobility in a given network.

Step 5. Establish Risk Mitigation Priorities. By looking at the results of consequence analysis and the mitigation strategies and countermeasures identified, as well as estimated costs, the IHS owner can establish priorities among the potential risk mitigation packages. This set of risk mitigation priorities should be documented in the Interstate Asset Management Plan and serve as an input into the agency's overall investment decision-making process. It is in this process that investments from each of the agency's programs, including risk mitigation, must be looked at side by side and the agency must then determine the desired mix of investments.

In the event that the more rigorous consequence modeling approach was utilized in Step 3, avoided direct and indirect losses arising from the implementation of each mitigation strategy for a given asset is computed. This is treated as a benefit for use in a benefit/cost analysis, where the cost component is the cost of the mitigation strategy being employed for the asset. As an alternative to a benefit/cost analysis, a return-on-investment analysis can be performed which will allow for phased mitigation strategy implementation over time to better accommodate all the network needs.

3.3 Institutional Responsibilities for Risk Management

The implementation of the proposed risk management approach for the Interstate Asset Management Framework requires a strong commitment and dedicated involvement of a broad spectrum of representatives from various organizational levels and functional areas within an agency. Although it is technically feasible to perform the analysis described in Section 3.2 solely for the purpose of populating the Interstate Asset Management Plan with a set of priorities for risk mitigation, realistically an IHS owner interested in instituting a risk management approach must make a sustained commitment to working on this issue. This section describes the institutional responsibilities required for an IHS owner establishing an ongoing risk management function.

First and foremost, the basic requirement for instituting a risk management approach is direction and continuous support for the effort from top executives. Next, there must be committed involvement by all of the pertinent departmental managers who have a role in the effort. It is suggested that a team or steering committee consisting of these managers be established to provide oversight of and direction to the risk management program efforts. There also needs to be involvement by subject matter experts and caretakers of the various management systems and databases (e.g., pavement, bridge, maintenance, sign, financial, etc.). This multidisciplinary team should collectively possess a working knowledge of the owner agency's mission, policies, plan, procedures, and critical assets and operations. Important agency departmental functions such as the following should be represented:

- Planning and programming;
- Budget and finance;
- Maintenance and operations;
- Construction;
- Design;
- Materials testing;
- Environmental management;
- Pavement and bridge management;
- Safety;
- Traffic operations;
- Facilities management;
- Communications; and
- Regional or district executives.

Given the nature of the threat/hazard emergency planning and response recovery processes, there are external stakeholders, such as the State Emergency Management Agency, State Police, threat-specific specialists, and local first responders that should be considered as part of, or serve as a resource to, the team or steering committee.

This steering committee should establish protocols for risk analyses, including identification of hazards/threats with significant consequences, developing and costing countermeasures, and benefit/cost analysis. The team or steering committee may direct selected risk analyses to be performed on certain asset groups or corridor segments. Upon completion and presentation of these risk analyses to the committee, the committee should determine priority and recommended courses of action for implementation. These actions can be programmatic, for example, placing remotely controlled variable message signs at all major interchanges or implementing seismic retrofits on bridges located in a specific seismic region, or project-specific, for example, upgrading a designated detour route between two critical IHS interchanges.

Once high priority risk mitigation countermeasures have been identified for promulgation, they must be funded, planned, and programmed. Most DOTs have a standing program management committee or process whereby periodic adjustments are made to multi-year Statewide Transportation Improvement Plans (STIP). All DOTs have more worthy projects than they can afford to do. One method of garnering funding for a proposed risk mitigation effort would be for the risk proposal to directly compete for funding against other worthwhile projects based on their ability to meet preestablished system performance goals and on benefit/cost analyses relative to those goals.

In addition to funding specific risk mitigation investments, transportation agencies should and do establish annual discretionary or contingency funds specifically for risk mitigation or disaster response, and have priority risk abatement or disaster recovery efforts vie for portions of such funds. A challenge in establishing such a fund is setting aside enough funding to address difficult-to-predict needs, while not setting aside so much money that this creates unduly complications in the capital programming process. Some amount of funding and attention is needed specifically for disaster response. Many transportation agencies have established the importance of budgeting for this function, and having well-established and well-rehearsed protocols in place for responding to specific types of disasters.

The bottom line is that the successful implementation of an ongoing risk assessment process as a component of the Interstate Asset Management Framework requires institutional planning, commitment, and continued personnel and financial support. The benefits of a successful risk assessment process go beyond the fundamental of risk avoidance, albeit the primary purpose, to the augmentation of the credibility and accountability of the organization itself.

CHAPTER 4

Data and Tools for Interstate Assets

Transportation asset management is a data-driven process that requires collecting, processing, storing, and retrieving data from a variety of sources and putting the data to use in investment decision making. Having sufficient, detailed data in a usable format is critical to successful asset management implementation, so much so that data is frequently seen as a valuable asset requiring investment. Analytical tools are used to store and track data, and use the available data to support predictions of future conditions, analysis of investment need, and other applications.

This section addresses the data and tools required to implement the Interstate Asset Management Framework. Section 4.1 provides an overview of how asset data and tools support asset management. Section 4.2 describes existing data resources available for supporting management of IHS assets. Section 4.3 discusses existing analytical tools. Section 4.4 presents a set of recommendations for use of data and tools to support IHS Asset Management. Section 4.5 discusses gaps in the available data and tools. Appendix A details the literature review performed as part of this research, and contains more detail on asset management data and tools.

4.1 Overview

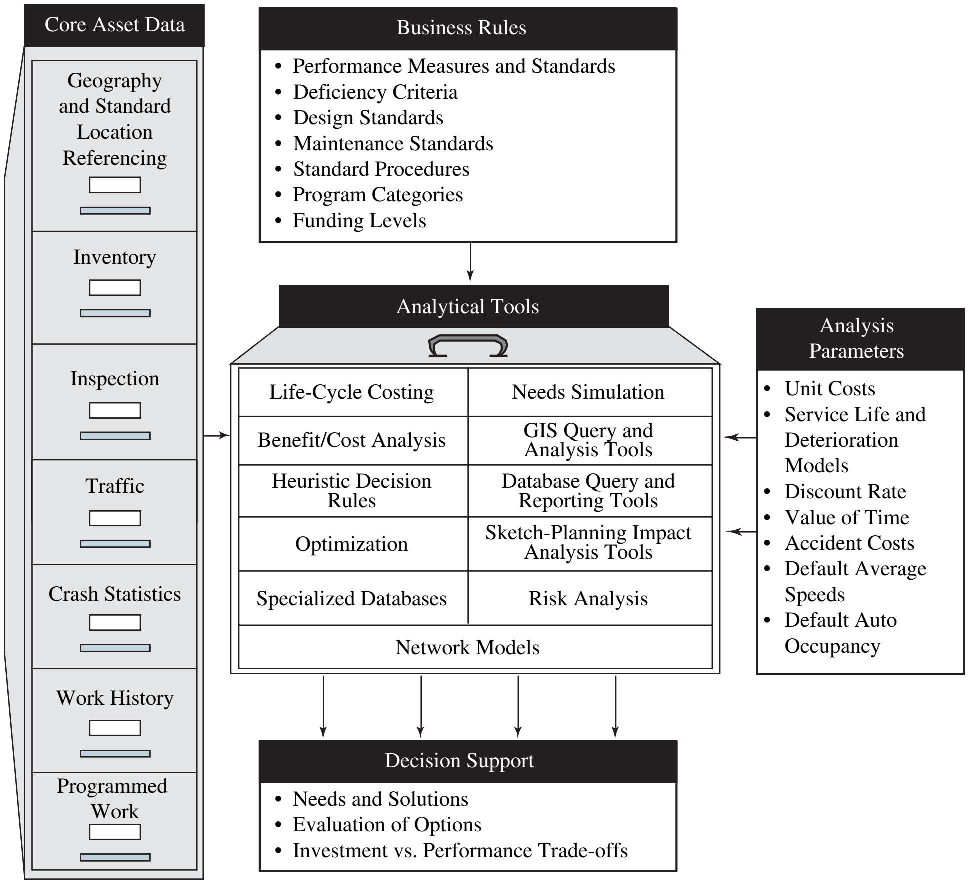
Implementing an asset management approach for the IHS first requires basic data on the full set of IHS assets. Table 2.1 lists the assets on the system, organized by roadway, structures, safety features, and facilities. At a minimum basic location, inventory and condition data are needed for each asset type. Additional data on potential actions and their costs are important for modeling asset performance. Agencies typically have data for pavements and bridges, but have varying amounts of data for other assets. Although asset location, inventory, condition, and cost data are perhaps the most obvious and most fundamental types of data required for implementing asset management, the framework described in Section 2.0 establishes the need for other data as well. Specifically, characterizing measures related to mobility, safety and environmental performance necessarily requires data in each of these areas.

Figure 4.1, reproduced from NCHRP Report 545 (*8*), provides a vision for how asset data and analytical tools support asset management. As illustrated in the figure, analytical tools utilize core asset data, together with business rules and analysis parameters. These tools use techniques such as life cycle costing, risk analysis, simulation, and optimization to produce their results, including analyses of needs and solutions, evaluations of different treatment options, and details on investment and performance tradeoffs.

The ideal system for supporting transportation asset management would be one that includes the following functionality for all assets and investment types:

- Storing and retrieving condition data;
- Establishing goals and performance measures;
- Identifying needs;
- Predicting future conditions and service levels based on different investment scenarios and/or performance targets;
- Supporting development of capital and/or operating plans; and
- Monitoring results.

Such a system could be used to help support each step of the asset management process. Many agencies began exploring the potential for management system integration in the wake of the requirements for agencies to implement seven types of management systems that were included in the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA). In practice, however, the ideal asset management tool does not exist. Data requirements, business rules, and analysis approaches vary significantly between asset and investment types, greatly complicating any attempt to define a single system for supporting the entire asset management process. Further, limits on computer processing speed and memory,



Source: *NCHRP Report 545*.

Figure 4.1. Context for an analytical toolbox.

though continually being relaxed, are nonetheless important factors that tend to restrict system functionality and scope.

Lacking the single, comprehensive asset management system, agencies must instead use a variety of different information systems, together with manual and/or spreadsheet approaches, to support implementation of asset management. This section discusses five basic types of tools for supporting the Interstate Asset Management Framework:

- **Investment Analysis—**These systems provide general guidance on the performance predicted for one or more asset types given a specified budget level.
- **Management Systems—**This category includes pavement, bridge, and maintenance management systems, as well as others. These systems are designed to support a broad range of functions for one or more asset types. They generally have inventory and condition data and may contain additional functionality described for the other categories listed here.
- **Needs and Project Evaluation—**Needs identification and project/treatment evaluation are central functions of an asset management approach. An extensive set of systems has been developed for supporting these functions. Typically these systems use data from other management systems or require project-specific inputs to perform analysis. Systems in this category include systems for needs identification; testing alternative policies for scoping, timing, or design; evaluation of projects or strategies; project prioritization; lifecycle cost analysis; and risk analysis.
- **Risk Assessment—**This category includes tools specifically designed to calculate risks of system failure, predict consequences of risk, and assist in prioritizing investments in risk mitigation.
- **Results Monitoring—**This category includes systems that help monitor performance and costs over time, such as on costs and effects of maintenance and construction actions.

4.2 Asset Management Data

Federal and state transportation agencies have been collecting highway related data since the 1950s. Although the reasons for data collection have varied, typically data have been collected to support infrastructure management practices, comply with Federal mandates, support research, and support Federal resource allocation.

This section provides an overview of data available for IHS Asset Management, focusing on Federally mandated data sets and other types of databases commonly maintained by state DOTs. Federally mandated data sets have significant potential for supporting the framework because all agencies have access to the same data in the same format. However, the framework is flexible so that agencies can augment Federal data with data from their other databases. While agencies typically follow Federal guidelines for data collection, even when collecting data that goes beyond Federal reporting requirements, in some areas there are no specific standards on how certain types of data are to be collected, stored, or reported. The following subsections are organized by asset type, with additional subsections on mobility, safety, and environmental data.

Almost every aspect of the Interstate Asset Management Framework requires data of some kind. Fortunately, as described below, most agencies have already made significant data investments and have access to a wide range of data. It is recommended that agencies work to fully leverage these existing data resources.

Roadway Data

Highway Performance Management System (HPMS)

The HPMS is a national transportation data system providing detailed data on highway inventory, condition, performance, and operations. It describes functional characteristics, traffic levels, and pavement conditions for all IHS sections. Since its initial development, the HPMS has been modified several times. It has recently undergone a major reassessment, referred to as HPMS Reassessment 2010+. The objectives of this initiative were to reflect changes in highway systems, national priorities, technology, and to consolidate and streamline reporting requirements. The final assessment report (*9*), described in Appendix A, lists additional data items to be added to the HPMS. The current version of the HPMS includes two measures of pavement condition: PSR and IRI. HPMS 2010 will contain additional measures of rutting/faulting and cracking, consistent with AASHTO standards for pavement data collection.

Pavement Management Systems (PMS) Databases

Most agencies collect pavement data required to run a pavement management system (PMS). PMS databases are needed for supporting the Interstate Asset Management Framework, but there is no standard format for how this information is collected or stored. For example, in a recent survey of 45 state DOTs performed by Applied Research Associates, more then 80 percent reported that they collect basic pavement inventory data (e.g., pavement type, lane width, shoulder type, shoulder width, number of lanes, layer thicknesses). Between 35 to 40 percent reported that they collect detailed inventory data (e.g., pavement layer material properties, subgrade type, and drainage).

The survey also showed variances in terms of the types of pavement condition data collected. All of the agencies surveyed collect IRI and rutting data. Over 90 percent collect data on fatigue/alligator cracking and transverse cracking, while 84 percent collect data on longitudinal cracking in the wheel path. In addition, 29 percent of the agencies in the survey collect Present Serviceability Index (PSI), 69 percent collect surface friction, and 56 percent collect a composite index. (These figures are for hot-mix asphalt (HMA) pavement. They vary for other types of pavement.)

Structure Data

National Bridge Inventory (NBI)

The NBI is a Federally mandated database of bridge inventory and conditions compiled by state DOTs for submission to FHWA. It contains data on all bridges and culverts on or over U.S. roads that are greater than 20 feet in length, and data on many tunnels. The NBI data set contains condition data by bridge component: deck, superstructure, substructure, channel/channel protection, and culvert. It also contains data on a bridge's functionality, such as underclearances and load posting information.

Pontis Bridge Management System (BMS)

In contrast to the situation with PMS, most states (over 40) license the AASHTO Pontis BMS, making this system the defacto standard for BMS data in the United States. The Pontis database contains all the NBI data items, as well as more detailed element-level inspection details. For example, the NBI file contains a single condition rating for a bridge's superstructure. 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, floor beams, etc. AASHTO has developed standard element descriptions and condition state language, referred to as "Commonly Recognized (CoRe) elements" for use with Pontis and other BMS (*10*). However, states using Pontis may specify their own elements and most have done so, supplementing or replacing the CoRe element language. Further, most agencies that have implemented Pontis have added agency-specific data items to the Pontis database.

Other Structure Data

The NBI file described above contains inventory information for many tunnels and inventory and condition information for some culverts (where the length of the culvert measured along the centerline of the roadway is over 20 feet long). There are no other Federal databases containing data on non-bridge structures, including tunnels, culverts, retaining walls, sign support structures, and other structures. However, a number of agencies store data on other structures in their BMS. The collection of data on these assets varies significantly between state DOTs.

FHWA has published *Guidelines for the Installation, Maintenance, and Repair, of Structural Supports for Highway Signs, Luminaries, and Traffic Signals (11)*. This guide recommends performing an element-level inspection for these structures, similar to that commonly performed for bridges, and recommends specific elements that should be inspected for each structure type. Separately FHWA has developed the *Highway and Transit Tunnel Inspection Manual (12)* with recommended inspection practices for tunnels. AASHTO has published the *Asset Management Data Collection Guide* (*13*). This document contains recommendations regarding data collection for a number of assets, including drainage assets. There are no Federal guidelines for asset management data for culverts, retaining walls, or noise barriers, though Appendix A describes recent work describing available systems and approaches for these assets.

Safety Feature and Facility Data

Many state DOTs maintain some form of inventory of their safety features and facilities, ranging from paper files and maps to computer database systems. There are no Federal standards for collection of asset data for safety features and facilities, and no real consistency in the data available from one agency to another. The most common approach to using this to support asset management is through development of maintenance levels of service (LOS) as part of a performance-based budgeting or maintenance quality assurance program. This approach is detailed in NCHRP Web-Only Document 8 (*14*). LOS values are typically calculated by maintenance program (e.g., roadside, drainage, vegetation, etc.) and can be reported either on a letter scale (A through F) or numeric scale.

Four resources detailed in Appendix A describe the state of the practice in asset management data collection for safety features and facilities. NCHRP Synthesis 371 (*15*) details data available for signals, lighting, signs, pavement markings, culverts (treated as structures in this report), and sidewalks. The 2006 white paper "The Use of Highway Maintenance Management Systems in Statewide Highway Agencies" describes a survey of maintenance management data and systems performed in 2005 (*16*). Further, the report on the recent Transportation Asset Management Domestic Scanning Tour conducted as part of NCHRP Project 20-68 details best practices examples for asset data collection in a number of agencies (*17*). The *Asset Management Data Collection Guide (13)* provides examples of best practices for a number of assets, and recommends specific inventory and condition data items to collect for assets including signs, guardrails, and pavement markings. Also, this guide presents a set of criteria for determining what data to collect for an agency's assets that is particularly applicable to assets classified here as safety features.

Mobility Data

The HPMS is the major source of mobility data for the IHS, particularly at a national level. It contains average annual daily traffic (AADT) data for all segments and additional functional data needed for modeling mobility-related measures. The FHWA Highway Economic Requirements System—State Version (HERS-ST) takes HPMS data as an input and can be used to model mobility measures. All DOTs have developed some form of database for tracking highway inventory and traffic data in addition to what is required for HPMS reporting. There are no standards for how this additional information is collected or stored. NCHRP Web-Only Document 97 (*18*) details best practices in collecting IHS mobility and operations data.

Safety Data

Fatality Analysis Reporting System (FARS)

NHTSA National Center for Statistical Analysis maintains the Fatality Analysis Reporting System (FARS). Established in 1975, FARS contains data describing all fatal accidents occurring on public roads in the United States. Data included in the FARS database are collected by state and local police officers, coroners, emergency medical services, and state motor vehicle administrations. Data describing approximately 40,000 fatal accidents are added to the FARS annually.

Highway Safety Information System (HSIS)

The FHWA's Highway Safety Information System (HSIS) is a multistate safety database that contains accident, roadway inventory, and traffic volume data. The University of North Carolina Highway Safety Research Center and the FHWA maintain the database. The participating states—California, Illinois, Maine, Michigan, Minnesota, North Carolina, Utah, and Washington—were selected based on the quality of their data, the range of data available, and their ability to merge data from the various sources. HSIS is used to study current highway safety issues, direct research efforts, and evaluate the effectiveness of accident countermeasures.

State Crash Data Systems

Crash data are collected by police officers at the scene of crashes. Every state has a unique system for collecting crash data based on police accident reports (PAR), and an administrative structure for controlling the data. Most PAR data collected by states are similar in nature. Different data schemas have been developed for crash reporting, but there is no national standard for these data. The TransXML schema is one example developed through NCHRP Project 20-64. As described in Appendix A, this schema is based on the Model Minimum Uniform Crash Criteria (MMUC).

NHTSA's National Center for Statistical Analysis maintains a sample of state crash data through its National Accident Sampling System/General Estimates System (NASS/GES). The NASS/GES contains an annual sample of police-reported traffic crashes in the United States, which is used to estimate the number of U.S. traffic accidents and their injury outcomes. Unlike the FARS, which only contains data describing crashes involving fatalities, the NASS/GES contains data on both fatal and nonfatal accidents. The NASS/GES was created in 1988. More than 50,000 accidents are recorded in this database each year.

State Highway Safety Improvement Plans (HSIP)

Each state is required to develop a HSIP on an annual basis detailing its use of Federal transportation safety funding. At a minimum, a state's HSIP has sections on planning (including information on data collection and maintenance, identification of hazardous locations and elements, and project priorities), implementation of planned safety improvement and evaluation of completed improvements. The HSIP is a useful source of data for information on state-level safety improvement needs and trends.

Environmental Data

There exists little environmental data available, particularly on a consistent basis from agency to agency, for supporting the Interstate Asset Management Framework. NCHRP Web-Only Document 103 (*19*) details data sources and analytical tools used by transportation agencies for environmental management.

Risk-Related Data

Supporting the risk management approach described in Chapter 3 requires information on risks to transportation infrastructure and information for predicting consequences, as well as the detailed asset data described in previous subsections. Information on the risks to transportation infrastructure is particularly sparse. The NBI contains data on certain types of risks to structures, through detailing bridge design types and materials, through specifying whether or not a bridge has fracture critical details, and by storing information on bridges' vulnerability to scour. The review found no other data sources available on a consistent basis for use in assessing risk to infrastructure. However, in many cases individual IHS owners have performed some form of assessment of the risks they perceive to be greatest (e.g., of seismic vulnerability in California, likelihood of flooding in the event of a hurricane in Gulf Coast states, etc.). In theory the National Asset Database provides a comprehensive listing of critical infrastructures and assets. However, both the Department of Homeland Security and Congressional Resource Service have reported significant problems with this database, particularly with regard to consistency in classification of "critical assets" from state to state (*20*) (*21*).

For predicting consequences of risks, many state DOTs and Metropolitan Planning Organizations (MPOs) do have statewide or regional travel demand models that can be used to model the disruption in the event of system failure. Currently the Interstate 95 (I-95) Corridor Coalition is developing an integrated travel demand model for the states along I-95 that, once developed, could be used for consequence modeling. For bridges, the NBI specifies the traffic on and under each IHS bridge, as well as the detour distance around the bridge. This information can be used to approximate consequences for bridge-related risks.

4.3 Analytical Tools

This section describes the evaluation of the available analytical tools for supporting the Interstate Asset Management Framework. The review described in Appendix A yielded a large number of examples of analytical tools for supporting asset management. The existing tools have been organized by the system types described already: investment analysis systems; management systems; needs and project evaluation; risk assessment; and results monitoring. Specific systems available in the public domain are noted. Otherwise, the text describes general functionality available in the existing agency and commercial off-the-shelf (COTS) systems.

Investment Analysis

The review included several examples of investment analysis tools. FHWA's HERS-ST, the state version of the Federal HERS program, uses HPMS data to predict highway investment needs and measures. The system simulates both pavement preservation and highway capacity expansions needs. FHWA itself uses a Federal version of HERS for developing its biennial report on the conditions and performance of U.S. highways, bridges, and transit (the C&P Report). HERS-ST is notable in that it is one of few systems that generates needs for new capacity. This functionality is in contrast to that provided in other tools, which typically can evaluate a set of project or network improvements, but lack functionality for needs generation. Further, HERS-ST projects a wide range of performance measures, including selected preservation, mobility and accessibility, safety, and environmental measures. Issues agencies encounter in using HERS-ST include:

- The system is designed to model HPMS sample sections, using the expansion factor to approximate needs for nonsample sections. One can either run the system using sample section data, or supplement the HPMS data, quantifying the additional data items required for sample sections for universal sections, as well. For high-level analysis the use of sample section data is completely appropriate, but for more detailed analyses one may need to supplement the sample section data.
- The system has relatively limited modeling of pavement conditions, given the only measures of pavement condition available in the HPMS are IRI and PSR. FHWA plans to revise the pavement models in HERS in conjunction with the planned changes in the HPMS.
- The system relies on future traffic predictions in the HPMS. Frequently these values are populated using an overall adjustment factor, rather than through use of a travel demand model.
- Indiana DOT (INDOT) has developed an approach for using HERS-ST to support its planning process, accounting for all of the issues described above. The agency models each of its pavement sections as a sample section (supplementing the HPMS data with additional data available from its road inventory database), and defines specific improvements in HERS-ST, with traffic data generated from the agency's statewide travel demand model, where a specific improvement has been scoped. Also, INDOT disables the pavement deterioration models in HERS-ST, instead using its own, more detailed PMS for modeling pavement conditions.

The World Road Association (PIARC) offers HDM-4 for analysis of roadway management and investment alternatives. The system has been used internationally to evaluate road projects, budget scenarios, and roadway policy options. HDM-4 has functionality similar to HERS-ST, with a more detailed set of pavement models. However, the system does not use HPMS data as an input, and has not been implemented in the U.S.

FHWA's National Bridge Investment Analysis System (NBIAS) is designed for modeling national-level bridge investment needs. FHWA uses NBIAS in conjunction with HERS when preparing the C&P Report, and has recently made a number of enhancements to the system to facilitate state use. The system uses a modeling approach originally adapted from the Pontis BMS to predict bridge preservation and functional improvement investment needs. FHWA has performed work on NBIAS to modify its models to predict benefits in as similar as possible a manner to HERS, and to populate the system with default data, including default user cost models, agency cost adjustment factors for each state, and bridge deterioration models for each HPMS climate zone. The system takes NBI data as its input, but also can import element-level data where available.

The Multi-Objective Optimization System (MOOS) network-level model is a spreadsheet tool for bridge investment analysis detailed in NCHRP Report 590 (*7*). The system uses data on work candidates generated separately to project future conditions and performance given performance and/or budget constraints and objectives. The tool supports use of a multi-objective approach, but requires extensive data to run, to be specified for each individual bridge using the MOOS bridge-level model. The California DOT (Caltrans) has adapted concepts from NCHRP Report 590 in its recent revisions to the process for updating the Caltrans Strategic Highway Operations and Protection Plan (SHOPP). The bridge analysis performed for the SHOPP update process considers needs for bridge rehabilitation, guardrail improvements, seismic retrofit, scour mitigation, and functional improvement using a multi-objective approach. The process is supported by a number of tools, including the Pontis BMS and AssetManager NT described below.

AssetManager NT, developed through NCHRP Project 20-57 (*8*) and now released through AASHTO, is an investment analysis tool designed to integrate data from other investment analysis and management systems. It takes analysis results generated by systems such as HERS-ST, NBIAS, and agency management systems as inputs, and uses this information to show performance measure results over time for different funding scenarios. The system includes spreadsheet "robots" for automatically running HERS-ST and the Pontis BMS to generate system input. The system is unique in its ability to integrate analysis results from different sources in one display. However, COTS management system vendors have built upon their existing systems to provide similar functionality, where an agency uses the vendor's system for all of its analysis, as described later.

In addition to the systems described, a number of agencies have developed their own investment analysis approaches, frequently using spreadsheets, to support the process. The Alaska Department of Transportation and Public Facilities and Michigan DOT are two examples of agencies that have developed spreadsheet approaches. Other agencies have developed their own cross-asset analysis systems. The Ministry of Transportation of Ontario (MTO) has developed a prototype Executive Support System (ESS) for cross-asset analysis. The system includes functionality similar to AssetManager, as well as a preprocessor for using work candidate and asset inventory to simulate future conditions and performance. The New Brunswick

Department of Transportation has recently adapted the Remsoft Spatial Planning System (RSPS) to perform strategic analysis of its pavement and bridge investment needs. RSPS is a suite of tools originally designed for developing long-term forest management plans. RSPS includes the Woodstock modeling system, used to formulate optimization models, which are then solved using a separate linear program (LP) solver.

Management Systems

Pavement. PMS are used to collect, store and retrieve pavement inventory and condition data. These systems are used to reduce data, summarize conditions, support development of pavement treatment rules, model future conditions, and perform analysis of investment needs, and develop standard query reports. All U.S. agencies have some form of PMS, and all use their pavement systems to support HPMS and other reporting. There are a number of commercially available PMS, including systems offered by the Army Corps of Engineers, Deighton, Agile Assets, and Stantec. There are several additional state-specific systems in use.

Typically PMSs allow for specification of multiple measures of distress, including roughness, rutting, cracking/faulting, and other measures. Most systems support flexible specification deterioration models for each measure of distress and decision rules, allowing for a range of treatments triggered by different distress measures. The available systems use different approaches to project-level analysis for recommended specific treatments over time for given pavement section and network-level analysis for predicting overall conditions over time given a budget constraint and/or other constraints.

In part because the available systems are so flexible in their design, a challenge agencies face in using the available systems is in determining what distress measures to model, how to predict deterioration over time, and what treatments should be triggered at different condition levels. Increasingly, agencies are using the concept of Remaining Service Live (RSL) for developing pavement deterioration models and treatments. RSL typically is defined as the life of an asset from the time it is completed for use until application of the first significant rehabilitation or reconstruction of the asset. The placement of a structural HMA overlay (versus a thin overlay) or reconstruction signals the end of a pavement's serviceable life; the application of minor maintenance treatments is not considered significant enough to indicate the end of service life. In conjunction with the concept of RSL, survival analysis can be used to determine the mean service life for a family of pavement sections or other assets with similar characteristics (e.g., design, usage, climate). Survival analysis utilizes information on assets still in service and assets that have either failed or been rehabilitated or reconstructed to predict a time-dependent survival probability that can be used to establish a pavement deterioration model.

A feature of the more advanced commercially available systems is that these systems can model other assets besides pavement, provided an agency has the data and models to support such an analysis, and subject to a number of modeling assumptions. Also, the systems from Deighton and Agile Assets offer the ability to view analysis results across assets modeled in the system. Utah DOT has successfully used the Deighton's dTIMS CT system to perform analysis across assets, including pavement, structures, safety, mobility, and maintenance needs.

Bridge. BMS are used for storing bridge inventory and inspection data, supporting reporting, modeling bridge conditions, recommending work, and other functions. Nearly all U.S. agencies have a BMS to support collection of bridge inspection data. Many, though substantially fewer, use their BMS for bridge modeling. Commercially available bridge management systems that have been put into production in the United States and Canada include AASHTO's Pontis, Delcan's BRIDGIT, and Stantec's Ontario Bridge Management System (OBMS). All of these systems store data and model bridges at an element or component level, going beyond characterizing conditions at a finer level than the deck, superstructure, and substructure ratings in the NBI.

In addition to these systems, many agencies have developed their own systems for storing bridge inventory and inspection data and/or modeling bridge conditions. Agencies such as Alabama DOT and New York State DOT developed BMS prior to the release of Pontis and continue to use their agency-specific systems. Other agencies have developed bridge inventory and inspection systems, while using Pontis for any modeling needs, or use Pontis with extensive customizations. For instance, Caltrans has developed the Structures Maintenance and Reports Transmittal (SMART) system using a Pontis database and custom tables, with a custom user interface. Florida DOT has made extensive customizations to Pontis, and has developed a standalone spreadsheet for bridge analysis (incorporated in the MOOS Bridge Level Tool detailed in NCHRP Report 590).

Maintenance. Maintenance management systems (MMS) often are used to inventory and characterize conditions of roadside assets besides pavements and bridges, including road shoulders, nonbridge structures, and safety features. Transportation agencies use a number of different tools to support their maintenance management functions. Different approaches to maintenance management systems can be summarized as follows:

- **Legacy highway MMSs.** Several states use MMS that were developed in the 1970s and 80s. These systems are often mainframe or client/server systems that field crews use to enter labor, equipment, and materials usage by activity type. These systems enable maintenance managers to develop maintenance budgets and plans based largely on what work was accomplished in previous years. In the legacy systems, the inventory data are either nonexistent or consist of a rudimentary features inventory. As these legacy systems have been upgraded, many have evolved into inventory-based systems, as described below.

- **Inventory-based highway MMSs.** These systems provide many of the features of the legacy systems, and add more sophisticated approaches for tracking inventory data. A number of commercially available asset management systems fall in this category, including Agile Assets' Maintenance Manager, Infor's Asset Management Suite, CartêGraph's Management Suite, Exor's Highways Suite, and the Maintenance Activity Tracking System (MATS) jointly developed by the DOTs of Maine, New Hampshire and Vermont.
- **Nontransportation work management systems.** Many large private sector firms that are responsible for some type of asset maintenance use work order systems to plan, schedule, and track maintenance activities. One example of this type of system is IBM's Maximo. Work orders can be generated by Maximo automatically based on preventive maintenance schedules, or specified by maintenance mangers based on local knowledge. Information associated with work orders can include location, date, activity, personnel, materials, and equipment usage (both planned and actual). Although these systems are not designed specifically to support the public transportation sector, they can be used by transportation agencies wishing to track maintenance work orders.
- **Enterprise resource planning (ERP) systems.** ERP systems are enterprise-oriented products that offer a suite of integrated modules covering financial and operations management. SAP is a common ERP system. SAP has several financial modules including General Ledger, Payables and Receivables, Controlling (budgeting), and Asset Accounting. Its also includes four modules that may be applicable to the maintenance management function: Plant Maintenance, Service Management, Materials Management, and the Project System. A cross-application timesheet module (CAT) also is available through SAP, which interfaces to the financial, logistics, and human resource families of products. In addition, a business information warehouse product provides data warehouse capabilities, allowing linkages between SAP and external data. A number of state DOTs are implementing ERP systems to support maintenance management, including Pennsylvania, Idaho, and Colorado.
- **Performance-based budgeting systems.** A number of DOTs have developed spreadsheets or systems for supporting a performance-based maintenance budgeting approach, as detailed in NCHRP Web Document 8 (*14*) and described previously. This approach requires agencies to conduct physical inspections on a sample of the network and model the relationship between expenditure and the resulting condition. The analytical functionality required to support this type of budgeting is not widely available in the types of systems described above. Therefore, agencies pursing this approach often develop standalone tools that draw information from their MMS.

Other. Management systems have been developed for a variety of other assets, including but not limited to signs, culverts, tunnels, ITS equipment, and facilities. Generally, but by no means exclusively, these systems focus on supporting collecting and reporting basic inventory and inspection data. There are many best practice examples for these systems, but little or no standardization between them concerning data requirements and functionality.

Regarding other structures besides bridges, there are varying practices in use for managing these. Most agencies do store data on culverts that are at least 6.1 meters (approximately 20 feet) long, as these are included in the NBI. In many cases, agencies store data on shorter culverts, tunnels, and other structures in their BMS, as well. This approach, where used, facilitates use of BMS functionality for predicting future conditions and performance. However, often data on other structures is stored separately, or simply not stored in an electronic format. New York's Metropolitan Transportation Authority—Bridges and Tunnels uses its Capital Programming System to store detailed data on conditions and predicted future needs for nine major bridges and tunnels in and around New York City. FHWA has issued guidance on tunnel inspection procedures and developed a Tunnel Management System that demonstrates collection of tunnel inventory and inspection data. Also as noted in Section 4.2, FHWA has issued guidance on sign, light, and traffic signal support structures recommending inspection data be collected for these structures using the element-level approach established in Pontis.

Needs and Project Evaluation

Many of the analytical tools developed for asset management fall into this category. Typically these tools are used to analyze a user-defined scenario or project, calculating costs, performance measures, or other parameters used to support the decision-making process.

Surface Transportation Efficiency Analysis Model (STEAM) and ITS Deployment Analysis System (IDAS) are tools for evaluating network performance for a specified set of transportation improvements. Both systems require information on the improvements to be evaluated, and output from a travel demand model. STEAM uses this information to calculate a wide range of measures of transportation and environmental performance for multimodal improvements. IDAS is designed to evaluate the benefits of more than 60 types of ITS investments.

A number of tools are available to evaluate project-level costs and benefits. BCA.Net is a web-based tool developed by FHWA for highway benefit-cost analysis. The system predicts costs and benefits for a range of different highway projects, and includes functionality for sensitivity analysis. BCA.Net builds upon the models developed for older benefit-cost analysis systems, most notably MicroBENCOST. A key feature of the system is that because it is web-based, an agency user can run the system without installing any software other than an Internet browser. StratBENCOST is another system that uses MicroBENCOST models, but applies them to multiple project alternatives. TransDec is a tool for multimodal, multi-objective project analysis. It helps prioritize projects or project alternatives considering multiple objectives and measures. AssetManager PT is a spreadsheet tool for project analysis. It helps prioritize projects given information on the costs, benefits, and performance impacts of a set of projects.

Several available tools are spreadsheet tools intended for detailed lifecycle cost analysis (LCCA) for pavement or bridge projects. RealCost is FHWA's current tool for pavement LCCA, replacing a number of earlier LCCA tools. The system includes a number of advanced features, including models for predicting user costs due to construction, and probabilistic modeling of analysis inputs using Monte Carlo simulation. BLCCA is a lifecycle cost analysis tool designed for bridge LCCA. It is designed to use data from systems such as Pontis. Like RealCost, it includes probabilistic modeling of input parameters. The MOOS bridge level model predicts bridge life cycle costs as well. It differs from BLCCA in a number of respects. Specifically, MOOS includes consideration of multiple objectives (e.g., minimizing costs, maximizing condition, or maximizing overall utility) and incorporates preservation models from Pontis. However, it lacks features of BLCCA such as modeling of uncertainty in input parameters.

Many agencies have developed their own tools for project-level analysis. Often these tools are used for initial screening of candidate projects. For instance, Caltrans uses the spreadsheet tool Cal B/C for project analysis. Wisconsin DOT developed a spreadsheet for calculating project-level user benefits as part of its Mobility Project Prioritization Process. The Ministry of Transportation of Ontario recently developed a prototype spreadsheet tool, the Priority Economic Analysis Tool (PEAT), for project-level benefit-cost analysis, adapting models from HERS-ST and other systems. South Carolina DOT has developed the Interactive Interstate Management System (IIMS) for ranking interchange needs, and calculating the costs and benefits of user-defined interchange improvements.

Risk Assessment

There are relatively few tools available for assessing risks of system failure for IHS assets. Appendix A provides a number of examples where risks have been characterized and prioritized using either calculations of economic losses (e.g., through creating risk scenarios and using a travel demand model to estimate consequences) or thresholding approaches.

To the extent that tools have been implemented for risk assessment, they typically have been used for assessing risks to structures. As described earlier, Caltrans recently implemented a multi-objective needs analysis approach supported using AssetManager that includes consideration of risks to structures, adapting the approach detailed in NCHRP Report 590.

Recently NCHRP published the Disruption Impact Estimating Tool (DIETT) for prioritizing risks to transportation choke points such as bridges and tunnels (*22*). It includes an Access tool for filtering choke points and a spreadsheet for prioritizing choke points based on potential economic losses if the choke point were closed. The system is intended to be used in conjunction with the Science Applications International Corp. (SAIC) Consequences Assessment Tool Set (CATS).

Lloyds Register has introduced the Arivu system for prioritizing maintenance actions for a range of assets such as bridges, drainage structures and lighting based on risk. This tool has been implemented for transportation agencies in the United Kingdom.

The MOOS bridge level model described earlier is intended as a project analysis tool, in that it considers a range of different projects and is not limited to risk mitigation. However, the tool can be used to prioritize risk mitigation for bridges by focusing on project types intended to mitigate risks of failure (e.g., seismic risks).

Results Monitoring

Transportation agencies typically use their pavement, bridge, and maintenance management systems, described above, for monitoring asset conditions over time. All agencies have highway inventory systems and geographic information systems (GIS) for storing geospatial data. These systems are integrated to greatly varying degrees, with some agencies integrating most or all of their management and inventory systems with each other and their GIS, while others have minimal integration.

For monitoring project delivery all agencies have additional systems for construction and project management. A number of agencies use AASHTO's Trns*Port suite to support preconstruction and construction management. Trns*Port includes 14 separate modules, with functionality in areas such as construction cost estimation, letting and awards, construction administration, bidding, and construction management.

Summary of the Tool Evaluation

The analytical tools identified through the review were evaluated to determine the degree to which they support the Interstate Asset Management Framework. Table 4.1 lists systems and tools currently maintained, support at least one step in the framework, and are available in the public domain and/or through NCHRP research, from AASHTO or from FHWA.

4.4 Guidance on Data and Tools for IHS Asset Management

This section provides guidance on using available data and tools for supporting the Interstate Asset Management Framework. Guidance is provided for each asset category, as well as for the areas of mobility, safety, environment, and integrating results. Additionally, Table 4.1 lists specific analytical tools that can be used to support asset management analyses consistent with the guidance presented below.

A general issue in considering the data and tools needed for asset management is that of degree of coverage. While it is generally agreed that good data supporting quantification of qualitative policies, goals, and objectives often are required to properly manage highway assets, and agreement that asset management decisions should be supported by data, there is debate over what constitutes good data and exactly how that data should be used. Generally, the more complete, accurate, and timely the data, the more expensive it is to collect. In determining the extent to which data should be collected for the Inter-

Table 4.1. Analytical tool summary.

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

state Asset Management Framework, it is important to weigh the cost of data collection against the cost of poor decisions from incomplete or inaccurate data. Also, it is important to consider the possible use of the data for supporting asset management, and try to avoid the situation whereby an IHS owner collects too little data to support asset management decisions or, alternatively, more data than can practically be put to use in a systematic manner. The guidance below has been developed considering the need to find a balance between these extremes.

Roadways. IHS owners should collect roadway inventory and inspection data consistent with HPMS reporting requirements on an annual basis. All IHS sections should be treated as HPMS sample sections, implying the full set of HPMS data items should be quantified for each section. Further, IHS owners should collect additional measures of pavement condition consistent with the requirements of COTS pavement management systems and expected future HPMS requirements.

Agencies should use a pavement management system for assessing current conditions, monitoring performance trends, setting performance and budget targets, and identifying candidate projects when updating the capital plan for pavements. Existing COTS and agency-specific systems that support measures of roughness, cracking, faulting and rutting provide sufficient support for implementing the Interstate Asset Management Framework. An RSL approach is recommended for modeling pavement needs. Where possible, survival analysis should be used to establish pavement deterioration models considering relevant performance risk. HERS-ST should be run to validate the results obtained from an agency's PMS, or to act as a substitute for assessing conditions and setting performance and budget targets where an agency lacks a PMS.

Structures. IHS owners should collect inventory and condition data on all structures, preferably on a two- to four-year basis. This guidance applies to bridges and other nonbridge structures—tunnels, culverts/drainage structures, noise barrier walls, retaining walls, overhead sign structures, and high mast light poles—as all of these structures have the potential to fail catastrophically, and thus lead to system failure (closure of a portion of the IHS for some period) and possibly loss of life.

Bridge data are already collected for IHS bridges consistent with NBI requirements. In addition to collecting NBI data, IHS owners should collect inventory and condition data for all structures at the element or subcomponent level. NBI data is collected at the component level—deck, superstructure, and substructure. These data provide an overall picture of bridge condition, but are not sufficient for identifying specific bridge preservation projects such as painting and repairs to elements such as bearings or joints. Element level data provides the finer level of detailed condition required to identify candidate projects.

IHS owners should use a BMS for assessing current conditions, setting performance and budget targets, and identifying candidate projects when updating the capital plan for structures. Pontis and other agency-specific systems that support analysis of element or component-level conditions provide a strong basis for implementing the Interstate Asset Management Framework. NBIAS provides sufficient support for assessing current conditions and setting performance and budget targets for bridges. Spreadsheet analyses, preferably calibrated using a BMS or NBIAS, may be used to support setting performance and budget targets.

Safety Features and Facilities. IHS owners should collect inventory and condition data for all assets listed in Table 2.1, including safety features, facilities, and shoulders, sufficient for estimating the asset extent and the percent of the extent functioning as intended. A maintenance management system, which supports a maintenance quality-assurance approach for assessing current conditions and setting performance and budget targets by asset category, provides support for IHS asset management. Alternatively, an RSL approach can be used, particularly for discrete assets with known construction dates, such as facilities. The *Asset Management Data Collection Guide (13)* recommends specific data items to collect for selected asset types, including signs, pavement markings, and guardrails. Also, this guide recommends criteria for determining what data to collect as part of an asset management data collection and is a particularly valuable reference for determining what data to collect for assets classified here as safety features.

Mobility and Safety. IHS owners typically have basic data required for mobility and safety. The mobility-related data items required for the Interstate Asset Management Framework are collected for HPMS sample segments. IHS owners should collect HPMS sample data for their entire IHS. IHS owners already have access to counts of crashes and fatalities.

IHS owners should use HERS-ST to help set targets and predict future values for mobility and safety measures. Agency travel demand models, where available, can be used in conjunction with HERS-ST to more accurately assess current conditions and provide better estimates of future traffic.

Environment. For this area the primary challenge is in defining a set of environmental performance measures, as described in Chapter 5. At a minimum, IHS owners should document environmental goals and commitments for IHS assets, and track the degree to which they meet these commitments on an annual basis. The prototype Environmental Information Management System developed through NCHRP Project 25-23 (2) (*19*) can be used to support an agency's commitment tracking process.

Risk Assessment. The risk assessment approach described in Chapter 3 should be used to prioritize risk mitigation investments for IHS structures, at a minimum. Existing BMS do model performance risks, but do not consider needs related to potential system failures from scour, seismic retrofit, fracture critical bridges or other risks. Realistically, much of the analysis of risks of system failure must be handled outside of existing systems. DIETT or a multi-objective approach such as that developed by Caltrans and supported using AssetManager can be used to characterize risks to structures.

Additional Guidance. Agencies should integrate data from their management systems for setting performance and budget targets across asset and investment types. In performing this analysis, agencies should compare predicted performance across the full range of asset and investment types for multiple investment scenarios. AssetManager NT, other emerging COTS systems and/or agency-specific systems can be used to support this analysis.

Projects for implementing safety or capacity improvements should be evaluated using BCA.Net or comparable approaches. For major capacity expansion projects, ITS investments, or other candidate projects expected to have significant network effects, network models such as IDAS or STEAM should be used for candidate evaluation.

Where analytical tools that explicitly account for uncertainty in project costs, outcomes and other parameters are unavailable, sensitivity analysis should be used to test the analysis results for variation in key modeling assumptions. A summary of key assumptions and the sensitivity of the results to uncertainty should be prepared for each tool used for analysis.

4.5 Gap Assessment

The research team found the following gaps in the availability of data and tools for supporting the Interstate Asset Management Framework:

- Regarding other assets besides pavement and bridges, there is a very large gap between the data and tools needed to support asset management concepts and the reality on the ground. NCHRP Synthesis 371 painstakingly documents this issue for a selected set of assets. Stated simply, many IHS owners do not have ready access to inventory and condition data needed to describe their asset inventories or summarize even rudimentary measures of physical condition. The existence of this gap suggests the following with regard to an Interstate Asset Management Framework:
  - It lends credence to the concept that an agency should focus improving its asset management approach starting with the assets on its highest priority network. If there is value to be gained in or a case that needs to be made for improving business processes, it makes most sense to start with the IHS.
  - It points to the likelihood of challenges in implementing a new framework, even one that does focus solely on an agency's highest priority network. This issue has been duly noted in development of the implementation guidance in Chapter 6.
  - It makes the case that the Interstate Asset Management Framework cannot simultaneously be immediately applicable to all IHS assets *and* push the technical envelope for other assets besides pavement and bridges. To provide a framework that is first and foremost of immediate practical value, this report makes a distinction between "core" and "comprehensive" measures required for an Interstate Asset Management Framework in Chapter 5, and recommends use of a "percent functioning as intended" as a basic measure for characterizing other assets besides pavement and structures.
- Improvements to the HPMS, consistent with the planned improvements to this system, will provide better data for IHS assets. Specific improvements for enabling improved IHS asset management include treating all IHS sections as HPMS sample sections and supplementing the pavement measures in the existing HPMS with measures of rutting, cracking, and faulting.
- The RSL approach recommended for pavement analysis can be implemented using existing management systems. Unfortunately, the approach requires data and models that are not yet supported in FHWA systems such as HERS-ST. Some COTS pavement management systems can support an RSL approach if appropriately configured.
- Although there are a number of tools available for analyzing user-defined improvements, there are few tools for high-level investment analysis, particularly across asset and investment types. For instance, HERS-ST and HDM-4 were the only systems identified through the review that simulate generation of new highway capacity. AssetManager NT was the only system identified in the public domain for combining investment analysis results across asset and investment classes.
- The risk management approach described in Chapter 3 assumes that certain risks should be handled programmatically using management systems. Some risks are handled in such a fashion, but many are not. The review included examples of approaches to handling risk programmatically, particularly with regard to structures, but more work is needed to introduce these approaches in COTS systems.
- Few tools were identified that can be used to support analysis of risks of system failure in support of the approach described in Chapter 3, though many quantitative techniques do exist for performing risk assessment. Further

research is needed to develop tools and approaches for simplifying the process of prioritizing investments in risk mitigation.

- The AssetManager tools are valuable tools for supporting the Interstate Asset Management Framework, but realistically will require further enhancement to provide comprehensive support. AssetManager NT can be used to integrate analysis results for multiple asset and investment types, but can work with data from no more than four sources at a time. AssetManager PT is a valuable tool for project prioritization, but is implemented as a spreadsheet prototype and not integrated with AssetManager NT.

CHAPTER 5

Performance Management

This section describes the performance management approach recommended as part of the Interstate Asset Management Framework, and identifies core and comprehensive performance measures for managing IHS assets. In this study, "core" measures are performance measures that any IHS owner agency should, in theory, be capable of capturing and should appear in any Interstate Asset Management Plan. It is recommended that IHS owners collect the additional "comprehensive" measures described here, pending time and resource limitations.

Section 5.1 provides an overview of the role of performance measures in asset management. Section 5.2 summarizes the approach used to evaluate different potential measures for IHS asset management. Section 5.3 details the recommended core and comprehensive performance measures. Section 5.4 identifies the most significant gaps related to defining a set of performance measures for characterizing the IHS assets.

5.1 Overview

Performance measurement, defined as "the use of statistical evidence to determine progress toward specific defined organizational objectives . . . ," (*23*) is a cornerstone of transportation asset management. Performance management encompasses the development of a set of measures for characterizing the performance of an organization, setting specific targets or goals for those measures, and monitoring the organization's progress in meeting those goals.

In recent years, much attention in the transportation community has been paid to adapting performance management concepts originally developed in the private sector for use in improving transportation management. Defining performance measures is a key step in implementing an asset management approach. Once performance measures are defined for an organization, they help support asset management in three basic ways. First, performance measures can be used to quantify policy goals and objectives in a practical way. For example, Oregon DOT translates agency goals into specific performance measures in its annual performance progress report. Figure 5.1 provides an example for this report, depicting traffic fatalities per 100 million of vehicle miles traveled over time (2001 to 2006). The figure also shows agency targets set for this measure in support of the goal of improving travel safety in Oregon.

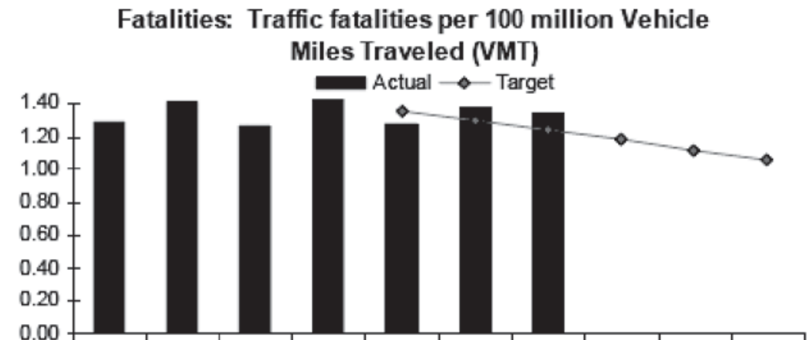
The second basic use of performance measures is to help evaluate different options in the resource allocation process, such as for determining how to prioritize different investments and/or comparing the impact of different funding levels. Figure 5.2 is an example from the pilot performed for the current study. For a sample interstate corridor, the figure shows predicted Pavement Quality Index (PQI) for different annual budget levels.

The third basic approach for using performance measures to support asset management is to use performance measures for monitoring progress to provide feedback on the effectiveness of a program, and/or provide information on trends over time. For example, Virginia DOT has established a web-based dashboard for tracking system conditions and performance. Figure 5.3 shows data on IHS pavement conditions from the dashboard application. The dashboard provides details on performance, safety, condition, and finance measures, as well as on customer satisfaction and project delivery. Measures are summarized at a statewide level and broken down by system, county, and district.

The motivations for establishing performance measures for asset management are well-understood. However, there are no standard measures defined for managing IHS assets. The remainder of this chapter describes the approach used to evaluate different performance measures for inclusion in the Interstate Asset Management Framework and presents a recommended set of core and comprehensive measures.

5.2 Evaluation Approach

Given the importance of performance measures to asset management, a critical activity undertaken as part of this study was to evaluate performance measures that can be used to



	00	01	02	03	04	05	06	07	08	09
Actual	1.29	1.41	1.26	1.46	1.28	1.38	1.34			
Target					1.36	1.30	1.24	1.18	1.12	1.06

Source: Oregon Department of Transportation (*24*).

Figure 5.1. Use of performance measures for quantifying goals.

characterize IHS assets, and on the basis of the evaluation, recommend a set of performance measures to include in the Interstate Asset Management Framework. A key resource in structuring and performing the evaluation was *NCHRP Report 551,* which details a review of existing practices related to performance management, and provides guidance for establishing a set of measures (*4*). Figure 2.4 provides a framework for establishing performance measures and targets for asset management. The approach to developing a set of performance measures for use in reporting IHS conditions in an Interstate Asset Management Plan has been adapted from this framework. As indicated in Figure 5.4, identifying

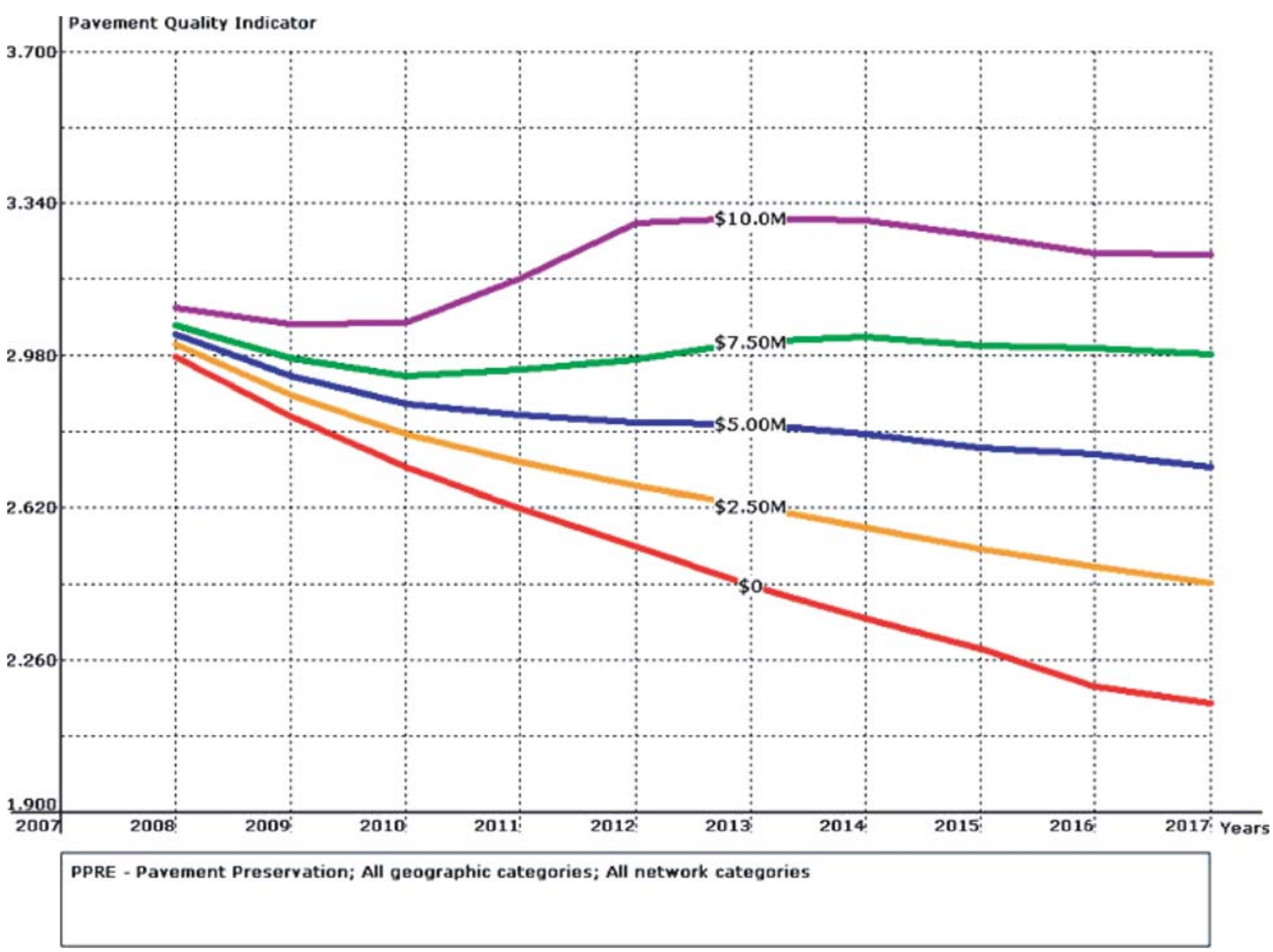
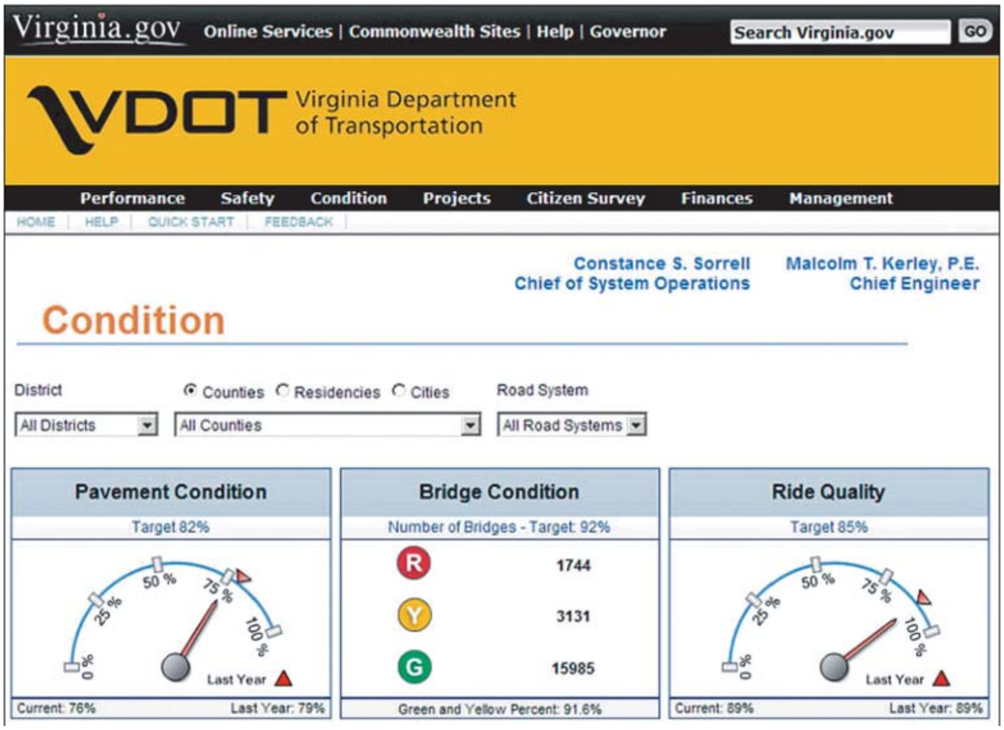


Figure 5.2. Use of performance measures for evaluating options.



Source: Virginia Department of Transportation (*25*).

Figure 5.3. Use of performance measures for tracking progress.

performance measures involves five basic steps. The following is a description of the activities performed for each of these.

Step 1—Review Existing Measures

A review of the performance measurement literature was performed, as detailed in Appendix A. The review started with the materials compiled by the research team previously and summarized in *NCHRP Report 551* (*4*). These materials were supplemented with more recent materials and examples of measures reported at a national level and/or measures of condition or performance that can be calculated specifically for the IHS.

Based on the review, a master list was compiled of existing IHS performance measures. The list included, but was not limited to:

- Measures listed in *Measuring Performance Among State DOTs* (*26*);
- Quality-of-service measures from the *Guide to Effective Freeway Performance Measurement* (*18*), including measures in the areas of Congestion, Reliability, Throughput, Customer Satisfaction, Safety, Ride Quality and Environment;
- Interstate measures included in the *FHWA C&P Report* (*27*);
- Highway-related measures listed in the *U.S. DOT Fiscal Year 2006 Performance and Accountability Report* (*28*); and
- Additional measures identified through the review.

Step 2—Assess Needs

The focus of this step was on defining how and why performance measures should be used for supporting the Interstate Asset Management Framework described in Chapter 2. Defining a set of performance measures is not an end in itself, but a means to support asset management using the approaches described in Section 5.1: quantifying policy goals and objectives; facilitating evaluation of options; and monitoring progress. In this step the research team considered what types of measures are needed for supporting asset management, and how well the existing measures compiled in Step 1 provide this support.

Five basic categories of measures were established for supporting the Interstate Asset Management Framework. These categories include:

- **Preservation**—Measures in this category characterize the physical condition of transportation assets;
- **Mobility**—This category describes how well the transportation network is performing its basic function of supporting transport, and includes measures of throughput and congestion;
- **Safety**—This category includes measures of crashes and fatalities, as well as other measures related to safety;
- **Environment**—Measures in this category characterize the environmental impact of the IHS, and the degree to which an IHS owner is meeting its environmental goals; and

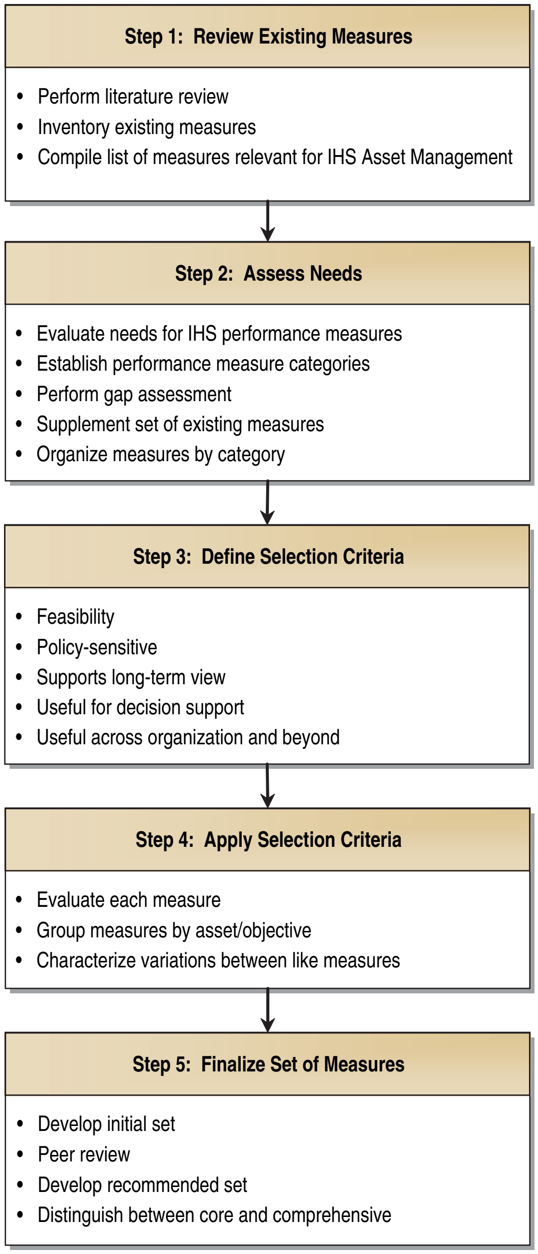


Figure 5.4. Performance measure evaluation approach.

- **Project Delivery**—Measures in this category describe how well an agency is delivering projects compared to its capital plan.

The existing measures identified in Step 1 were organized in the categories listed above. Next a gap analysis was performed to assess issues including:

- Do the existing measures address all of the assets on the IHS? As discussed in Chapter 4, large amounts of data are available for pavements and bridges relative to other assets. However, it is important that the framework address all IHS assets.
- Considering the underlying reasons for implementing asset management for IHS assets, are there applications for which performance measures may be needed, but for which no measures are identified?
- How well do the existing measures align with the available data described in Chapter 4? Note that the availability of data for calculating a measure, or lack thereof, is not in and of itself an indication of whether a measure is needed to support the Interstate Asset Management Framework. However, to the extent there are multiple measures that can be used to characterize a single asset or objective, emphasis was placed on measures that could be calculated given available data.
- To the extent there are issues in aligning measures and data, are there supplemental or alternative measures that can be more easily captured and/or that make better use of the available data?
- Are additional categories needed to adequately classify performance measures that may be needed to support asset management for the IHS? Can any of the categories be consolidated?

The result of this step was a supplemented list of performance measures, organized by category. Also, this step resulted in identification of a number of gaps in the existing set of performance measures. These are discussed further in Section 5.4.

Step 3—Define Selection Criteria

Next the research team established a set of criteria for evaluating performance measures to be included in the Interstate Asset Management Framework. Criteria used for this step were adapted from *NCHRP Report 551* and include:

- **Feasibility**—It should be feasible to collect data for this performance measure, and to quantify the performance measure for the IHS. Ideally, the measure can be calculated from Federally mandated data, or other data generally collected for IHS assets, as discussed in Chapter 4. If the data requirements extend beyond what is widely available for the IHS, this should be noted.
- **Policy-Sensitive**—It should be possible to relate the measure to an agency's stated policy objectives, and help quantify whether the outcome of a policy objective has been achieved. This criterion tends to favor outcome measures that reflect outcomes achieved, versus output measures that quantify the activities performed by an organization.
- **Supports Long-Term, Strategic View**—The measure should facilitate long-term tracking. Ideally, it should be possible to make forecasts of the measure over time to support analyses of lifecycle costs and benefits and to review past performance.

- **Useful for Decision Support—**The measure should provide information that helps support the decision-making process. It should be collected frequently enough and demonstrate changes clearly enough to reflect impacts of agency actions. Ideally, it should be possible to distinguish between changes in the measure resulting from actions under an agency's control and external drivers.
- **Useful Across the Organization and Beyond—**The measure should be easily understood and communicated within an organization and to external stakeholders. The measure should function as part of a family of measures that can be used to describe performance at different levels of aggregation (e.g., corridor, state, entire IHS system), different time horizons, and for different audiences.

Step 4—Apply Selection Criteria

In this step, criteria were applied to the set of measures compiled previously, including measures identified in Step 1 and additional measures for which a need was identified through the gap analysis performed in Step 2. The result of this step was an evaluation of each of the measures on the basis of the criteria described above.

After an initial attempt to classify individual measures for each criterion on a high/medium/low scale, the research team found that a more useful approach was to group like measures (e.g., by category and asset), and characterize the variation between members of the group descriptively. For instance, for bridge preservation measures, there are many possible measures of bridge condition, most derived from NBI and/or element-level data described in Chapter 4. Generally speaking, the detailed measures derived from the available bridge data that are most useful for decision support (e.g., element-level conditions) are least useful for communication across and outside an organization, and most likely to require additional data that may or may not be available consistently from one agency to another. Thus, these measures are best considered as a group, weighing the relative advantages and disadvantages of each of the alternative measures compared to the others.

Step 5—Finalize Set of Measures

The last step of the process was to finalize the set of performance measures recommended for the Interstate Asset Management Framework. The research team developed an initial set of recommendations that addressed all of the assets on the IHS and each of the categories identified previously. Where multiple measures were available for characterizing a given asset or objective, the research team relied upon the results of Step 4, supplemented with best practice examples, to pare down the list to keep it as short as possible while still providing comprehensive coverage.

Following development of the initial set of measures, a project workshop was held to review all aspects of the project. This workshop was held in Dallas, Texas in March 2008. Participants included representatives from FHWA, state DOTs, and the private sector, as well as the Project Panel. Based on comments received from workshop participants and panel members, the research team revised the initial set of performance measures and developed the recommended set presented in Section 5.3. Further, the research team distinguished between core measures that in theory any IHS owner should be capable of capturing and should appear in any Interstate Asset Management Plan and additional comprehensive measures. Ideally, every IHS owner would report the core measures described here, at a minimum, and plan in the future for collecting and reporting the full set of comprehensive measures.

5.3 Recommended Measures for IHS Asset Management

Table 5.1 details the core set of performance measures recommended for the Interstate Asset Management Framework. Performance measures are organized by category. For each category, the table lists the asset type, where applicable, as well as the measure type and measure. Table 5.2 lists additional, comprehensive measures.

Note that the measures are intended to characterize overall conditions of the portion of the IHS managed by a given organization, rather than a specific section or the overall transportation network. Additional detailed data are required in every category for making project-level and operational decisions, such as for determining appropriate treatments at the asset level. Additional high-level measures may be useful for evaluating the overall state of the transportation network. The following paragraphs discuss each category.

Preservation. This category includes measures of asset condition for each asset type. For pavements, two measures are recommended: structural adequacy and ride quality. PSR can be used to approximate structural adequacy. However, most agencies have established agency-specific measures that consider rutting, cracking, and faulting. Pending update of the HPMS, these agency-specific measures are preferable to PSR.

For characterizing bridge conditions, the percent of bridges classified as structurally deficient (SD) is recommended as the best overall measure available for supporting IHS asset management. Note that the determination of whether or not a bridge is functionally obsolete (FO) is not recommended as a measure of bridge condition, as this measure specifies whether the bridge is designed to current functional standards rather than characterizing its physical condition. Thus, a bridge could be classified as FO but not have any preservation needs.

The recommended pavement and bridge measures are tracked and can be predicted using agency pavement and

Table 5.1. Recommended core performance measures for the Interstate Asset Management Framework.

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

bridge management systems, or alternatively using HERS-ST and NBIAS developed by FHWA. It is important to note that existing pavement and bridge management systems consider multiple objectives and constraints in developing work recommendations, and use additional measures and criteria for recommending work besides the measures listed in Table 5.1. The recommended pavement and bridge measures are intended to provide an overall indication of asset conditions, and not intended for use as a tool for prioritizing work or a replacement for pavement and bridge management systems.

For other assets beside pavements and bridges, this report recommends calculation of the percent of the asset quantity "functioning as intended" as the measure that can best support the Interstate Asset Management Framework.

An important issue in considering the measures in this category is that of what measures should be considered core versus comprehensive. In reality, all assets on the IHS are of great importance. However, the fact that all assets are important does not necessarily mean that it is vital for an IHS owner to capture and report performance measures for all IHS assets in the near term as part of its Interstate Asset Management Plan, possibly diverting resources from other important activities to do so. Further, it is assumed that IHS owners do now and will continue to address public safety issues (e.g., pending failure of a structure) even in the absence of an Interstate Asset Management Plan. Thus, the consideration of what assets are core versus comprehensive was based primarily on consideration of asset extent and degree to which data are available.

Mobility. This report recommends using travel time index (the ratio of actual travel rate to the ideal rate) and average delay as the best overall measures of mobility. Both measures can be calculated from readily available HPMS data and predicted using HERS-ST, and can be reported by rural/urban roads, by corridor, and/or separately for autos and trucks. Winter maintenance is included here as a comprehensive measure in the mobility category, with a measure of average time to bare pavement following a snow event. In cold weather, states' winter maintenance is a core issue, but is generally not managed by system.

Safety. Crash and fatality rates are recommended as the best overall measures of safety outcomes. Typically these are reported in terms of total numbers of crashes and fatalities, and the rate reported as the number per 100 million VMT.

Environment. Rather than recommending a specific set of measures as in the other categories, this report recommends a report card approach for the Environment category, whereby an IHS owner establishes a set of environmental milestones, and reports whether they are achieving them on a pass/fail basis. These milestones may include any of the examples listed above, and should include an indication of whether or not the IHS owner is satisfying its environmental commitments.

Other. Cost control and schedule adherence are recommended as comprehensive measures of project delivery. Reporting delivery measures is becoming increasingly

Table 5.2. Additional recommended comprehensive performance measures for the Interstate Asset Management Framework.

Category	Asset Type	Measure Type	Measure
Preservation	Shoulders	Asset Performance	Percent functioning as intended
	Tunnels	Asset Performance	Percent functioning as intended
	Culverts/drainage structures	Asset Performance	Percent functioning as intended
	Noise barrier walls	Asset Performance	Percent functioning as intended
	Retaining walls	Asset Performance	Percent functioning as intended
	Overhead sign structures	Asset Performance	Percent functioning as intended
	High mast light poles	Asset Performance	Percent functioning as intended
	Lighting	Asset Performance	Percent functioning as intended
	Median barriers	Asset Performance	Percent functioning as intended
	Impact attenuators	Asset Performance	Percent functioning as intended
	Surveillance and monitoring equipment	Asset Performance	Percent functioning as intended
	Signal and control equipment	Asset Performance	Percent functioning as intended
	Rest areas	Asset Performance	Percent functioning as intended
	Toll plazas	Asset Performance	Percent functioning as intended
	Weigh stations	Asset Performance	Percent functioning as intended
	Maintenance depots	Asset Performance	Percent functioning as intended
	Pump houses	Asset Performance	Percent functioning as intended
	Communication facilities	Asset Performance	Percent functioning as intended
Mobility		Winter Maintenance	Average time to restore pavement surface
Delivery		Schedule Adherence	Percentage of total projects finished on or before original scheduled contract completion date
		Cost Control	Annual ratio of actual construction cost to bid amount

common, but is typically done on an overall basis rather than by system. It is not strictly required that consideration of project delivery be handled in an Interstate Asset Management Plan if an IHS owner handles this issue separately.

No measures are recommended regarding security or social impacts, as it is generally not feasible to isolate existing measures to the IHS. However, security and social impacts as well as measures of economic impact may be very relevant in characterizing the overall importance of a transportation system and in justifying investments, particularly large investments in additional capacity.

Customer satisfaction measures are not included under the assumption that the public is likely to assess the level of satisfaction with the transportation system as a whole, rather than the IHS specifically.

5.4 Gap Assessment

The following are the most significant gaps related to defining a set of performance measures for characterizing IHS assets (or transportation assets in general):

- There is no national standard for accurately characterizing structural adequacy of pavement. In the absence of such a measure, it is recommended that agencies use an agency-specific index instead or PSR. PSR is reported in the HPMS, but does not consider a full range of pavement distresses. The expected update to the HPMS will add additional measures of pavement condition to the HPMS, and should facilitate standardization of an overall measure of structural adequacy.

- Average IRI is recommended as a measure of ride quality. This recommendation is based on the fact that IRI is available through HPMS data and is the most common measure available for characterizing ride quality. However, there are significant state-to-state differences in measuring IRI and issues with the measure that complicate use of IRI as a standard.
- There is a need for definitions of a new, standard measures of bridge condition and functional adequacy. The existing measures defined by FHWA include SD/FO classification and Sufficiency Rating (SR). Of these, SD classification best measures condition, but is a binary measure (a bridge is or is not SD). Ideally, a numeric index would be defined that allows for specifying different levels of urgency for addressing bridge needs. Also, ideally this measure would be based on more objective measures of bridge condition than possible using the current set of bridge condition ratings. FO classification measures functional adequacy, but is also a binary measure, and a number of agencies do not report this measure when discussing bridge conditions either because they feel it misstates the level of need and/or needs to be updated to better reflect current functional standards. SR is problematic as it combines structural and functional considerations, complicating interpretation of the measure.

  Various efforts have been undertaken to define alternative bridge measures, but these have thus far failed to result in widespread adoption of new, standardized measures. Most notably, as described in Chapter 4, most agencies now collect element-level condition data, and can use this data to calculate the Health Index developed by California DOT. The basic conundrum in recent efforts to develop new bridge measures is that without improvements in data collection it is difficult to formulate measures that offer any real improvement upon the existing measures, and changes in data collection needed to yield new measures require widespread consensus if they are to be standardized between states. National leadership is needed to break this logjam.
- There is a need for standard measures of condition for other assets beside pavement and bridges. Research is ongoing to develop level of service standards for asset management as part of NCHRP Project 20-74(A). In the absence of any standard measures for preservation of other assets, percent functioning as intended is recommended here. The major shortcoming of this measure is that lacking national standards, each IHS owner must define what it means for a given asset to be classified as functioning as intended. If this measure is to be used, further work is needed to define what it means for different asset types.
- New measures are needed for characterizing environmental performance. There are few environmental measures that can be both localized to the IHS and used to support the asset management process. Also, there is little consistency from one IHS owner to another concerning how environmental data are collected and reported. For instance, measures of emissions are often used for characterizing environmental impact (e.g., pounds of carbon monoxide and/or other pollutants) and these measures can be calculated using systems such as HERS. However, it is not meaningful to report the measures specifically for the IHS in the absence of corresponding data for other systems. Other measures of environmental performance include counts of environmental features that are constructed or maintained (e.g., wildlife crossings, culverts/fish passages and other features), measures of wetland reclamation (e.g., the ratio of wetlands reclaimed to that affected), and measures of how well an agency is meeting its environmental commitments. These measures are meaningful when localized to the IHS, but there is no standardization in how they are reported between agencies.
- There are no standards for characterizing project delivery. AASHTO's report on comparative performance measures between state DOTs (*26*) discusses this gap and identifies the need for one or more standardized delivery measures to facilitate comparative measurements.

CHAPTER 6

Implementation Guidance

6.1 Implementing the Interstate Asset Management Framework

The objective of this research effort is to "develop a practical framework for applying asset management principles and practices to managing Interstate Highway System (IHS) investments." The question of whether the uniquely important attributes of the IHS warrant a differentiated asset management framework will be proven one way or another by the number of IHS owners and key stakeholders who embrace the concepts and implement the principles and practices recommended in this report. This section attempts to address the following issues related to implementation:

- Why implement Interstate Asset Management?
- What are the primary motivating factors?
- What are the primary focus areas?
- Who are the stakeholders—what are the opportunities for collaboration?
- Where are the champions?

Implementation—Yea or Nay?

An initial question an IHS owner must answer in considering how to implement the Interstate Asset Management Framework is whether to implement it at all. To understand how best to present the case for an Interstate Asset Management Framework, it can be instructive to first address those who are *unlikely* to immediately implement such a concept. These "nonimplementers" fall into two simple and distinct categories: 1) those who accept and have implemented transportation asset management but fail to perceive the need for a distinct approach tailored to the IHS; and 2) those who are generally disinterested in implementing transportation asset management practices beyond gathering basic inventory and condition information.

The first group of nonimplementers would be those who perceive themselves to be practitioners of transportation asset management, but who fail to see the advantages of a separate framework for the IHS. An agency in this category may have a well-considered approach to asset management, but simply not have a set of assets or organizational structure that lends itself to making distinctions based on IHS designation. These agencies will presumably continue to apply a common asset management framework to interstate and noninterstate facilities alike.

On the surface it may appear that such agencies in the second group, by definition, would not implement a differentiated asset management approach for the IHS. On the other hand, it is conceivable that exposure to the unique framework of asset management for the IHS could stimulate new interest and potentially serve to transform nonasset management practitioners into newfound supporters. It is certainly plausible that some nonpractitioners who appreciate the unique importance of the IHS system and the value of approaching such IHS issues as operational management and capital investment needs via a systemic and structured asset management approach may become newly motivated.

This leaves a third group of agencies consisting of those who *will* perceive that the benefits of an Interstate Asset Management Framework outweigh the costs and challenges and that a differentiated approach for the IHS should be implemented. In most cases these will be IHS "owner" agencies such as state DOTs and toll authorities. But it is likely that other stakeholders also will play a role in deciding whether and how to implement an Interstate Asset Management Framework: stakeholders such as MPOs, emergency management agencies, law enforcement officials, military organizations such as the National Guard or the Department of Defense agency overseeing the national Strategic Highway Network (STRAHNET), and national organizations with a surface transportation focus such as the American Trucking Association, the American Automobile Association, the American Road and Transportation Builders Association, the Highway Users Alliance and the U.S. Department of Transportation.

Implementation—Motivating Factors

There are a number of factors that might drive an agency toward implementing an IHS-based asset management approach. While in reality a combination of factors likely will be at play within any particular agency, it is instructive to look at them individually. Implementation efforts may be:

- Culture driven;
- Leadership driven;
- Private sector driven;
- Stakeholder driven; or
- Event driven.

Culture Driven

Some agencies are more likely to move toward implementation because the underlying philosophy as well as the specific practices of transportation asset management have become integral to the way they are led, managed, and function day to day, from headquarters to field units and across functional areas. They are very likely to be those organizations currently practicing and gaining significant benefits from applying transportation asset management principles. They are led and managed by leaders and managers who would find it inconceivable that critically important decisions about allocating and managing scarce resources could be made any other way. They are organizations populated with staff whose buy-in is so ingrained that changes in leadership and management can occur without jeopardizing the continuity of asset management practices. The widespread application of transportation asset management in such organizations implies that they would tend to be both open and receptive to new and better practices, and therefore will be open to the notion that the IHS ought to be differentiated on the basis of its unique significance.

Implementation actions motivated by the culture of an organization are most likely to be successful and sustainable since they are more likely to occur within multiple functions and at multiple levels, engaging a broad array of internal stakeholders who will become vested in making it work. The leadership of such organizations can be expected to play a facilitative and supportive role, having grasped the benefits of having at their fingertips a stronger foundation of factual information, a richer array of policy choices, and an enhanced state of readiness to cope with and manage risks that can disrupt the operation of the premier highway network for which they are responsible—the IHS.

Leadership Driven

Certainly many, if not most, significant changes affecting organizations are driven or strongly influenced by leadership factors. The question of whether to embrace a differentiated asset management approach for IHS assets should find resonance with transportation agency leaders who come to recognize that among the greatest risks they face are the potentially dire events that might cause major disruptions in service along the most important transportation routes on their system. Such emergencies can and do occur—fierce storms, fiery crashes, hazardous spills, damaging earthquakes, structural failures—and examples abound that demonstrate how they are handled by the agency will have a profound and lasting effect on the reputation of that agency and the tenure of its leadership. Invariably in the aftermath of catastrophic events questions are raised about whether they might have been anticipated in some way and managed more effectively using risk assessment practices and advanced contingency planning. This is why there is a good chance that many transportation leaders will respond favorably to the notion that the IHS and key NHS routes deserve special attention—not to the exclusion of other systems but as an overlay that affords a heightened level of asset management attention to their most critical transportation arteries.

In contrast with culturally driven processes, leadership-driven implementation strategies are more likely to focus on specific aspects of IHS asset management, resulting from the perceptions and priorities of individual leaders. For obvious reasons, this motivation is the most susceptible to changes in the leadership of an organization.

Private Sector Driven

A number of states (Virginia and Florida foremost among them) have awarded performance-based lump sum contracts for various combinations of maintenance, repair, and operational activities along IHS routes. Such contracts typically involve a minimum of five years to amortize investments in equipment and facilities that are often required. In addition, some owners (such as the City of Chicago, and the States of Indiana and Texas) have awarded long-term concessions (of anywhere from 50 to nearly 100 years) to private companies who will manage and collect tolls along IHS and similarly significant NHS corridors. Both approaches involve the establishment of a comprehensive suite of specified performance standards to provide an objective method to guide and monitor the contractor, and to facilitate the transfer of various, predetermined risks (from pavement distress to snow removal) to a private sector entity.

Note that worldwide, the most pervasive application of risk-based asset management principles and practices to interstate-type highway systems occurs among private sector managers and operators governed by performance-based fixed-price contracts and driven by financial incentives to minimize costs and maximize profitability. The process of pricing such contracts is built upon risk/reward models, and so risk assessment and risk management are ingrained in their processes (a unique example is the mitigation of the difficult-to-predict risks of ice and snow through the purchase of specialized insurance packages.) It is testimony to the effectiveness of asset management for Interstate-type highways to observe how investment decisions by the private sector are driven by their finely tuned management systems and models that track current condition and rates of asset deterioration and that indicate on the basis of traffic forecasts and other information optimal schedules for preventive maintenance and repair activities.

The same tools are available to public agencies seeking to optimize the efficient and effective use of their most important highway assets.

Stakeholder Driven

While owning agencies are the most likely to lead the implementation of an IHS asset management approach, leaders and staff of these agencies need little to remind them that the most significant highway routes on their network are also the most significant routes in a local transportation context as well. Many regional and local entities, such as MPOs, local governments, and other state and Federal agencies, are likely to have strong, vested interest in the continuing operational integrity of the IHS and other key NHS routes considered part of an agency's "highest priority network." The same will be true of the private sector, including major companies and regional industries that ship goods as well as individual citizens whose ability to earn a living and the very quality of their lives depend upon continuous access to a viable system of interstate and other major highways.

It is not uncommon for incident management programs and traffic management centers serving major IHS routes in metropolitan areas to emanate from, or even be sponsored by and managed with, local resources. Certainly the ability of emergency response entities—police, fire, ambulance, environmental hazard teams, and, under certain circumstances, the military to use the IHS to reach the locations requiring their urgent attention, including locations on the system itself—earn them standing as significant stakeholders whose interests may provide a key impetus for establishing an Interstate Asset Management Framework.

Event Driven

This is the least desirable but not necessarily the most uncommon driver of implementing changes such as a risk-based Interstate Asset Management Framework. In the aftermath of a major disruption, much attention is focused on whether and how it could have been avoided, and what measures could have been taken to reduce the magnitude and duration of the adverse impacts. There is nothing like a catastrophic event to drive change, but the inescapable question is that if certain actions make sense to reduce the likelihood and impacts of a recurrence, then inevitably the question will be raised about why weren't these same actions implemented earlier. IHS owners and key stakeholders may wish to ponder in advance of such catastrophic events: 1) what the risks of worst case scenarios may be in terms of major disruption in service; and 2) what actions in the aftermath are they likely to be implementing that would have made just as much, if not more, sense to implement as a preventive or mitigating measure before an event ever occurred.

6.2 Primary Focus of Implementation

Just as the motivation for implementing a differentiated IHS asset management approach will vary, so will there be variations in the primary areas of interest. An Interstate Asset Management Framework may focus on areas that vary according to function (preservation, mobility, safety, and environment), or level within the organization (policy level issues, program and project prioritization issues, management and operational issues), or any combination of these. For example, an IHS-owning transportation agency may focus on system preservation at the program and project levels while focusing on levels of service and mobility issues at the policy level.

Policy and Strategic Focus

An Interstate Asset Management Framework can focus on a variety of policy level and strategically important issues confronting agency and political decision makers, including (as examples):

- Network coverage—are key geographic regions and major transportation corridors adequately served with IHS access and capacity?
- Is there sufficient network resilience and redundancy to facilitate the management of potential major disruptions?
- Should the investment in people and processes be made to identify potentially significant risks to IHS highways and to manage those risks by formulating strategies aimed at reducing the likelihood of their occurring and mitigating impacts if they do occur?
- Is there an adequate "operations" mentality that drives the agency's inclination and ability to deal with both recurring congestion and nonrecurring incidents?
- Are relationships, resources, and training in place to ensure adequate response to various contingencies in various locations along the IHS and comparable NHS corridors?

- How adequate are current investment levels and strategies, and are the unique requirements inherent in the IHS being addressed with current resource allocation processes, including transportation improvement plans, annual budgets, and other funding structures and mechanisms?
- To what extent should a differentiated Interstate Asset Management Framework extend beyond policy considerations and into program and project level priority setting as well as operational management?

Program and Project Prioritization Focus

The primary focus of an Interstate Asset Management Framework may address issues relating to IHS programs and project prioritization, including:

- Should separate funding be allocated for IHS capital and operating budgets as opposed to having IHS projects compete with projects on lower order systems?
- Should performance targets for IHS be differentiated from non-IHS facilities?
- Should performance targets be differentiated *among* IHS routes based upon their relative role or importance (functional criticality) in serving local area, state-level, or national needs?
- Should national priorities that may not represent state or local priorities be addressed and, if so, how?
- Is there a need for more and better data for IHS assets than are currently available to determine performance targets and levels?

Operational Management Focus

There is a rapidly growing recognition among highway agencies and stakeholders of the need to pay significant attention to the allocation of resources for operational management (beyond capital investments and physical maintenance), particularly on higher order systems such as the IHS. After a century or more in which most state highway agencies have focused their attention and resources on capital investments and maintenance of the roadway networks under their jurisdiction, there is a clear trend emerging in the direction of real-time operational management, involving:

- Surveillance of traffic conditions;
- Rapid response and clearing of incidents;
- Traveler's information;
- Electronic toll collection;
- Ramp metering;
- Preclearance of trucks; and
- Work zone safety.

While some agencies have extended such operational services to surface streets, the overwhelming emphasis has been on controlled access highways such as the IHS. Key issues to address with an IHS asset management system include the level of investment in operations versus capital improvements and maintenance, the distribution of investments among operational service categories, and the benefits gained in terms of improved reliability and safety.

Work Category Focus

An Interstate Asset Management Framework may emphasize different work categories (such as preservation, mobility, safety, environment) depending upon the unique needs and motivations of the agency. As the premier highway network, IHS corridors may be confronted by a variety of risks in each of these areas that can threaten their viability in meeting critically important transportation needs in ways different from the rest of the highway network, including:

- **Preservation—**Examples include structural adequacy of bridges and pavements to handle the higher magnitude and frequency of loads typically carried on interstate highways, as well as visibility and reflectivity of pavements and markings under varying weather and lighting conditions essential to routes carrying significant levels of nonlocal traffic, and the physical condition of rest area facilities important to long distance through corridors.
- **Mobility—**The IHS was conceived and completed to serve mobility goals on a national as well as a regional scale. Mobility performance measures include levels of service, travel time, and operational dependability during recurring peak period loadings as well as for nonrecurring incidents that occur at any time, such as crashes, hazardous material spills, and special events.
- **Safety—**While the IHS and similarly designed and built highways on the NHS are clearly the safest, especially when compared with surface arterial streets and highways lacking controlled access, the combination of high speed and variable speeds, along with the mix of trucks, buses, passenger cars, and motorcycles affects not only the frequency but the severity of crashes as well. So while risks may be lower, the potential adverse consequences can be greater on these high order systems.
- **Environment—**IHS routes are typically the largest in scale and can have the most severe impacts on the natural, built and cultural environments when it comes to noise, wildlife, vegetation, water quality and quantity, communities, open spaces, and historic resources. Environmental issues are often beyond the normal sphere of transportation asset management, but particularly in the case of an IHS-oriented framework, participants in this research project felt strongly

that they are an important component in view of the size of IHS facilities and the various adverse impacts to the natural, social, and built environments that can occur.

There are a variety of potential areas of focus that may provide key reasons for considering the implementation of a differentiated asset management framework for the IHS.

6.3 Leadership Roles and Implementation Planning

The underlying motivations for implementing an Interstate Asset Management Framework as well as the primary areas on which to focus will have a significant bearing upon the leadership roles that are taken. At the same time, whether and how an asset management framework for the IHS is implemented within a particular organizational entity both influences and is influenced by how that responsibility is parceled out in terms of leadership roles and responsibilities.

Lead Office. Experience with state DOTs and their implementation of transportation asset management principles and practices reflects a wide variation in roles and responsibilities, ranging geographically from headquarters to field operations as well as functionally from planning and design to materials and maintenance. Often such responsibilities vary by asset class. For example, it is quite common for a centralized structural division (with design responsibilities for new and remedial design) to play the lead role for bridge management systems while a decentralized network of materials or maintenance offices takes the lead for asset management activities involving pavements. In some DOTs, as well as within the AASHTO committee structure, the focus of asset management is strongly influenced by resource allocation policy level issues, and asset management is led by the planning function. There is clearly no single set way. It is essential in implementing an Interstate Asset Management Framework to take into account the unique organizational framework of each agency, preferences among managers and staffs, and the actual day-to-day practices that in a de facto way define relationships, roles, and responsibilities.

Integration. For entities that already practice transportation asset management and have decided to differentiate in some manner an Interstate Asset Management Framework, they can integrate the framework as a separable yet adjunct set of activities within the overall asset management framework or further differentiate by assigning leadership and management responsibilities for the Interstate Asset Management Framework to separate organizational units or to separate individuals. This implementation decision is fraught with "shades of gray." Depending upon the way it is done and the people involved (people and personalities are inevitable and unavoidable factors), the decision to differentiate IHS asset management may ultimately succeed or fail. Most significantly, the degree of integration among transportation asset management activities should be the result of conscious decisions and strategies that work best for the agency.

Champions and Communities of Practice. What seems to be universal, at least in the early stages of implementing an asset management framework, is the need for a "champion." Typically, this champion can be anyone with sufficient interest and influence—from the front office to the front lines—to make it happen. A champion may be designated by someone in authority or may simply emerge from among members of affected groups. In any case, a champion is one who does not rest until the mission is accomplished.

Possible champions may include:

- Leader of the organization;
- Functional or geographic managers;
- First line supervisors; and
- Key technical or policy level staff.

The champion of implementing an Interstate Asset Management Framework, which in one way or another will stand apart from other transportation asset management activities, will bear the burden of prevailing in the likely deliberations and debates about why such a differentiated approach is needed at all. The arguments about the unique significance of the IHS, the benefits (and burdens) of a risk-based approach, the need for mitigation strategies and contingency plans, the strong interest of outside stakeholders—most if not all of these arguments are likely to be relevant to the champion.

The chances for a successful implementation of any change are immeasurably improved when a lone champion coalesces with others who buy in and support the ideas, and thereby form a community of practice—a group of champions and supporters whose common commitment is to the successful implementation of the proposed change. The strongest communities of practice are cross cutting, spanning the full range of relevant functions and hierarchies across an organization.

Implementation Plan. Implementing an Interstate Asset Management Framework, like any deployment of a new or modified way of doing business, requires a systematic plan to clearly define the objectives, formulate the change process, establish a schedule and responsibilities, identify and secure resources, and measure progress. Ideally such a plan would be developed not only by internal lead agency participants but by involving outside stakeholders who can lend support to the effort and to the utilization of the results. Assembling an implementation planning team would be an invaluable step in the process.

Stakeholders and Collaboration

Under almost any circumstance the owner of an IHS route or network (state DOT, state or regional toll authority, or private sector lessee or concessionaire) will be involved in the core data components of an asset management system involving inventory and condition information of the primary asset categories: pavements and structures. The use of this data to influence policy, program, and project decision making varies considerably however. Even more variable is the role of nonowner stakeholders in applying asset management principles to transportation facilities under the ownership and control of others. Yet, nonowner stakeholders may well have a level of interest in IHS facilities comparable to owner-operators by virtue of how critical the IHS is to their own underlying core missions.

The opportunity for state DOTs and other owner/operators of IHS assets to engage stakeholders as partners can be an appealing characteristic of an Interstate Asset Management Framework if it is developed with collaboration and consensus building in mind.

Federal. The IHS is a national resource. It was funded 90 percent by the Federal government, but while the Federal government is charged with overseeing maintenance to ensure that the national investment in the IHS is preserved, as a practical matter there is little or no decision-making authority at the Federal level in the day-to-day management of IHS assets. Yet clearly the criticality of the IHS to the nation's well being is if anything stronger than when the system was first conceived. FHWA is charged with reporting biennially to Congress on the condition, performance and funding needs of the nation's Federally funded highways and bridges, of which the IHS is the most significant. FHWA is therefore a key stakeholder in the availability of inventory and condition information which it collects through the efforts of the state DOT.

Note that whether the Federal role should involve more than information gathering and reporting is a subject of some debate. But even in its most limited role the Federal government is clearly an important stakeholder of an IHS asset management approach.

AASHTO. It may be more likely to achieve implementation of an Interstate Asset Management Framework by multiple states on a national scale by working through a peer process facilitated by AASHTO's Subcommittee on Asset Management than by way of Federal direction. AASHTO's policy-making structure, in its deliberations on future Federal authorizing legislation, seems to be moving toward the recognition that the time has come for AASHTO itself to propose nationally consistent, outcome driven, accountability measures to which the DOTs would agree up front as offering fair and reasonable performance assessments. The sense among an increasing number of DOTs is that a surface transportation program legislative reform agenda holding states accountable for how Federal funds are spent, coupled with the recognized need to better define the Federal interest in transportation, is inevitable and will lead to a core set of common measures. DOTs believe that by working through AASHTO, they would be better served by developing such proposals themselves rather than having them imposed by Congress or the U.S. DOT as potentially unfunded mandates. The IHS, with its critically important national role, represents one of the strongest candidates for the near term implementation of such national performance measures. At the same time, it is clear from deliberations among AASHTO members that the DOTs feel very strongly about how such measurement systems may be used in terms of setting appropriate targets and evaluating performance. The clear consensus is that they must be customized for, and left to, individual state circumstances to account for the substantial variation in every significant aspect, from soils to weather conditions, from topography to traffic characteristics, from conditions and needs to financial capacity. Implementing an Interstate Asset Management Framework on a state-by-state basis, with AASHTO providing a coordination mechanism, seems like a suitable way to advance towards a performance-based, outcome-driven program structure.

MPOs. MPOs are charged under Federal statute with long range planning and short range capital program development for over 400 metropolitan areas in the United States. Some MPOs have areawide financial, operational, and governance functions that go well beyond the core set of Federally mandated activities (the Metropolitan Transportation Commission in the San Francisco Bay Area, with its responsibilities for financing and operating programs, is among the best examples). What this means is that a number of MPOs are positioned as partners with state DOTs, toll authorities, and private sector operators in terms of their ongoing interest in activities affecting resource allocation decisions. The need for mutual trust in such partnership arrangements can be best served with full and open access among all partners to a common set of information as well as tools made available to analyze and apply such information to decision making. An Interstate Asset Management Framework could serve as an excellent way to build, test, and sustain this partnership arrangement.

Local Government. Since the IHS invariably serves as not only the nation's and individual states' most important highway network but serves similarly in terms of its significance across metropolitan regions and often within individual counties and municipalities, an implicit choice among "owners" and local authorities is whether or not to initiate a collegial, outreach approach to the management of IHS assets. This kind of collaboration must be forged on a case-by-case basis. In some cases (such as Wisconsin and Michigan) county governments are responsible for highway maintenance, including interstate highways under contract with the state DOTs, and share an operational need for asset management information. (Michigan is unique in its statutory requirement that local governments implement an asset management approach to managing all streets and highways in the state.)

Law Enforcement and Emergency Response Organizations. In the vast majority of cases, responsibility for law enforcement, environmentally hazardous spills, fire, crash investigations, emergency evacuations, and other similar man-made or natural emergencies lies with organizations other than the highway agency. The importance of addressing the needs of these organizations in terms of both prevention as well as emergency response is self evident. The process of addressing such needs in an objective and systematic way can effectively be incorporated into an Interstate Asset Management Framework, particularly if the process is carried out in a collaborative way.

Regional, Statewide, and Multistate Forums. With the risks, opportunities, and decisions on resource allocation and operational management of interstate highways invariably affecting multiple stakeholders, consideration ought to be given to convening a meeting of stakeholders, either on a periodic or as needed basis. Such forums may occur in a variety of ways, from summit meetings among principals to consider policy level issues to operational managers addressing real time traffic management and emergency response. Within a state such forums might be organized on a regional basis—within metropolitan or rural areas, or on a statewide basis. Many states sponsor statewide transportation conferences, which might also provide a venue for initiating regional or statewide forums.

On a multistate basis, IHS asset management forums might be organized around specific major interstate corridors. In fact, a number of such multistate corridors have coalesced around the country (I-95, I-15, I-10, and others) to address real-time operational issues as well as long-term economic goals centered on the movement of freight. Such voluntary corridor coalitions are already addressing asset management issues involving potential major disruptions in service as well as the investment needs associated with heavy growth in freight movement. An approach that involves formulating risk-based assessments and strategies along multistate interstate corridors would be a natural adjunct to activities already underway or likely to be initiated in the foreseeable future along such corridors.

An Implementation Reference List

A quick and relatively painless way to develop an IHS asset management implementation strategy customized to each application (as well as a way of assessing and validating earlier decisions to implement an Interstate Asset Management Framework) is to utilize an implementation reference list such as the one provided below:

1. Implementation: Yea or Nay? (Whether to Implement):
   - Currently use asset management tools to establish performance goals investment decisions, guide investment decisions, and monitor performance?
   - Have experience with and have benefited from risk management methodologies?
   - Recognize potential benefits of differentiating the IHS from other highways in performing asset management?
2. Motivating Factors (Why Implement):
   - Culture Driven?
   - Leadership Driven?
   - Private Sector Driven?
   - Stakeholder Driven?
   - Event Driven?
   - Other Factors?
3. Focus Areas (What to Implement):
   - Policy & Strategic?
   - Program & Project Priorities?
   - Operational Management?
   - Functional Categories?
   - Other Focus Areas?
4. Leadership and Implementation Planning (How to Implement):
   - Lead Office?
   - Integration?
   - Champions & Communities of Practice?
   - Implementation Plan?
   - Objectives
   - Process
   - Responsibilities
   - Schedule
   - Resources
   - Progress
5. Stakeholders and Collaboration (Buy-in for Implementation):
   - Federal?
   - AASHTO?
   - MPOs?
   - Local Government?
   - Law Enforcement and Emergency Response?
   - Regional, Statewide, and Multistate Forum?

6.4 Benefits of Implementation

At the March 13, 2008 workshop conducted as part of this research effort, the participants conducted a wide-ranging discussion of the key benefits and challenges that a state DOT would likely encounter in establishing an asset management program for its IHS. (In reviewing these benefits, and also challenges in the following section, it is apparent that a majority of the items relate to asset management generally, rather than the specific benefits and challenges associated with an Interstate Asset Management Framework. However the full range of topics discussed at the workshop is presented here.) The following benefits were identified by the group (the consultant team has provided a brief description of each.)

General

- **Right Thing To Do—**For some agencies the underlying principles and specific practices of asset management have become integral to the way the organization is led and managed and the way it functions day-to-day, from the headquarters to the field and across functional areas.
- **Defining Roles and Responsibilities for a Sustainable Stewardship Approach—**Transportation agencies are increasingly expected to conduct their activities in a manner that supports broader societal goals to sustain and improve the environment. Agencies are accepting these broader responsibilities and asset management provides a framework in a systematic, measurable manner.
- **Initiate Asset Management Elsewhere—**An Interstate Asset Management Framework can serve as a pilot to test principles, policies, and procedures as an initial step toward application to the entire network.

Internal Procedures

- **Defined Core Performance Measures—**Effective asset management requires organizations to identify what their core performance measures should be and then focus upon the achievement of those measures to accomplish the organization's mission. This would be particularly beneficial for the IHS.
- **Makes Use of Data and Identifies Data Limitations—**Many agencies collect a great deal of condition and performance data that are not actually applied to any practical purpose. Effective asset management will put these data to work and foster a greater understanding of the data's strengths and limitations.
- **Defensible Prioritization Approach—**Effective asset management facilitates the prioritization of investments based upon systematic data-driven analysis rather than anecdotes.
- **Comprehensive Evaluation, including Improved Economic Analysis—**Properly conducted, this systematic analysis extends beyond traditional measures of asset condition to include a broader range of considerations, including an economic evaluation of costs and benefits. This is particularly important to the highest order network such as the IHS.
- **Strengthen Predictive Performance and Modeling Capability—**Bridge and pavement management systems typically include predictive modules that permit agencies to model the effects of different levels and types of investments on asset condition. Focusing on the IHS where the data are often the most reliable and complete will ultimately have broader benefits to the entire highway network.
- **Rational Risk Approach—**A quantitative approach to characterizing risks of system failure and development of risk mitigation strategies are fundamental aspects of an asset management framework and particularly applicable to the IHS where the consequences of disruption in service can be quite severe.
- **Continuous Improvement of a Replicable Process—**Asset management establishes a process that can be repeated annually through each program cycle and provides the basis for continued fine-tuning of that process to improve efficiency and effectiveness.

Communication with External Stakeholders

- **Meet Stakeholder Expectations—**Asset management improves an agency's ability to meet stakeholder expectations in terms of both results on the ground and conveying an image of an effectively managed results-oriented organization.
- **Accountability with Customers and Their Elected Representatives—**Asset management fosters an environment in which the asset owner establishes a set of expectations with the public and elected officials and then has its performance measured against those expectations.
- **Building Consensus in Political Environment—**A consistent record of achieving expectations builds consensus in the political environment that an agency is effectively managed and can deliver on its promises.
- **Justifying Increased Funding for IHS Projects—**Establishing credibility in this manner lays the foundation to secure approval for increased funding. Several state DOTs have successfully utilized this strategy to enact transportation revenue programs.

Outcomes

- **More Effective and Efficient Allocation of Financial and Other Resources—**At its foundation, asset management is about resource allocation. If it is not influencing the allocation of resources, its utility has to be questioned.
- **Improved Performance with Constrained Funding—**Application of asset management principles (e.g., early intervention strategies before significant deterioration occurs) can lead to improved asset condition even with limited funding.

- **Leads to Reasonable Expectations that Validate Intuition—**When the processes are working properly, asset management tends to provide quantified verification for findings that, as involved managers, we already knew.
- **Defensible and Timely Decisions.**
- **Preventive Maintenance Funding—**As noted above, effective asset management lends support to early intervention strategies.
- **Fewer Unmitigated Disasters (i.e., more averted system failures)—**Asset management, particularly when enhanced with risk management processes, provides the early warning signals to support proactive intervention before a situation becomes untenable.
- **Reliability of Access to Key Facilities—**Effective asset management should focus resources on key facilities such as the IHS.
- **Global Competitiveness—**One of the keys to the rise of the United States during the post-World War II era as the economic engine of the planet was the comparative advantage provided by our highway network, as exemplified by the IHS. That advantage has eroded in recent years—an effective asset management program can support the restoration of a highway network that should improve the nation's competitiveness in a global economy.

National Perspective

- **Focus on IHS and its Defined National Mission—**Adoption of an asset management framework for the IHS will refocus attention on the preservation of this nationally critical system in its post-new construction phase.
- **Framework for Interstate Discussions—**Asset management can provide a common framework of definitions and processes to facilitate effective communication among the states that can foster a consistent (although not identical) approach to managing the nation's premiere highway system, the Interstate.
- **Enhanced Regional Cooperation—**These interstate discussions can lead to improved regional cooperation among states and toll authorities that operate common and connecting links and networks to the benefit of each other and the traveling public.
- **Make the Case for IHS Criticality More Competitive with Other Needs—**As at the state level, an effective asset management program can establish credibility and help build the case for increased Federal funding for the IHS.

6.5 Challenges

Consistent with the approach to benefits, the March 13, 2008 workshop participants identified the following as implementation obstacles and costs:

General

- **Resistance to Change; Parochialism—**As Machiavelli famously observed, change is inherently difficult to achieve and is often resisted by parochial interests oriented to turf protection.
- **Internal Stakeholder Buy-In—**Obtaining the enthusiastic support of the agency personnel most directly affected by an asset management program is a key hurdle in a successful rollout. Many initiatives have foundered to a lack of this support—outright openly expressed opposition is unusual but a silent pattern of passive resistance is equally debilitating.
- **Too Big a Challenge; Fear of Getting it Wrong—**Since by its nature asset management emphasizes a comprehensive approach there is a very real danger that it can founder of its own weight. Several agencies have overcome this obstacle through a phased implementation model in which the initial steps are modest to achieve credibility and success that builds upon itself.
- **Perceived as Cost Excessive—**In an era of constrained budgets and declining revenues it can be difficult to justify a program where the costs are immediate and easily measurable while the benefits are longer term and less defined.
- **Lack of a Champion in a State—**The absence of a passionate and committed champion is a key obstacle to the successful rollout of an asset management program. Similarly, a change in agency leadership, which occurs all too frequently in today's environment, can cost a program its champion and place further implementation in doubt.
- **Do Not Reward Bad Behavior—**There is a concern that asset managers who have conducted their stewardship role poorly will be rewarded with additional funding since reported needs will be greater. This dynamic was in play during debates on a national bridge inspection and repair program; some states were concerned that a needs-based funding formula would penalize them for maintaining their bridges in a state of good repair.

Internal Procedures

- Getting bogged down in data issues:
  - **High Data Threshold—**Effective asset management requires a great deal of highly disaggregated data in order to produce meaningful results. This poses a challenge to agencies that rely upon system averages for condition data.
  - **Data Quality—**Even if data are available in the required level of detail, there can be challenges regarding the quality of the data. Condition ratings, for example, may vary significantly among districts or even between individuals within a single district unless there is an effective quality control program to assure replicable results.

– **One More System to Feed**—Many agencies have a plethora of management information systems, some of which produce results of questionable utility. Asset management may be perceived by some as one more on that list.

- **Finite Staff Time**—Perhaps an agency's most precious resource is staff time (whose numbers are typically declining both relative to the mission and in absolute terms). Allocating the staff time that effective asset management requires poses a significant challenge.
- **Finite Resources in Addition to Staff Time**—Other resources (funds, people, facilities, and equipment) are also in limited supply and applying them to asset management means they are not available for other priorities.
- **Tools May Be Unavailable or May Not Deliver**—Tools are primarily in the categories of data collection systems for inventory and condition information and management information systems. Many agencies have had unsatisfactory experiences in both categories.
- **Difficulty in Quantifying Risk**—As noted above, a quantitative approach to characterizing risks is a key potential benefit of asset management. However, developing meaningful numbers for low probability events is a challenging task.
- **Inability to Achieve Consensus on Details**—As always, the devil is in the details and achieving internal consensus on the myriad aspects of an effective asset management program is often an arduous proposition.
- **Paralysis by Analysis**—Having achieved the capability of modeling the performance effects of various investment levels and patterns, it is possible to have too much of a good thing and becoming bogged down in endless iterations. The number of alternative scenarios to be tested should be limited to a number that the mind can readily comprehend.

Communication with External Stakeholders

- **External Stakeholder Buy-In**—Just as achieving buy-in from internal stakeholders can be problematic, so too is the case for external parties who may question the commitment of resources to the undertaking, or not understand or care about the results.
- **Elected Officials' Comprehension**—Elected officials are among the most important external stakeholders, particularly those serving on legislative budget committees. Such officials may have little understanding of the goals and purposes of an asset management program.
- **Political Influence**—As noted above, asset management focuses on resource allocation. However, as a practical matter, politics are also very involved in resource allocation and the political dynamic may produce far different results than the asset management program.

Outcomes

- **Results Refute Intuition; Do Not Make Sense**—Even agencies that have devoted a great deal of careful attention to developing an accurate asset management program have experienced receiving results that simply don't make any sense. Some have had to resort to a "k factor" approach to make the numbers come out the right way.
- **Cross-Silo Comparisons and Competition**—Asset management can produce a programming dynamic in which, say, pavement and bridge projects are competing for the same limited pot of funds. While some would argue that this is a desirable exercise, it can be a bruising process for the participants.
- **Local Interstates May Suffer**—Focus on the most nationally significant IHS routes may cause a reduction in resources allocated to other routes in particular states.
- **Intimidating Needs Results**—The asset management program may generate a list of needs that is so overwhelming as to be politically unacceptable.

National Perspective

- **Achieving Consistent Definitions**—In order to be meaningful, an asset management framework for the IHS will require consistent definitions for items such as condition levels among the states. Achieving such consistency has proven to be problematic in the past due to variation in circumstances across the states.
- **Comparable Measures State-to-State (also could be seen as a benefit by elected officials)**—A national Interstate Asset Management Framework could lend itself to conclusions being drawn about comparative performance among the states. Such comparisons have, on occasion, been inappropriately conducted in the past, causing many states to view such an exercise with trepidation.

CHAPTER 7

Conclusions

The basic premise behind the Interstate Asset Management Framework is that the IHS represents the most critical set of highway assets in the United States, and that asset management promises an approach to help IHS owners keep the system in operation in the most efficient manner. The IHS is a lifeline for the U.S. economy, providing mobility for highway passengers and freight traveling within and across the country, as well as to Canada and Mexico. Since the IHS was conceived, other countries have emulated the U.S. example, helping develop their economies through similar, national networks of high-standard highways. Keeping this national system in operation is a prerequisite for keeping the U.S. economy competitive internationally. And achieving this objective without unduly straining scarce resources for transportation will help further strengthen the U.S. economy.

Though there is national consensus on the importance of preserving the IHS, past approaches to managing transportation assets are unlikely to be effective for meeting this goal. As the system ages, there will continue to be increased needs for investing in asset preservation, and increased risks from any failure to preserve IHS assets in a state of good repair. IHS owners need to adopt flexible, performance-based approaches that target investments where they are most needed rather than where historic precedent or institutional arrangements dictate. Also, they need good data on their IHS assets, supplementing the data already available on roads and bridges with additional data on other structures, safety features, facilities, and risks to the system.

Transportation asset management offers a set of tools and approaches for better managing transportation infrastructure. This report summarizes asset management concepts, develops an approach for applying these concepts to IHS assets, and recommends that IHS owners develop an Interstate Asset Management plan embodying the framework. The plan should detail the state of an agency's IHS assets, present a set of performance targets for those assets, and spell out what will be needed to meet those targets. Chapter 5 describes recommended core and comprehensive performance measures for inclusion in an Interstate Asset Management Plan, and Chapter 4 describes data and tools for supporting plan development.

An area of particular importance in managing IHS assets is in managing risk. Chapter 3 describes a scenario-based approach IHS owners can implement to better manage risks of system failure, in addition to other approaches for managing programmatic risks (e.g., risks of cost overruns).

There are numerous benefits as well as clear challenges involved in the implementation of asset management principles in general, and in applying them to the IHS in particular. Chapters 4 and 5 discuss the gaps in available systems, approaches and measures for IHS asset management, and Chapter 6 discusses implementation challenges.

An overriding challenge in managing the IHS is the tension between national consistency and local prerogatives. The IHS was built with a national set of standards and serves vital, national interests. As the emphasis in managing the system has shifted from design and construction to operations, it is now clear that there would be significant benefit for enhancing IHS asset management to having national standards reporting of conditions and performance of IHS assets. However, the state DOTs, toll authorities, and other agencies that operate and manage the system need to have flexibility in how they manage the IHS on a day-to-day basis. The IHS is of national importance, but management of the system must be based on consideration of challenges at the state, corridor, and local level.

Each and every agency and entity responsible for the highest order highway network, including key NHS routes, must reach its own conclusions for its own reasons on whether and how to undertake all or parts of the Interstate Asset Management Framework. Motivating factors will vary, as will areas of emphasis, specific approaches, sources of leadership and organizational characteristics. What does not vary is the simple fact that the potential consequences of deterioration or disruption to the nation's most important arteries will be severe in terms of impacts upon the economic well-being and quality of lives of our citizens. Coupled with the high expectations and low tolerance of failure to perform that confronts every transportation agency, the rationale for implementing a risk-based asset management framework for the Interstate Highway System becomes increasingly apparent. By taking advantage of best practices in asset management and risk management, system owners and operators can most effectively combat the effects of deteriorating infrastructure, minimize costly system disruptions, and ensure that the national highway system continues to serve as an engine for helping drive our economy forward.

References

(*1*) AASHTO Standing Committee on Highways, Motion to Amend the Definition to Advocate the Principles of Transportation Asset Management, May 6, 2006.

(*2*) Cambridge Systematics, Inc., Parsons Brinckerhoff Quade & Douglas, Inc., Roy Jorgensen Associates, Inc., and P. T. Thompson. *Transportation Asset Management Guide,* AASHTO publication RP-TAMG-1, Contractor's Final Report prepared for NCHRP Project 20-24(11), 2002.

(*3*) Gordon, P., Richardson, H. W., and B. Davis. Transport-Related Impacts of the Northridge Earthquake. *Journal of Transportation and Statistics,* Volume I, Number 2, 1998.

(*4*) *NCHRP Report 551: Performance Measures and Targets for Transportation Asset Management.* Transportation Research Board of the National Academies, Washington, D.C., 2006.

(*5*) Science Applications International Corp. *2002 AASHTO Guide to Highway Vulnerability Assessment for Critical Asset Identification and Protection,* Contractor's Final Report prepared for NCHRP Project 20-07/Task 151B, 2002.

(*6*) Science Applications International Corp. and PB Consult. *Guide to Risk Management of Multimodal Transportation Infrastructure,* Draft Final Report prepared for NCHRP Project 20–59(17), 2007.

(*7*) Patidar, V., Labi, S., Sinha, K. C., and P. Thompson. *NCHRP Report 590: Multiple-Objective Optimization for Bridge Management Systems.* Transportation Research Board of the National Academies, Washington, D.C., 2007.

(*8*) Cambridge Systematics, Inc., PB Consult, and System Metrics Group, Inc. *NCHRP Report 545: Analytical Tools for Asset Management.* Transportation Research Board of the National Academies, Washington, D.C., 2005.

(*9*) FHWA. *Highway Performance Monitoring System (HPMS) Reassessment 2010+ Final Recommendations Report,* 2008.

(*10*) AASHTO. *AASHTO Guide for Commonly Recognized (CoRe) Structural Elements,* 1997 (amended 2001).

(*11*) FHWA. *Guidelines for the Installation, Maintenance, and Repair, of Structural Supports for Highway Signs, Luminaries, and Traffic Signals,* 2007.

(*12*) FHWA. *Highway and Rail Transit Tunnel Inspection Manual,* 2005.

(*13*) AASHTO-AGC-ARTBA Joint Committee, *Asset Management Data Collection Guide: Task Force 45 Report,* 2006.

(*14*) Smith, K. L., Stivers, M. L., Hoemer, T. E., and A. R. Romine. *NCHRP Web Document 8: Highway Maintenance Quality Assurance.* TRB, National Research Council, Washington, D.C., 1997.

(*15*) Markow, Michael J. *NCHRP Synthesis 371: Managing Selected Transportation Assets: Signals, Lighting, Signs, Pavement Markings, Culverts, and Sidewalks.* Transportation Research Board of the National Academies, Washington, D.C., 2007.

(*16*) Applied Pavement Technology, Inc. *Use of Highway Maintenance Management Systems in State Highway Agencies,* 2006.

(*17*) Cambridge Systematics, Inc. and Michael D. Meyer. *U.S. Domestic Scan Program: Best Practices in Transportation Asset Management,* Scan Tour Report, NCHRP Project 20-68, 2007.

(*18*) Cambridge Systematics, Inc., Texas Transportation Institute, University of Washington and Dowling Associates. *NCHRP Web-Only Document 97: Guide to Effective Freeway Performance Measurement—Final Report and Guidebook.* Transportation Research Board of the National Academies, Washington, D.C., 2007.

(*19*) Cambridge Systematics, Inc., Parsons Brinckerhoff and Venner Consulting, Inc. *NCHRP Web-Only Document 103: Final Report for NCHRP Research Results Digest 317: Prototype Software for an Environmental Information Management and Decision Support System.* Transportation Research Board of the National Academies, Washington, D.C., 2007.

(*20*) Department of Homeland Security Office of Inspector General. *Progress in Developing the National Asset Database,* Publication OIG-060-40, 2006.

(*21*) Moteff, John. *Critical Infrastructure: The National Asset Database,* Congressional Research Service Report for Congress, Publication RL33648, 2007.

(*22*) Friedman, David, Monteith, M. C., Kay, D. H., Couts, V. B., Trombly, J. W., Bratvold, D., and I. Hirshmann. *NCHRP Report 525 Volume 11: Disruption Impact Estimating Tool—Transportation (DIETT)—A Tool for Prioritizing High-Value Transportation Choke Points.* Transportation Research Board of the National Academies, 2006.

(*23*) Cambridge Systematics, Inc. *Multimodal Transportation: Development of a Performance-Based Planning Process,* NCHRP Research Results Digest 226, 1998.

(*24*) http://www.oregon.gov/ODOT/CS/PERFORMANCE/ accessed in August 2008.

(*25*) http://dashboard.virginiadot.org/ accessed in August 2008.

(*26*) AASHTO. *Measuring Performance Among State DOTs,* 2006.

(*27*) FHWA. *Status of the Nation's Highways, Bridges, and Transit: 2006 Conditions and Performance Report,* 2006.

(*28*) U.S. Department of Transportation. *Fiscal Year 2006 Performance and Accountability Report,* 2006.

APPENDIX A

Literature Review

A literature review was conducted to investigate recent research and current state-of-practice related to performance measurement, risk assessment and risk management implementation by transportation agencies. The sources for the literature review included FHWA reports, NCHRP reports, published papers in professional journals (ASCE, TRR, etc.), and current practices from Federal, state, and local agencies. This appendix summarizes the review, organized by risk management, asset data and analytical tools, and performance management.

A.1 Risk Management

The review of risk management literature focused on two primary areas: asset/operations-specific approaches to risk in management systems; and statewide or regional approaches to management of catastrophic/severe risk. Two resources merit special mention: the *2002 AASHTO Guide to Highway Vulnerability Assessment* (*1*), and the draft final report for NCHRP Project 20-59, *Guide to Risk Management of Multimodal Transportation Infrastructure* (2), provided to the research team by NCHRP. Key concepts from theses resources are discussed in Chapter 3, and the two documents are summarized under a separate heading since they embody state and Federal agency level guidance documents that are different from the other research studies included in the review.

Approaches to Risk in Management Systems

Many research studies have been conducted on the analysis and management of specific highway assets (especially bridges, tunnels, and roads) with risk-based methodologies. The risk categories analyzed in these studies include terrorism, earthquake, and loss of structural or functional performance of assets. Several risk-based methodologies were developed for bridge management systems and highway maintenance management systems using these concepts.

Risk-Based Bridge Management (*3*). This paper describes a methodology for bridge project selection based on reliability methods and optimization procedures. The authors use a Markovian model to simulate deterioration of structural components, and determine a reliability index for each element using either subjective assessment or first-order reliability methods. The overall reliability of the bridge is calculated as system reliability by combining the individual reliability of the components in a series system. Risk is estimated with the reliability of the bridge and the consequence of closure. The paper discusses methods for finding the optimum set of repairs that minimize the total network risk and describes use of a near-optimum algorithm for this application.

Risk-Based Prioritization of Terrorist Threat Mitigation Measures on Bridges (*4*). This paper discusses developing a risk-based methodology to facilitate prioritization of terrorist threat mitigation strategies on individual bridges. This methodology was designed to focus on a single bridge and the risk of terrorist attack associated with each of its many individual structural components. The methodology evaluated the bridge risk based on such factors as the component's importance to overall structural stability, its location and accessibility to terrorists, and its resistance to the specific threat. The result of the methodology was a rank-ordered list of components most at risk to attack, allowing prioritization and optimization of the mitigation design for the bridge. Once mitigation schemes are identified, the methodology can be utilized to recalculate mitigated risk, allowing for a direct indication of benefit/cost of the mitigation design.

A Risk-Based Decision-Support System for Bridge Management (*5*). This paper presents a novel framework for a risk-based decision-support system for an advanced bridge management system. The authors suggest evaluating bridge risk using structural safety reliability and anticipated consequences of the bridge's failure. The system they describe includes components addressing inspection, data collection and storage, deterioration modeling, structural assessment, economic appraisal of maintenance, MR&R actions through whole-life costing, work programming optimization methodologies, and a number of reporting facilities.

Risk-Based Asset Management Methodology for Highway Infrastructure Systems (*6*). This study applies risk-based models to highway maintenance management systems. The authors developed a systemic risk-based asset management methodology as a decision-making tool for highway planners and maintenance engineers to manage the maintenance of highway infrastructure systems.

A Risk-Based Maintenance Management Model for Toll Road/Tunnel Operations (*7*). The focus of this study was to develop a risk-based maintenance management model to prioritize preventive maintenance activities for equipment in complex plant installations like toll road/tunnel systems. The resulting model is based on the five core elements of the risk management process: identification, measurement, assessment, valuation, and control and monitoring. The model requires participation of different departments to determine the failure modes and effects of equipment and the corresponding preventive actions. The model can help operators to establish and determine suitable maintenance strategies for selecting the best courses of action in managing identified risks.

Risk-Based Life-Cycle Costing of Infrastructure Rehabilitation and Construction Alternatives (*8*). This paper presents a new approach for estimating life-cycle costs and evaluating infrastructure rehabilitation and construction alternatives, derived from probability theory and simulation application. In this study, highway pavement data are used to demonstrate the model concept and development. The developed risk-based life-cycle cost model considers the time to failure of each pavement rehabilitation/construction alternative and provides additional knowledge about the uncertainty levels that accompany the estimated life-cycle costs. The paper describes the various components of the developed model, the factors affecting pavement performance and service life, the statistical stratification process of highway pavement networks, and the data input modeling and simulation utilized for the analysis. The model can help engineers in the decision-making process regarding the selection of pavement construction and rehabilitation alternatives.

Approaches to Management of Catastrophic/Severe Risk

Several risk-based research studies have been conducted at the statewide or regional levels for highway infrastructure systems on catastrophic/severe risk. They include terrorism risk studies in Virginia and seismic risk studies in California, as well as development of a general vulnerability rating based on work originally performed by New York State Department of Transportation.

Assessing and Managing Risk of Terrorism to Virginia's Interdependent Transportation Systems (*9*). This study was conducted to assess and manage the risk of terrorism to Virginia's interdependent transportation infrastructure. The focus was to understand how the failure of one piece of infrastructure or any of its elements propagates in order to implement management policies that can mitigate the consequences. It uses several risk assessment and management models: the Hierarchical Holographic Model (HHM) for identifying risks; the Risk Filtering, Ranking, and Management (RFRM) for ranking risks; the Inoperability Input-Output Model (IIM) for accounting for direct and indirect impacts/consequences; and the Partitioned Multi-Objective Risk Method (PMRM) for accounting for extreme events. At the statewide level, the direct and indirect economic impacts of transportation infrastructure disruptions (natural hazard, intentional attack, etc.) on various dependent industry sectors are assessed using the IIM. The industry impacts are measured in two metrics, economic losses and percentage of inoperability. Workforce impacts are also considered in the IIM in terms of income reduction and the number of workers affected. The data from the Bureau of Economic Analysis (BEA) Input-Output Table and the Regional I-O Multiplier System II (RIMS II) is used in IIM for ranking industry sector impacts. Census workforce data and commodity flow data are used to quantify the disruption to the transportation system produced by an act of terrorism.

Modeling the Impact of Infrastructure Interdependencies on Virginia's Highway Transportation System (*10*). In this study, risk assessment and risk management techniques are used to identify system vulnerabilities and the risks associated with those vulnerabilities. HHM described above is used to identify risks and vulnerabilities. Information used in HHM includes jurisdictional, intermodal, economic and user perspectives. A case study is presented focusing on risk management and finding ways to unlock the interdependencies of the highway system to reduce the risks associated with those interdependencies. As part of the project findings, a sampling of risk management options is introduced in two categories: Response (form response teams, alternative routes, redundancy in the system, etc.); and Unlock Interdependencies (alternate forms of transportation, overstocking critical facilities, staggering work schedules, etc.).

Seismic Risk Assessment of Transportation Network Systems (*11*). In this study, the risk from earthquakes to a transportation system is evaluated in terms of direct loss from damage to bridges and travel delays in the transportation network. The direct loss is estimated from repair costs due to damage to bridges and is dependent on the size of the bridge and the expected damage state of the bridge. The travel delays resulting from closure of damaged bridges are calculated using origin-destination (O-D) tables, coupled with network analysis of the pre-earthquake scenario with a base transportation network and the post-earthquake scenario with a modified transportation network. The consequence of earthquakes on the transportation network is evaluated for a magnitude 7.0 earthquake scenario in California. The information for bridge inventory and the highway transportation network was obtained from transportation agencies for this study. The study reports that liquefaction damage is the largest contributor to the repair cost which is used as a measure of the loss from damage.

System Risk Curves: Probabilistic Performance Scenarios for Highway Networks Subject to Earthquake Damage (*12*). The authors develop methods for evaluating the performance of highway systems subjected to severe earthquake impacts. In this study, the total transportation network delay is estimated with user-equilibrium network analysis methods to evaluate the network system performance due to seismic induced damage. The bridge damage and highway network link damage is evaluated by means of a damage index with Monte Carlo simulation techniques and bridge fragility curves. The fragility curves for individual bridges are developed on the basis of empirical damage data and dynamic analysis performed on bridge structures. These curves are used to generate network damage states for various earthquake scenarios by means of Monte Carlo simulation. To test the approach changes in system performance in different scenarios are measured in terms of additional total network delay for a set of sample scenarios. The final result of these efforts is a transportation system risk curve, which shows the annual probability of exceedance and the hazard-consistent probability for different levels of network delay.

Multi-Objective Optimization for Bridge Management Systems (*13*). Appendix B of this report details an approach to calculating a vulnerability rating for a structure for scour, fatigue, seismic, and other vulnerabilities. This approach is in turn based largely upon work performed by the New York State Department of Transportation. The vulnerability scoring approach described here provides a thresholding approach for assessing structures risk that can be used in conjunction with the risk assessment approach described in Section 3. Note that other portions of this report are also relevant, and described further in the review of data and analytical tools.

AASHTO and NCHRP Guides to Risk Management

2002 AASHTO Guide to Highway Vulnerability Assessment (*1*). This document, developed in the immediate aftermath of the 9/11 attack, focuses on providing high level guidance for vulnerability assessment of highway transportation assets against terrorist threats, including bridges, tunnels, roadways, interchanges, tollhouses, and roadside infrastructure (e.g., signs, barriers, sensors). It provides a six-step process for conducting a vulnerability assessment. Key aspects of the guide include:

- Reliance of the organization to organize and sustain a multidisciplinary team ready to identify critical assets, perform vulnerability assessments, and subjectively identify costs and effectiveness of countermeasures.
- Guidance on selecting critical assets and subjectively assigning "asset criticality" scores over a number of asset factors and their subsequent aggregation to determine a criticality factor for each asset.
- Guidance on subjectively assessing "asset vulnerability" scores over a number of factors and their subsequent aggregation to determine a vulnerability factor for each asset.
- Guidance on combining and analyzing the criticality and vulnerability assessments to determine countermeasure action.
- Guidance on countermeasures spanning the capital, maintenance and operational areas, countermeasure packaging, and first-order estimation of costs for countermeasures.
- Guidance on reviewing operational and security planning.

The guide relies heavily on experience, expertise, and resource commitment. There is very little automation of the process and the factors chosen are subjective to a point where different teams looking at the same asset or vulnerability could potentially come up with different scores and mitigation priorities. The Guide also stops short of proposing a methodology to compute/impute the consequences of extreme events.

NCHRP Project 20-59: Guide to Risk Management of Multimodal Transportation Infrastructure (*2*). This report seeks to improve upon the concepts presented in the 2002 AASHTO Guide, and expand the applicability of the procedures developed to all intentional, unintentional, and natural hazards and all modes of transportation, not just highways. It makes significant proposals in formalizing the risk management process, but it consciously avoids consequence modeling benefit/cost analysis, return on investment calculations, and/or other economic analysis of risk consequences and mitigation measures. Further, event probability is not fully tied into risk calculation for all threats/hazards.

A.2 Asset Data and Analytical Tools

Data

Cambridge Systematics, U.S. Domestic Scan Program: Best Practices in Transportation Asset Management (*14*). This scan report identifies best practice examples of the application of asset management principles and practice in

U.S. transportation agencies. The scan participants included FHWA officials, representatives from state transportation agencies in Michigan, North Carolina, Ohio, Oregon, and Vermont, a university professor in transportation engineering and planning, and a consultant support staff.

Highway Performance Monitoring System Reassessment 2010+ (*15*). The report summarizes the HPMS 2010+ reassessment recommendations, including stakeholder input, proposed recommendations, and impacts of the reassessment. The reassessment is intended to address current and future business needs, address new data requirements in transportation reauthorization legislation, and update HPMS to take advantage of technological improvements.

Managing Selected Transportation Assets: Signals, Lighting, Signs, Pavement Markings, Culverts, and Sidewalks (*16*). This study examines the state-of-the-practice for managing transportation infrastructure assets other than pavements and bridges, including traffic signals, lighting, signs, pavement markings, drainage culverts, and sidewalks. A key finding is that the amount of data and manner collected varies significantly for these assets between different agencies.

Culvert Management Systems: Alabama, Maryland, Minnesota, and Shelby County (*17*). This report provides details about the culvert management data and practices used in four jurisdictions, and provides guidance for agencies seeking to improve their culvert management approach.

Highway and Rail Transit Tunnel Inspection Manual (*18*). This manual was developed by FHWA and the Federal Transit Administration (FTA). It provides specific information for the inspection of both highway and rail transit tunnels. The goal of the manual is to provide uniformity and consistency in assessing the condition of the various tunnel components and to present good maintenance and rehabilitation practices.

Guidelines for the Installation, Maintenance, and Repair of Structural Supports for Highway Signs, Luminaries, and Traffic Signals (*19*). This document is designed to provide guidance for the installation, inspection, maintenance, and repair of structural supports for highway signs, luminaries, and traffic signals. It recommends using an element-level approach for inspecting these structures, similar to that used for bridges using the AASHTO Pontis BMS.

Colorado DOT, Feasibility of a Management System for Retaining Walls and Sound Barriers (*20*). This report makes the case that the management systems for retaining walls and sound barriers are feasible and can be modeled on existing systems for bridge management such as AASHTO's Pontis BMS. It presents the tasks for full development of wall and barrier management including the proposed data and procedures specific to walls and barriers and recommendation on inspection practice and intervals.

Use of Highway Maintenance Management Systems in State Highway Agencies (*21*). This paper details surveys of 29 state highway agencies on the state-of-the-practice in MMS. It shows there is considerable variation between agencies in the data collected in their MMS and the state of MMS implementation.

XML Schemas for Exchange of Transportation Data (*22*). For the NCHRP 20-64 Project detailed in this report, a research team developed TransXML—a family of broadly accepted public domain eXtensible Markup Language (XML) schemas for exchange of transportation data. The following pilot business areas were selected as the focus of the study: Survey/Road Design; Transportation Construction/Materials; Highway Bridge Structures; and Transportation Safety. The report discusses the possible benefits by adopting and expanding TransXML, and highlights efforts designed to help ensure its success.

Asset Management Data Collection Guide (*23*). This guide was prepared by a joint committee of AASHTO, the Associated General Contractors of America (AGC) and the American Road and Transportation Builders Association (ARTBA). It reviews asset management concepts, discusses current data collection practices, and presents a set of criteria for determining what data to collect. Also, this guide recommends inventory and condition data items that should be collected for:

- Drainage assets, including culverts, ditches, drop inlets, catch basins, drains, curbs, and sidewalks;
- Roadside assets, including grass, slopes, and fences;
- Pavement assets, including pavement and shoulders; and
- Traffic assets, including signs, pavement markings, pavement markers, guardrail, guardrail treatments, and traffic barriers.

Analytical Tools

A comprehensive review of asset management tools was recently performed for NCHRP Project 20-57 and documented in NCHRP Report 545 (*23*). The research team used the materials gathered through the NCHRP 20-57 project as a starting point. This information was supplemented with a review of the literature published since the completion of NCHRP Project 20-57 and additional best practice examples and information on data resources. Also, the research team reviewed materials from other relevant NCHRP efforts, and materials available on systems developed or distributed by

AASHTO, FHWA and other Federal agencies. The review was performed to help answer two questions:

- What asset data and analytical tools are *in use* in the United States and/or international agencies that could help support the Interstate Asset Management Framework; and
- What data and analytical tools are available in the public domain for immediate implementation during the framework pilot?

The following is a summary of the materials reviewed.

Analytical Tools for Asset Management (*24*). This report details the set of analytical tools available as of 2005 and describes two new tools developed through the NCHRP 20-57 Project: AssetManager NT for network-level asset analysis and AssetManager PT for project-level analysis. In establishing the needs for a new analytical tool, the NCHRP 20-57 research team reviewed the available literature, performed detailed interviews of 10 transportation agencies, and prepared detailed profiles of 11 tools available in the public domain, including:

- Highway Economics Requirements System State Version (HERS-ST);
- Highway Development and Management Tool (HDM-4);
- Surface Transportation Efficiency Analysis Model (STEAM);
- Intelligent Transportation Systems (ITS) Deployment Analysis System (IDAS);
- Pavement LCCA Tool, now titled RealCost;
- EAROMAR (Economic Analysis of Roadway Occupancy for Maintenance and Rehabilitation);
- MicroBENCOST, since superseded by BCA.NET;
- StratBENCOST;
- Transportation Decision Analysis Software (TransDec);
- National Bridge Investment Analysis System; and
- Bridge Life Cycle Cost Analysis (BLCCA) Tool, detailed in *NCHRP Report 483: Bridge Life-Cycle Cost Analysis* (*25*).

Further, the report details what tools are available and/or in use, discusses the gaps in existing tools, and details the need for new functionality, both in the AssetManager tools developed through the project and in other analytical tools.

Pavement Management Applications Using Geographic Information Systems (*26*). This synthesis describes approaches to integrating PMS and Geographic Information Systems (GIS). It reports that approximately half of state DOTs use global positioning systems (GPS) as part of their data collection process, though data collected by GPS present issues because of the lack of compatibility with historical data and interoperability with existing systems. The synthesis concludes that the benefits of implementing a GIS for supporting pavement management outweigh the costs, but relatively few DOTs are using GIS as part of their pavement management decision process.

Multi-Objective Optimization for Bridge Management Systems (*13*). This report reviews approaches to multi-objective optimization, and prototype application of a heuristic approach to BMS data. It recommends adapting the incremental benefit cost (IBC) approach already used for simulation models in many management systems for use in a multi-objective approach, expanding this into an incremental utility cost (IUC) approach to factor in additional objectives. The report also describes two spreadsheet tools developed through the project, the Multi-Objective Optimization System (MOOS) bridge-level and network-level models. Although MOOS is intended to integrate programmatic risks with risks of system failure, as these concepts are described in Section 3, it can be used to prioritize risks of system failure consistent with the approach detailed in Section 3.

AASHTO Guidelines for Maintenance Management Systems (*27*). This document describes MMS functionality at a general level and identifies the components of a comprehensive MMS that agencies should consider in terms of their approach to maintenance management and their operating environment. These components include: planning; programming and budgeting; resource management; scheduling; monitoring and evaluation; and maintenance support and administration.

Disruption Impact Estimating Tool—Transportation (DIETT)—A Tool for Prioritizing High-Value Transportation Choke Points (*28*). This report details a tool developed to prioritize risks to transportation choke points (TCP) such as bridges and tunnels. The tool includes a Microsoft Access application for filtering a set of TCPs. The Access application exports data to an Excel spreadsheet which is used to perform the prioritization. The example provided with the study shows the example prioritization of bridges based on NBI data and additional parameters used to characterize the economic value of freight traffic utilizing the TCP. DIETT is designed to work in conjunction with the Consequences Assessment Tool Set (CATS) developed by Science Applications International Corp. (SAIC).

Prototype Software for an Environmental Information Management and Decision Support System (*29*). This details data sources and analytical tools used by transportation agencies for environmental management. This reference describes the prototype environmental information management system developed through NCHRP Project 25-23(2) for storing environmental management data for supporting long-range planning, project development and maintenance.

A.3 Performance Management

Guidance Documents

Performance Measures and Targets for Transportation Asset Management (*30*). This report provides a comprehensive review of current practices in transportation performance measurement, drawing upon an extensive literature review and in-depth interviews of 15 state transportation agencies. Its review was used as the starting point for the current study. The report provides an assessment of performance measures for facility preservation, operation, improvement, and expansion, though the primary focus of the report is on preservation measures. It describes different approaches for classifying performance measures, and presents a set of criteria and guidelines for selecting performance measures. Volume II of the report is a guide for selecting performance measures, with an approach to classifying measures and examples of the measures in use in different state DOTs.

Guide to Effective Freeway Performance Measurement (*31*). This guidebook was developed through NCHRP Project 3-68. It provides comprehensive treatment of the topic of freeway performance measurement, particularly regarding congestion and mobility measures. The guide recommends a set of core measures that agencies should collect for all freeways, as well as supplemental measures. Measures are classified according to whether they are measures of quality of service or agency activity, by the extent of the measure (e.g., measured section-by-section, over an area, or across an entire state). The guidebook also details possible applications of the performance measures, including real-time, operations planning, short-term planning, and long-term planning applications.

Measuring Performance Among State DOTs (*32*). This report recommends the use of comparative performance measurements for enabling different agencies to compare their performance in order to improve customers' satisfaction and communication between agencies. The report reviews literature related to this topic and details a series of workshops held for the study. It presents principles for comparative performance measurement and includes a detailed framework for developing a comparative performance measurement initiative. Further it recommends the use of seven core measures for comparing performance between DOTs in the following four strategic focus areas:

- **Preserving the Physical Condition of the Transportation System.** Percentage of vehicle miles traveled on state's NHS pavement that meets or exceeds an "acceptable" performance standard, based on IRI; and percentage of state's bridge deck area on the NHS that meets structural condition targets (measured using element-level inspection data).
- **Managing Congestion.** Annual hours of delay per traveler on freeways and principal arterials.
- **Managing Project Delivery.** Average actual project letting and completion versus scheduled letting and completion; and annual ratio of actual construction cost versus bid amount.
- **Safer Travel.** Three-year moving average annual number of fatalities per 100 million vehicle miles traveled; and three-year moving average annual number of fatalities per 100,000 population.

Effective Organization of Performance Measurement (*33*). As part of NCHRP Project 8-36, Task 47, this AASHTO Standing Committee on Planning (SCOP) study assesses how transportation agencies, particularly state DOTs, incorporate performance measurement functions within their overall organizational frameworks. The report provides useful "lessons learned," based on case study research, for transportation organizations that are setting up new programs or adjusting and reorganizing existing programs. It identifies the most effective organizational attributes that contribute to a successful program.

Measuring and Improving Infrastructure Performance (*34*). This report prepared by the National Research Council's Committee on Measuring and Improving Infrastructure Performance provides guidance on developing a framework for performance measurement, and on using performance measures in decision making on infrastructure. The report focuses on implementing performance-based infrastructure management in urban regions and on four broad categories of infrastructure: transportation, water, wastewater, and municipal waste. This study is notable in several respects. It was conducted in the wake of a series of early studies that identified the need for increased investment in infrastructure, but prior to the more recent wave of studies of performance-based planning, asset management, and performance measures represented by the other documents described previously. Further, it provides an unusually comprehensive treatment of the underlying concepts of performance measurement as they relate to publicly owned infrastructure. Finally, it reflects upon a number of topics that, even over a decade later, still seem quite timely for managing IHS assets, including handling of multiple objectives in decision making and factoring in uncertainty and risk.

State-of-the-Practice Examples

A number of state-of-the-practice examples have been compiled and are summarized in the guidance documents detailed earlier. To supplement this information, the research team reviewed two additional examples of national-level summaries of the condition of the IHS and/or the nation's highways.

Status of the Nation's Highways, Bridges, and Transit: Conditions and Performance Report (C&P Report) (*35*). The United States Department of Transportation prepares the C&P Report for the U.S. Congress on a biennial basis. It is intended to provide an objective appraisal of the nation's highways, bridges, and transit systems. The report uses data from FARS, the HPMS, the NBI, and the National Transit Database (NTD) to evaluate the physical conditions and operational performance of the nations' surface transportation system. It includes a section specifically on conditions of the IHS. Measures for which predicted changes in conditions are reported include IRI, percent of vehicle miles traveled (VMT) on roads with IRI < 95, percent of VMT on roads with IRI ≤ 170, total delay, total user costs, travel time costs and bridge investment backlog.

U.S. DOT Fiscal Year 2006 Performance and Accountability Report (*36*). This document measures the agency's progress towards achieving a set of targets for the nation's transportation system in support of six strategic goals, identifying performance measures and targets for each. Highway-related measures in the report are summarized below, organized by strategic goal:

- Safety:
  - Fatalities per 100 million VMT; and
  - Fatalities involving large trucks per 100 million VMT.
- Mobility:
  - Percentage of travel on the NHS meeting pavement performance standards for "good" ride; and
  - Percentage of total annual urban-area travel that occurs in congested conditions.
- Global Connectivity:
  - Percent share of the total dollar value of DOT direct contracts that are awarded to women-owned businesses;
  - Percent share of the total dollar value of DOT direct contracts that are awarded to small disadvantaged businesses.
- Environmental Stewardship:
  - Ratio of wetlands replaced for every acre affected by Federal-aid highway projects;
  - Percent of DOT facilities characterized as No Further Remedial Action Planned under the Superfund Amendments and Reauthorization Act; and
  - 12-month moving average number of area transportation emissions conformity lapses.
- Security:
  - Transportation Capability Assessment for Readiness Index Score.
- Organizational Excellence:
  - For major Federally funded infrastructure projects, percentage that meet schedule milestones established in project or contract agreements, or miss them by less than 10 percent; and
  - For major Federally funded infrastructure projects, percentage that meet cost estimates established in project or contract agreements, or miss them by less than 10 percent.

International Resources

Transportation Asset Management in Australia, Canada, England, and New Zealand (*37*). This is a compilation report of an international scan of asset management techniques and processes from four countries. The report addresses leadership and organizational challenges, asset management's role in decision making, data use, and technical approaches, lessons in effective program delivery, and human resource requirements. The scan team synthesized the data from the scan into a list of lessons which could be applied to infrastructure resource allocation in the United States, including:

- Common asset management performance measures can be categorized into condition, function, and capacity indicators. In some instances, these categories serve as the basis for cross-asset evaluation and prioritization methods.
- All transportation authorities interviewed use the concept of risk in their prioritization process. Whereas, the application of risk is absent from most U.S. agencies' asset management frameworks.
- The integration of asset management into public-private ventures is instrumental in ensuring assets are returned to the public entity in good condition and good service is delivered to the users during the life of the contract.
- Data itself should be treated as an asset; data collection should have a clear purpose and be directly tied to a performance measure used in the decision-making process.

Transportation Performance Measures in Australia, Canada, Japan, and New Zealand (*38*). This international scan was conducted to help provide U.S. agencies with a background on the issue of performance measures in transportation decision-making. The scan team identified a number of common themes and lessons applicable to U.S. agencies. These include:

- The international transportation officials in the scan clearly distinguished between outcome (i.e., the ultimate characteristic of the performance of the system) and output (i.e., products and services leading to outcomes) measures.
- Identifying a small set of key performance measures, as the National Ministry in Japan has, encourages the use of the measures in decision making; localities can establish additional measures specific to their circumstance as appropriate.
- The most commonly used categories of measures were road network congestion, accessibility and mobility, road safety, travel time, and trip reliability; transportation system security was absent from all survey countries' measures.

- The best examples of performance measure use included a relatively dynamic set of measures, to address the evolving goals of the organization.

International Infrastructure Management Manual (*39*). The goal of this manual is to provide organizations with skills to monitor their assets cost-effectively. A series of steps is proposed to plan, prepare, and develop asset management within an organization. Based on the manual, in order for an agency to implement asset management, the organization should define: i) the levels of service for each of its assets, the current levels of service, the customers' expected levels and the levels the customers are willing to pay for; ii) forecast future demand; and iii) determine the physical condition and current utilization of its assets. The organization should also communicate with its customers to define their expectations. The manual also proposes a process for collecting and managing data. A framework is proposed to enable an organization to determine how an asset may fail to achieve its expected level of service. Determining the failure mode of an asset can help the organization in monitoring the asset. Likewise, the manual addresses the issue of identifying and evaluating risks related to an asset. The manual provides examples of asset management in Australia and New Zealand.

A.4 References

(*1*) Science Applications International Corp. *2002 AASHTO Guide to Highway Vulnerability Assessment for Critical Asset Identification and Protection,* Contractor's Final Report prepared for NCHRP Project 20-07/Task 151B, 2002.

(*2*) Science Applications International Corp. and PB Consult. *Guide to Risk Management of Multimodal Transportation Infrastructure,* Draft Final Report prepared for NCHRP Project 20-59(17), 2007.

(*3*) Cesare, M., Santamarina, J. C., Turkstra, C. J., and E. Vanmarcke. "Risk-Based Bridge Management," *Journal of Transportation Engineering,* Volume 119, Number 5, 1993.

(*4*) Ray, J. C. "Risk-Based Prioritization of Terrorist Threat Mitigation Measures on Bridges," *Journal of Bridge Engineering,* Volume 12, Number 2, 2007.

(*5*) Flaig, K. D. and R. J. Lark. "A Risk-Based Decision-Support System for Bridge Management," *Proceedings of the Institute of Civil Engineers: Bridge Engineering,* Volume 158, Number 3, 2005.

(*6*) Dicdican, R. Y., Haimes, Y. Y., and J. H. Lambert. *Risk-Based Asset Management Methodology for Highway Infrastructure Systems,* Virginia Transportation Research Council, Virginia Department of Transportation, 2004.

(*7*) Ng, M. F., Tummala, V. M. and R. Yam. "A Risk-Based Maintenance Management Model for Toll Road/Tunnel Operations," *Construction Management and Economics,* Volume 21, Number 5, 2003.

(*8*) Salem, O., Abourizk, S., and S. Ariaratnam. "Risk-Based Life-Cycle Costing of Infrastructure Rehabilitation and Construction Alternatives," *Journal of Infrastructure Systems,* Volume 9, Number 1, 2003.

(*9*) Crowther, K. G., Dicdican, R. Y., Leung, M. F., Lian, C. and Williams, G. M., *Assessing and Managing Risk of Terrorism to Virginia's Interdependent Transportation Systems,* Report: VTRC-05-CR6 prepared for FHWA and Virginia DOT, 2004.

(*10*) Dryden, L. M., Haggerty, M. S., Lane, L. M. and C. S. Lee. "Modeling the Impact of Infrastructure Interdependencies on Virginia's Highway Transportation System," *2004 IEEE Systems and Information Engineering Design Symposium,* IEEE Cat. No.04EX785, 2004.

(*11*) Kiremidjian, A., Moore, J., Fan, Y., Yazlali, O., Basoz, N., and M. Williams. "Seismic Risk Assessment of Transportation Network Systems," *Journal of Earthquake Engineering,* Volume 11, Number 3, 2007.

(*12*) Shiraki, N., Shinozuka, M., Moore, J. E., Chang, S. E., Kameda, H., and S. Tanaka. "System Risk Curves: Probabilistic Performance Scenarios for Highway Networks Subject to Earthquake Damage," *Journal of Infrastructure Systems,* Volume 13, Number 1, 2007.

(*13*) Patidar, V, Labi, S. Sinha, K. C. and P. *NCHRP Report 590: Multiple-Objective Optimization for Bridge Management Systems,* Contractor's Final Report for NCHRP Project 12-67, 2007.

(*14*) Cambridge Systematics, Inc. and Michael D. Meyer. *U.S. Domestic Scan Program: Best Practices in Transportation Asset Management,* Scan Tour Report, NCHRP Project 20-68, 2007.

(*15*) FHWA. *Highway Performance Monitoring System (HPMS) Reassessment 2010+ Final Recommendations Report,* 2008.

(*16*) Markow, Michael J. *NCHRP Synthesis 371: Managing Selected Transportation Assets: Signals, Lighting, Signs, Pavement Markings, Culverts, and Sidewalks,* 2007.

(*17*) FHWA. *Culvert Management Systems: Alabama, Maryland, Minnesota, and Shelby County,* 2007.

(*18*) FHWA. *Highway and Rail Transit Tunnel Inspection Manual,* 2005.

(*19*) FHWA. *Guidelines for the Installation, Maintenance, and Repair, of Structural Supports for Highway Signs, Luminaries, and Traffic Signals,* 2007.

(*20*) Hearn, George. *Feasibility of a Management System for Retaining Walls and Sound Barriers,* Report CDOT-DTD-R-2003-8 prepared for the Colorado Department of Transportation, 2003.

(*21*) Applied Pavement Technology, Inc. *Use of Highway Maintenance Management Systems in State Highway Agencies,* 2006.

(*22*) Ziering, E., Harrison, F., Scarponcini, P., InfoTech, Inc., Michael Baker Jr., Inc. and C. E. Campbell. *NCHRP Report 576: TransXML—XML Schemas for Exchange of Transportation Data,* Contractor's Final Report for NCHRP Project 20-64, 2007.

(*23*) AASHTO-AGC-ARTBA Joint Committee, *Asset Management Data Collection Guide: Task Force 45 Report,* 2006.

(*24*) Cambridge Systematics, Inc., PB Consult, and System Metrics Group, Inc. *NCHRP Report 545: Analytical Tools for Asset Management,* Contractor's Final Report for NCHRP Project 20-57, 2005.

(*25*) Hugh Hawk. *NCHRP Report 483: Bridge Life-Cycle Cost Analysis,* Contractor's Final Report for NCHRP Project 12-43, 2003.

(*26*) Flintsch, G., Dymond, R. and J. Collura. *NCHRP Synthesis 335: Pavement Management Applications Using Geographic Information Systems,* 2004.

(*27*) AASHTO. *Guidelines for Maintenance Management Systems,* 2005.

(*28*) Friedman, David, Monteith, M. C., Kay, D. H., Couts, V. B., Trombly, J. W., Bratvold, D., and I. Hirshmann. *NCHRP Report 525 Volume 11: Disruption Impact Estimating Tool—Transportation (DIETT)—A Tool for Prioritizing High-Value Transportation Choke Points,* Contractor's Final Report Prepared for NCHRP Project 20-59(9), 2006.

(*29*) Cambridge Systematics, Inc., Parsons Brinckerhoff and Venner Consulting, Inc. *Final Report for NCHRP Research Results Digest 317: Prototype Software for an Environmental Information Management and Decision Support System,* NCHRP Web-Only Document 103, Contractor's Final Report for NCHRP Project 25-23(2), 2006.

(*30*) Cambridge Systematics, Inc., PB Consult, and Texas Transportation Institute. *NCHRP Report 551: Performance Measures and Targets for Transportation Asset Management,* Contractor's Final Report for NCHRP Project 20-60, 2006.

(*31*) Cambridge Systematics, Inc., Texas Transportation Institute, University of Washington and Dowling Associates. *NCHRP Web-Only Document 97: Guide to Effective Freeway Performance Measurement—Final Report and Guidebook,* Contractor's Final Report for NCHRP Project 3-68, 2006.

(*32*) AASHTO. *Measuring Performance Among State DOTs,* 2006.

(*33*) Padgette, Robert. *Effective Organization of Performance Management,* Contractor's Final Report for NCHRP Project 8-36(47), 2006.

(*34*) National Research Council Board on Infrastructure and the Constructed Environment. *Measuring and Improving Infrastructure Performance,* National Academy Press, Washington, D.C., 1995.

(*35*) FHWA. *Status of the Nation's Highways, Bridges, and Transit: 2006 Conditions and Performance Report,* 2006.

(*36*) U.S. Department of Transportation. *Fiscal Year 2006 Performance and Accountability Report,* 2006.

(*37*) FHWA. *Transportation Asset Management in Australia, Canada, England, and New Zealand,* 2005.

(*38*) FHWA, American Trade Initiatives, and LGB and Associates, Inc. *Transportation Performance Measures in Australia, Canada, Japan, and New Zealand,* 2004.

(*39*) NZ National Asset Management Steering (NAMS) Group, Institute of Public Works Engineering of Australia (IPWEA). *International Infrastructure Management Manual,* 2000.

APPENDIX B

Pilot Program

This section describes the pilot conducted of the Interstate Asset Management Framework. The pilot was conducted primarily to test application of the framework using existing data and tools. Section B.1 details the approach of the pilot. Section B.2 describes the data obtained. Section B.3 details the analysis performed, and Section B.4 summarizes conclusions from the pilot.

B.1 Approach

Participants in the pilot effort were selected by the research panel, and included representatives from the DOTs of California, South Carolina, and Wisconsin. Each participant identified an IHS corridor from their DOT's IHS network to include in the analysis. The corridors included in the pilot were as follows:

- **California—**Interstate 80;
- **South Carolina—**Interstate 95 (approximately 100 miles of this highway, extending south from the North Carolina border); and
- **Wisconsin—**Interstate 94.

The research team requested the same basic data and performed, to the extent feasible, the same analyses on the data from each pilot participant. The research team requested the following types of data from each participant, at a minimum:

- **Pavement/Highway Inventory—**Inventory and condition data for each pavement section, including the agency's HPMS file and additional pavement condition measures not included in the HPMS;
- **Bridge—**Pontis database or NBI file;
- **Other Structures—**Listing of other structures, including structure type, annual maintenance cost, replacement cost, estimated remaining service life, and any available listing of deficiencies for the asset;
- **Roadside Assets (signs, striping, traffic operations equipment, guardrails, right-of-way, shoulders, and any of the other structures listed above for which the agency lacks detailed asset data)—**Inventory of roadside assets including asset type, extent (e.g., counts of the asset over the corridor), and annual maintenance cost for the asset;
- **Facilities (rest areas, weigh stations, toll booths and any other buildings or other facilities associated with the pilot corridor)—**Inventory of facilities including facility type, location, and annual maintenance cost; and
- **Other—**Information on the status, scope and cost of planned, programmed or in-progress projects for the pilot corridor, counts of crashes and fatalities by year for the past five years on the pilot corridor.

Agencies were requested to provide whatever data they had already collected and were readily available from the set of data items described above, as well as additional relevant data (e.g., a description of risk scenarios or travel demand data that could be used to facilitate risk analysis).

Data were requested in December 2007 and received between January and February 2008. Once data were obtained, the research team performed a series of analyses to characterize existing conditions of each corridor, and predicted future conditions under different funding and risk scenarios. These analyses are described in Section B.3 and are considered typical of that required to develop an Interstate Asset Management Plan.

B.2 Summary of Data Obtained

All of the pilot participants were extremely helpful in facilitating collection of the data for the pilot, despite the fact that this frequently required coordination with a number of different groups within their respective agencies. Table B.1 summarizes the data obtained from the pilot participants. The following paragraphs further detail the data obtained for each asset category.

- **Pavement/Highway Inventory—**All of the pilot participants had HPMS data and additional pavement condition

Table B.1. Summary of pilot data obtained.

Category	Data Obtained
Pavement/ Highway Inventory	• All participants had HPMS data • All participants had data on existing/historic conditions • One participant had PMS runs available
Bridges	• All participants had NBI data • All participants had additional element-level data • Two participants had cost models needed to run Pontis • One participant had supplemental information on structure-related risk (e.g., seismic, guardrails, scour, etc…)
Other Structures	• Limited data available
Roadside Assets	• Signs/pavement markings for one-third of the participants
Facilities	• Two participants had basic inventory and cost data for rest areas
Other	• All participants had crash data • All participants had project data • All participants have (or will soon have) travel demand model data, but none were in a position to define risk scenarios to analyze using travel demand data • One participant had some level of risk-related data – details on structure vulnerabilities of different types, with scores

data. One participant (South Carolina) had an in-house capability to simulate future conditions using its Pavement Management System (PMS) and provided PMS results for the pilot corridor.

- **Bridges—**All of the participants had NBI data and additional element-level data. Two participants (South Carolina and California) had developed deterioration and costs models for use in predicting future bridge conditions. One participant (California) provided additional data on a variety of risk-related bridge needs, including seismic vulnerabilities, scour mitigation needs, and safety improvement (guardrail) needs.
- **Other Structures—**Limited data were available on other structures. All of participants store some amount of structure data for nonbridge structures (e.g., tunnels and some culverts) in their bridge management system (BMS). Except for the data available through their BMS, none of the participants had available additional detailed structure inventory and condition data.

Roadside Assets. Limited data were available for roadside assets. One participant (Wisconsin) had inventories available for signs and pavement markings. Another participant (California) had data on roadside vegetation needs, as well as system-level data on roadside assets to support a maintenance budgeting process, though this was not localized to the pilot corridor. In some cases, participants indicated that individual districts likely had additional inventory data (e.g., in the form of spreadsheet inventories), but this information was not readily available and attainable within the timeframe requested.

Facilities. Facilities specific to the IHS for the pilot corridors included rest areas along each corridor. Two of the participants (South Carolina and Wisconsin) provided details on their rest areas, including maintenance and renewal costs.

Other Data. All of the participants had project information for programmed projects on the pilot corridors. All of the participants provided data on crashes and fatalities on the pilot corridors.

All of the participants had additional data beyond the minimum data requirements described above. For example, California recently updated its process for developing its Strategic Highway Operations and Protection Plan (SHOPP) and had data and results available from that effort. South Carolina had detailed data on highway interchanges and interstate highway sections, including potential interchange improvements and performance measures related to highway sections and interchanges in its Interactive Interstate Management System (IIMS). Figure B.1 shows an example screen from the IIMS showing an interchange diagram and predicted performance measures for an I-95 interchange. Wisconsin provided information on its passenger and freight demand models, as well as additional freight analyses.

Regarding risk, two of the participants had considered risk in operational planning in some manner (California through identifying "emergency lifeline routes" and South Carolina through developing hurricane evacuation plans). Also, California had significant additional data available regarding structure-related risk, as described above. All of the participants either had (California, Wisconsin) or were developing

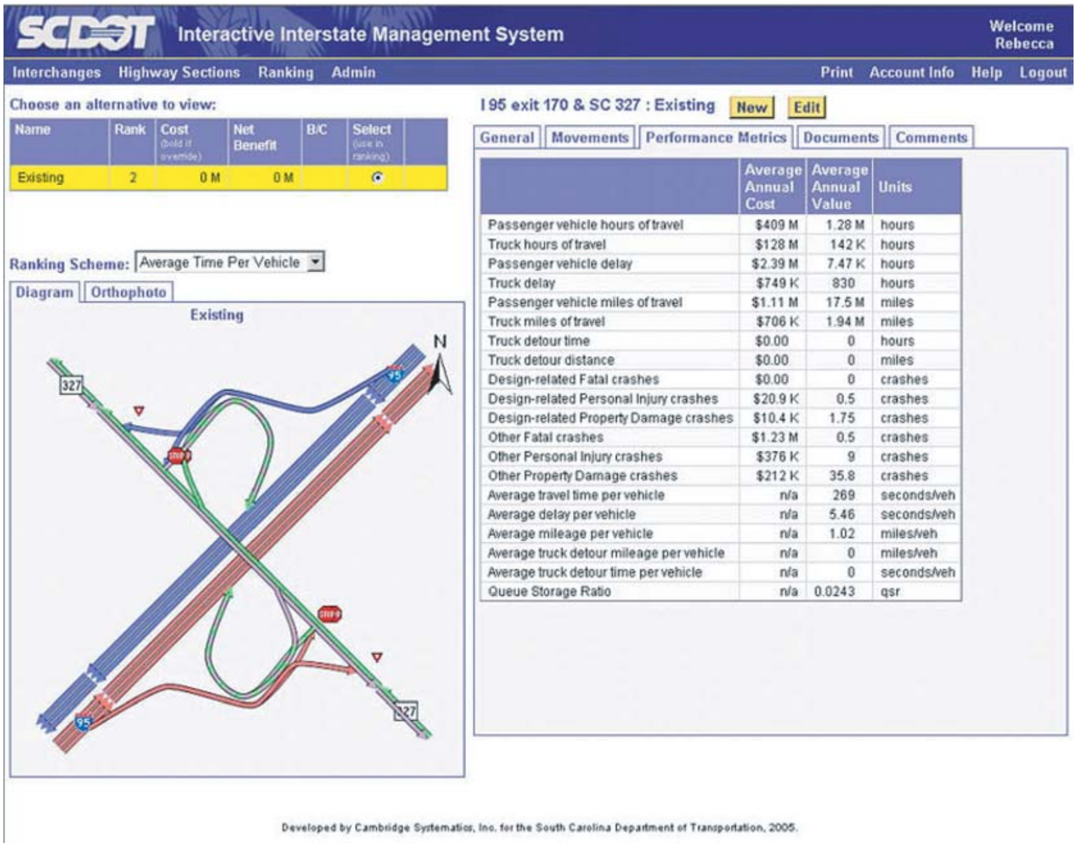


Figure B.1. Example South Carolina IIMS screen.

(South Carolina, through participating in the I-95 Corridor Coalition travel demand model development effort) travel demand models that could be used to support risk analysis. However, none of the participants had identified risk scenarios that could be used in conjunction with their travel demand models for quantifying potential consequences of different risks.

B.3 Analyses Performed

Using the data described in the previous section, a set of analyses was performed for each of the pilot corridors. The goal of the analysis was to predict future performance of the pilot corridors for different budget scenarios in terms of the core measures recommended for a typical Interstate Asset Management Plan. Also, to the extent feasible, analyses were performed to demonstrate application of the risk assessment approach recommended previously. The paragraphs below describe the analyses performed and specific analytical tools used for the pilot.

Pavement/Highway Inventory. This category of data can be used to predict pavement conditions, as well as a range of other measures, including mobility and safety-related measures. The research team used the FHWA Highway Economic Requirements System—State Version (HERS-ST)—to predict mobility and safety-related measures. HERS-ST is available at no cost and requires HPMS data as input. All of the pilot participants had this data available, and it was thus feasible to run HERS-ST for each of the pilot corridors.

HERS-ST predicts a limited number of measures of pavement condition, including Present Serviceability Rating (PSR), and International Roughness Index (IRI). However, HERS-ST's modeling of pavements is rudimentary compared to that feasible in most agency pavement management systems (PMS). Thus, where feasible, supplemental analysis results were used as an alternative to HERS-ST for predicting pavement condition. In the case of South Carolina, agency PMS results were available for the pilot corridor. For Wisconsin, research team members working with Wisconsin DOT on a separate effort used the remaining service life approach described in Interim Report 1 to analyze pavement conditions for the pilot corridor. For California, supplemental analyses were available at a system level, but not for the pilot corridor. Thus, the research team relied upon HERS-ST for predicted pavement conditions.

Bridges. For South Carolina, a set of Pontis simulations was run for the pilot corridor using South Carolina Pontis models. For California DOT (Caltrans), the bridge needs analysis approach defined for Caltrans' SHOPP update process was used. This entailed using Pontis to generate functional improvement needs, predict deterioration over time, and predict the benefits of certain types of bridge needs. For Wisconsin, state-specific models were not available and element data, though available, were not stored in the form of a Pontis database. Thus, NBIAS was used to predict bridge conditions for the Wisconsin corridor.

Other Structures and Roadside Assets. As noted previously, limited data were available for other assets besides pavement and bridges. Where such data existed, they were either in terms of remaining service lives of assets (e.g., of facilities) or average condition/level of service of some population of assets. The research team developed and tested spreadsheet models for applying a remaining service life approach to assets for which remaining life and rehabilitation/replacement costs were available, and for applying a maintenance level-of-service model to assets for which levels of service were defined.

Figure B.2 illustrates the results of applying a simple remaining service life model. In this example, an asset (e.g., a facility) is deemed to be "functioning as intended" if its age is less than the service life for that asset, and is deemed to be not functioning as intended if it has no remaining service life. Given an annual budget, it is a straightforward calculation to predict the age distribution over time for a population of assets, aging the assets each year of the analysis period and simulating renewal of an asset that has reached the end of its service life, to the extent this is feasible given the available budget. Performing this calculation requires remaining service life for each asset, renewal cost, and service life for a newly renewed asset. The figure shows the percent of a group of assets functioning as intended. In this example a $2M annual budget results in 63 percent of the assets functioning as intended at the end of 20 years (compared to a starting value of 75 percent), a $1M annual budget results in having 31 percent functioning as intended at the end of the period, and a $0.5M annual budget results in approximately 16 percent functioning as intended.

Where other agency systems and data were available, such as the SCDOT IIMS and data associated with the Caltrans SHOPP update process, the research team reviewed this information, but did not integrate these data sources into the analysis process except as otherwise noted.

Risk. The research team demonstrated the risk assessment approach for examining structure-related risk using data provided by Caltrans. Structure risks considered systematically by Caltrans include risks of seismic events, bridge scour, and guardrail failure. Previously Cambridge Systematics worked with Caltrans to develop a utility measure that included measures of vulnerability and consequence for each of these risks, as well as for other bridge investment needs. For example, for seismic risk, Caltrans has developed a list of proposed seismic retrofit projects, and calculated seismic vulnerability scores for each bridge. These scores provide an indication of the degree of risk, and data on the functionality of the bridge (e.g., traffic, detour distance around the bridge) provides an

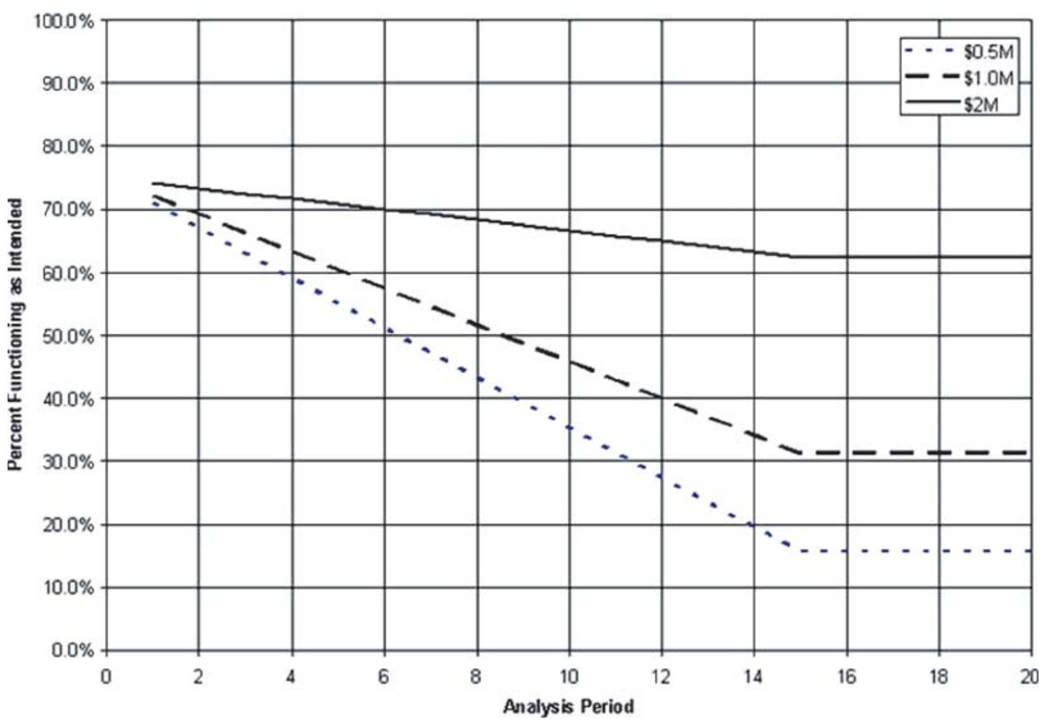


Figure B.2. Example calculation of percent functioning as intended versus annual budget using service life data.

indication of the consequences in the event of a seismic event. These measures were combined to predict the utility of addressing each identified seismic need, and to develop a relationship between utility achieved and predicted spending.

AssetManager NT. AssetManager is a set of analytical tools initially developed through NCHRP Project 20-57, and now licensed through AASHTO. AssetManager NT is a network-level tool that combines analysis results generated through other systems, displaying predicted conditions for a range of different performance measures and budget assumptions. The system is well-suited for applications such as supporting development of an Interstate Asset Management Plan, where results from different systems are combined with the goal of providing an integrated view of predicted conditions.

The research team imported into AssetManager NT data on pavement conditions, bridge conditions, mobility, safety, and risk. In the system one can view predicted conditions over time for a pilot corridor for a specified distribution of funds. Figure B.3 shows an example screen from the system. In this example results are shown for six different performance measures (pavement condition, bridge health index, number of Structurally Deficient bridges, delay, user costs, crash rate) for four different budget allocations. Each pane in the figure represents results for a different performance measure, and each series graphed shows results for a different budget allocation.

METIS. The major limitation of AssetManager is that the system shows results for different user-specified budget allocations, but does not provide support for optimizing a budget between different objectives. Performing a cross-asset allocation is a difficult proposition. Typically, one would solve such a multi-objective optimization problem by first defining a utility measure that encompasses all of the objectives one attempts to achieve by investing in IHS assets (as was performed for helping characterizing benefits of mitigating structure-related risks described above). Previously Cambridge Systematics developed a tool for solving multi-objective optimization problems using an evolutionary process, in which a user views different candidate solutions (which correspond to different potential objective functions), and gradually converges upon an optimal solution through manual evaluation of potential solutions. The research team used this tool, the Multi-Objective Evolutionary Tool for Interactive Solutions (METIS), to pilot the process of optimizing resources allocated to IHS assets.

Figure B.4 shows an example screen from METIS. In this screen, alternative resource allocation results are shown for four different candidate solutions with different weights on four different objectives: maximizing pavement condition (measured

Figure B.3. Example AssetManager screen.

Figure B.4. Example METIS screen.

using a pavement quality index), minimizing delay, minimizing the number of structurally deficient bridges, and mitigating seismic risk. As is the case for AssetManager, METIS uses analysis results generated from other systems to support its projections. The end user reviews each solution, selecting one solution to rule out at each analysis step, and the system uses this information to narrow in on an optimal allocation of resources between assets for best meeting the competing objectives.

B.4 Conclusions

The research team developed the following conclusions on the basis of the pilot analysis:

1. IHS owners typically have data readily available concerning highway inventory and traffic, pavement conditions, bridge conditions, crashes, rest areas and planned projects. IHS owners have limited data available on other structures besides bridges, as well as on roadside assets. Further, IHS owners typically lack at least some of the data required to support the risk analysis approach recommended as part of the Interstate Asset Management Framework.
2. It is feasible to predict basic measures of pavement condition, bridge condition, mobility, and safety for IHS assets using readily available data and tools. Key analytical tools for such an exercise include an agency's PMS and BMS (typically the AASHTO Pontis BMS), FHWA's HERS-ST, and AASHTO's AssetManager. Where an agency does not have a management system implemented to predict future IHS conditions, one can use HERS-ST as an alternative for predicting pavement conditions, and FHWA's NBIAS for predicting bridge needs.
3. It is feasible to predict measures related to other structure-related risk using available tools, and supplemental analyses, provided an agency has compiled data on these risks. One of the three pilot participants had the data available to support such an exercise. Chapter 4 describes available tools for assessing structure-related risks.
4. The three pilot participants had sufficiently detailed data and tools to support analysis of pavement and bridge conditions. They had data on some other assets besides pavements and bridges, but generally lacked analytical tools or models for predicting conditions of these assets over time. Chapter 4 describes data and tools needed for modeling needs of these assets.
5. It is feasible to use a utility maximization approach to approximate the optimal allocation of resources between different IHS assets to achieve a set of objectives. However, supplemental analysis outside of existing tools available from AASHTO and FHWA is needed to implement such an approach.

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	Air Transport Association
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
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
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