NCHRP REPORT 677

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Development of Levels of Service for the Interstate Highway System

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP REPORT 677

Development of Levels of Service for the Interstate Highway System

DYE MANAGEMENT GROUP, INC.
Bellevue, WA

WITH

PAUL D. THOMPSON CONSULTING
Castle Rock, CO

QUALITY ENGINEERING SOLUTIONS
Conneaut Lake, PA

Subscriber Categories
Administration and Management • Economics • Highways •
Maintenance and Preservation • Planning and Forecasting • Policy

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.
2010
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 677

Project 20-74A
ISSN 0077-5614
ISBN 978-0-309-15516-8
Library of Congress Control Number 2010938853

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.

The members of the technical panel selected to monitor this project and to review this report were chosen for their special competencies and with regard for appropriate balance. The report was reviewed by the technical panel and accepted for publication according to procedures established and overseen by the Transportation Research Board and approved by the Governing Board of the National Research Council.

The opinions and conclusions expressed or implied in this report are those of the researchers who performed the research and are not necessarily those of the Transportation Research Board, the National Research Council, or the program sponsors.

The Transportation Research Board of the National Academies, the National Research Council, and the sponsors of 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 the 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

COOPERATIVE RESEARCH PROGRAMS

CRP STAFF FOR NCHRP REPORT 677

Christopher W. Jenks, *Director, Cooperative Research Programs*
Crawford F. Jencks, *Deputy Director, Cooperative Research Programs*
Andrew C. Lemer, *Senior Program Officer*
Sheila Moore, *Senior Program Assistant*
Eileen P. Delaney, *Director of Publications*
Hilary Freer, *Senior Editor*

NCHRP PROJECT 20-74A PANEL
Field of Special Projects

Kirk T. Steudle, *Michigan DOT, Lansing, MI* (Chair)
Carl Chase, Jr., *Lexington, SC*
Tremain V. Downey, *California DOT, Sacramento, CA*
Wendy L. Gagnier, *AASHTO, Washington, DC*
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, *Baldwin, 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

NCHRP Report 677 presents a level-of-service-based approach to describing performance of Interstate Highway System (IHS) assets. It also provides a template and process that state departments of transportation (DOTs) can use to implement this approach for managing their IHS assets. Well-described levels of service are an effective means for communicating with public officials, highway users, and other stakeholders about asset performance and resources needed to ensure adequate performance. The IHS, the result of a major national investment, is vital to the nation's economy and an increasingly critical contributor to global production and distribution systems, but the system's assets are owned and managed by the states. While the specific measures that define excellent or poor levels of service may vary from one state to another, a consistent framework and measures for IHS levels of service would support benchmarks that DOTs and other responsible agencies can use to assess their Interstate maintenance and preservation needs and manage their IHS assets.

Global trade, population growth, and other factors are driving large increases in heavy trucks and other traffic on many of the nation's highways. This traffic growth has accelerated rates of pavement and other roadway deterioration and increased the significance of declining levels of service as a drain on the nation's economic vitality. At the same time, demands for on-time delivery of goods; personal mobility; and a safe, reliable, and environmentally responsible highway system have raised system maintenance costs and increased public dissatisfaction with service disruptions associated with highway repair and reconstruction.

One of the nation's most significant investments in transportation infrastructure is the Dwight D. Eisenhower System of Interstate and Defense Highways, typically referred to simply as the Interstate Highway System. The IHS, now in its sixth decade of service, is vital to the nation's economy and is an increasingly 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 the system's assets. Yet, limited funds make it increasingly difficult for many agencies to maintain adequate service on their IHS and other highways.

The IHS represents a substantial national investment in pavements; bridges and other structures such as retaining walls and large culverts; roadside assets such as fencing, guardrail, pipes and ditches; rest areas; and traffic-operation equipment such as signs and signals. The overall performance of the IHS is a function of the services these diverse assets are expected to provide, including smooth ride, safe operating speeds, crash avoidance and protection from serious injury, and fast and reliable access to markets and jobs. *Levels of* *service* describe in specific terms the degree to which a highway system generally, and assets comprising that system in particular, provides customer service, satisfies the demands of system users, and meets the objectives of other stakeholders. The development of a consistent framework and measures for IHS levels of service would provide benchmarks that DOTs and other responsible agencies can use to assess their Interstate maintenance and preservation needs and manage their IHS assets.

This report is the product of NCHRP Project 20-74A, research undertaken to develop (1) a standard way to describe the service level of Interstate Highway System assets and (2) a process that agencies can use to prepare a template for describing levels of service. The intent in this research was that levels of service would be defined in a standard way—for example, an "A through F" or "1 to 5" scale—with descriptive explanation of these ratings in terms that are meaningful to stakeholders. Specific indicators of service level might be suggested (for example, the International Roughness Index [IRI] as an indicator of pavement surface), but the measures that define level of service (for example, IRI less than 45 is level of service "A") could vary from one state to another. This report presents a template that DOTs can use to describe and measure IHS performance in their jurisdictions and a guide for implementing the level of service measurement process.

NCHRP Project 20-74A built on previous NCHRP-sponsored research to develop a practical framework for applying asset management principles and practices to managing Interstate Highway System investments. *NCHRP Report 632: An Asset-Management Framework for the Interstate Highway System* describes concepts, tools, and data requirements for implementing and using such a framework. For the research presented here, a team led by Dye Management Group, Inc., (1) assessed the current state of practice among transportation agencies regarding Interstate asset level of service measurement and (2) developed a scale and definitions of levels of service for Interstate system assets in order to address concerns of highway users, transportation agencies, and other stakeholders.

The research team selected level of service indicators for major assets, for which consistent measures exist or could be developed and used to establish service-level benchmarks and thresholds. The team then developed a template that can be used to assess, analyze, and report IHS performance at various levels of geographic focus and considering subsystem characteristics that may be important to management decisionmaking, such as urban or rural character. Throughout the research, the NCHRP project panel and other invited participants provided comments to enhance the likelihood that the research results would be useful to DOTs and other agencies responsible for IHS-asset management. This report includes guidance on implementing and using the level-of-service measurement framework. Fully implemented, the template and process described here will be useful for communicating with policymakers and other stakeholders about critical funding needs, supporting resource-allocation decisions, and demonstrating accountability in IHS management.

CONTENTS

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

SUMMARY

Development of Levels of Service for the Interstate Highway System

Background

The purpose of NCHRP Project 20-74(A) was to develop an approach to measuring levels of service of the Interstate Highway System (IHS). The IHS is perhaps the most significant surface transportation asset in the United States. The predecessor report to this research, NCHRP Project 20-74, states: "It is impossible to overstate the importance of the IHS to global, national, regional, and local area movements of people and goods." Given its significance, there is a very strong case for measuring IHS performance.

NCHRP Project 20-74 was undertaken to develop an asset management approach for the IHS. The initial research was published as *NCHRP Report 632: An Asset Management Framework for the Interstate Highway System.* One essential aspect of asset management is the use of performance measures to quantify the service levels that are being provided. This project, NCHRP Project 20-74(A), Development of Service Levels for the IHS, presents an approach to developing levels of service.

Research Objectives

The objectives of this research are to develop a standard way to describe the level of service of IHS assets and a process that transportation agencies can use to describe levels of service. The research presents a template that transportation agencies can use to measure the conditions of the IHS in their jurisdictions and a guide for implementing the level of service process. This will be used to communicate levels of service in terms that are meaningful to policymakers and other stakeholders. Agency leaders and managers will use this information to

- Communicate critical funding needs to decisionmakers,
- Direct resources to problem areas, and
- Demonstrate accountability to taxpayers.

This work also can provide background for discussions at the national level about IHS performance measurement.

Research Approach

The research team conducted the analysis under the guidance of the project panel. The research approach involved the following:

Assess the State of the Practice

This research identifies level-of-service indicators and measures that would enable monitoring of IHS conditions against national objectives. The team conducted a literature search, using resources from TRB, FHWA, NHTSA, AASHTO, and others.

In addition to the literature search, the team had first-hand experience with LOS practices in many state departments of transportation. This knowledge was particularly helpful for assets other than pavements and bridges (e.g., drainage, traffic control devices, and other roadside features), because much of the state-of-the-practice information in these areas is unpublished.

Although the terms "service level" and "level of service" are often used interchangeably in practice, the states that have been assessing and rating asset conditions the longest generally use level of service (LOS) as the preferred term. Therefore, level of service, or LOS, is used throughout this report.

A great deal of the asset LOS work currently being done by state DOTs, especially for assets other than pavements and bridges, is a component part of their maintenance quality assurance programs.

Develop LOS Indicators and Measures

The state-of-the-practice research yielded the most widely used LOS indicators and measures. Also, three state DOTs were identified as demonstration states that represented a cross-section of best practices (Florida, Mississippi, and Washington). The recommended LOS approach was applied using available data for these three states. The purpose was to demonstrate the application of LOS measures using actual data and to better understand the issues associated with national implementation.

A draft template was developed for each asset type and outcome area. The template showed each asset type, asset element, and description, along with LOS indicator, measure, and rating scale.

Develop Final LOS Template and Implementation Guide

The research team conducted a workshop in October 2009 to validate the research with the NCHRP panel and representatives from the demonstration states. The LOS template was then finalized, incorporating comments and findings from the workshop. An implementation guide was developed to assist department of transportation officials in developing an implementation plan and to assist users in data collection and application of the LOS template across asset groups and outcome areas.

State of the Practice

The research revealed a mature existing body of work and work in progress related to LOS and performance measurement for the nation's highway transportation system. This body of work is summarized and expanded on in two closely related NCHRP reports: *NCHRP Report 551: Performance Measures and Targets for Transportation Asset Management,* completed in 2006 and *NCHRP Report 632: An Asset Management Framework for the Interstate Highway System,* completed in 2009.

The following summarizes findings regarding the state of the practice:

- There is a mature state of the practice in measuring and reporting the operational performance of transportation systems at the state and regional levels, some of which is applicable to network-level reporting of IHS LOS. In almost all states, there is system-level measurement and reporting of LOS for major assets, as well as mobility and safety performance.

- There are well established and improving programs of data collection and reporting that address pavement and bridges as discrete asset classes. The states' pavement and bridge management systems, including condition assessment and reporting, provide a basis for establishing a national LOS assessment program for the IHS. The national focus is on bridges and pavements under the impetus of national data collection and reporting requirements, including FHWA requirements for the Highway Performance Monitoring System (HPMS) and the National Bridge Inspection program.
- There are a growing number of states that collect and report data on the functional performance or maintenance condition of IHS assets other than pavements and bridges. These states have established measurement and reporting programs that address maintenance LOS—often referred to as Maintenance Quality Assurance (MQA). MQA is now a widely adopted process with an established state of the practice. Typically, through their MQA processes, states address the functional performance of all assets within the Interstate right of way, including roadside features, drainage systems, and traffic control devices. With some variation in measurement approaches, states measure the LOS of these assets to determine if they are functioning as designed to meet asset preservation, mobility, and safety objectives. There is a growing body of best practice information and experience for these asset types that can provide the basis for a consistent national approach.
- For the mobility outcome area, previous research efforts, including NCHRP Projects 20-74, 20-60, and 20-24, concluded that state practices vary widely. Definitions, goal areas, and data collection and analysis techniques create difficulties for meaningful comparison of LOS measures at the national level. Although the state-of-the-practice research did not find much commonality among the states to allow a concise statement of practices, there were sufficient measures and data available to warrant development of a few key LOS indicators and measures for mobility. These were mainly related to measures of traffic delays and congestion, including percent of heavily congested travel, percent of on-time arrivals, and volume-to-capacity ratios.
- A well-developed state of the practice exists for measuring and reporting safety outcomes at the national and state levels. Transportation safety has long been a policy priority, with the systematic monitoring and reporting of fatalities, injuries, and crashes on the highway system. All state DOTs (or their sister public safety agencies) monitor and report safety performance. NHTSA has standardized the reporting of traffic fatalities through their Fatality Analysis Reporting System (FARS). Safety levels of service in terms of fatalities and fatality rates are already being reported for all public roads, including the IHS.
- Demonstration states identified some consistent goals or outcomes for the IHS. These include preservation, mobility, and safety. These goals are particularly well suited for the IHS since the original intent of the system was to provide safe, dependable, high-speed interstate transportation.

Level of Service Template

The LOS template provides direction to states and other jurisdictions for establishing their own IHS LOS programs. The template offers a national measurement approach for each of the goals/outcomes determined to be feasible at this time: preservation, mobility, and safety. The template specifies the elements to be measured along with their definitions and LOS indicators, measures, and thresholds.

Table S-1 illustrates the template. In this case, the outcome is preservation and the asset class is traffic control devices—passive. The "elements" are those aspects of asset to be measured,

Table S-1. Illustration of LOS template.

Goal/Outcome	Asset Class	Element	Definition	Indicators	Measure	Level of Service Thresholds				
						A	B	C	D	F
Preservation	Traffic Control Devices—Passive	Pavement Markings/ Symbols/ Legends	This element includes any pavement markings, other than line striping, such as exit-lane and through-lane arrows, route numbers, and symbols.	Faded, missing.	% of elements deficient.	0 - 4.9	5.0 - 9.9	10.0 - 14.9	15.0 -19.9	≥ 20
		Raised Pavement Markers	This element consists of reflective devices placed on the pavement to mark travel lanes and pavement edges, as well as ramp lanes and gore areas.	Non-reflective/ missing/ damaged.	% of elements deficient.	0 - 4.9	5.0 - 9.9	10.0 - 14.9	15.0 -19.9	≥ 20
		Signs	This element consists of all types of traffic signs, including regulatory and warning signs, guide and informational signs, regardless of the type of mounting (roadside posts, overhead sign structures, or attached to bridge structures).	Non-reflective/ missing/ damaged.	% of elements deficient.	0 - 4.9	5.0 - 9.9	10.0 - 14.9	15.0 -19.9	≥ 20

such as pavement markings. The "indicators" are the conditions to be measured, while the "measures" quantify the extent to which conditions exist. The "level of service thresholds" present different levels in which the LOS measures can be grouped. The thresholds are represented in two ways: as letter grades that can be understood easily by policymakers and other nontechnical personnel, and as quantified values for transportation professionals and other technical audiences.

The actual measured condition for each element can be plotted on this scale to clearly present the LOS currently being provided by the IHS.

Implementation Guide

The Implementation Plan and User Guide will assist agencies in developing and implementing their IHS LOS processes. The Implementation Plan will help administrators responsible for agency asset management while the User Guide is intended for those who will oversee the day-to-day LOS assessment process.

Implementation Considerations

There are a number of important considerations in developing an effective IHS LOS program. These include the frequency of LOS surveys, data collection, using a pass/fail versus a quantitative approach, data weighting, aggregation of measures, and implementation issues.

Appendices

IHS LOS measurement is complex, requiring considerable research and analysis. Practitioners developing such measures will benefit from the detail in the appendices (provided on the accompanying CD-ROM) on the IHS measurement state of the practice and the analysis of specific goal/outcome areas and assets.

CHAPTER 1

Introduction

1.1 Background

The purpose of NCHRP Project 20-74(A) was to develop an approach to measuring levels of service on the Interstate Highway System (IHS). The IHS is perhaps the most significant surface transportation asset in the United States. The predecessor report to this research, NCHRP Project 20-74, asserts that "It is impossible to overstate the importance of the IHS to global, national, regional, and local area movements of people and goods." Given its significance, there is a very strong case for measuring IHS performance.

NCHRP Project 20-74 was undertaken to develop an asset management approach for the IHS. The initial research was published as *NCHRP Report 632: An Asset Management Framework for the Interstate Highway System.* One essential aspect of asset management is the use of performance measures to quantify the service levels that are being provided. This project, NCHRP Project 20-74(A), "Development of Service Levels for the IHS" presents an approach to developing service levels.

1.2 Research Objectives

The research objectives of NCHRP Project 20-74(A) were

- To develop a standard way to describe the level of service of IHS assets and
- To develop a process that agencies can use to prepare a template for describing levels of service.

The purpose of LOS measurement is to establish a series of indicators and associated measurements that describe the LOS for the IHS. This is to be used to communicate LOS in terms that are meaningful to policymaker and stakeholder audiences. Agency leaders and managers will use this information to

- Communicate critical funding needs to decisionmakers,
- Direct resources to problem areas, and
- Demonstrate accountability to taxpayers.

This work also can provide a guide for discussing IHS performance measures at the national level.

1.3 Research Approach

The research approach involved the following activities.

1.3.1 Assess Current State of the Practice

The research was designed to identify level of service (LOS) indicators and measures that would enable monitoring of LOS against national objectives for the IHS. A literature search was conducted using the on-line search facilities of TRB, FHWA, NHTSA, AASHTO, and others.

Two documents that were particularly helpful in this endeavor were *NCHRP Reports 551* and *632*. The latter report was from NCHRP Project 20-74, the predecessor to the current research.

In addition to the literature search, several of the research team members had first-hand experience with LOS practices in at least 12 state DOTs. This knowledge was most useful for assets other than pavements and bridges (e.g., drainage, traffic control devices, and other roadside features) since the state-of-the-art practices that exist in these areas are mostly unpublished.

Members of the research team also attended the Second National Maintenance Quality Assurance Peer Exchange, held in Raleigh, NC, September 22–23, 2008. Much of the asset LOS work currently being done by state DOTs is a component part of their maintenance quality assurance programs.

1.3.2 Develop LOS Indicators and Measures

Based on the state of the practice, the most widely used LOS indicators and measures were identified. Also, three state DOTs were identified as demonstration states that represented a cross-section of best practices (Florida, Mississippi, and Washington). The recommended LOS approach was applied using available data for these three states. The purpose was to demonstrate the application of LOS measures using real data and to better understand the issues to be addressed as part of any implementation.

A draft template was developed for each asset type and outcome area. The template showed each asset type, asset element, and description, along with LOS indicators, measures, and a rating scale.

1.3.3 Develop Final LOS Template and Implementation Guide

A workshop was conducted in October 2009 to validate the research with the NCHRP panel and representatives from the demonstration states. This group included representatives from eight state DOTs, a county road agency, AASHTO, and the academic and consulting communities. The LOS template was then finalized, incorporating comments and findings from the workshop. An implementation guide was developed to assist DOT officials in developing an implementation plan and to assist users in data collection and application of the LOS template across asset groups and outcome areas.

The results of these research efforts are presented in this report.

1.4 Report Organization

This report is organized into six chapters and two appendices as follows:

- Chapter 1: Introduction presents the research objectives, analysis framework, and definitions of the terms and concepts used in this report.
- Chapter 2: Summary of the State of the Practice presents the highlights of Appendix A material on the state of current practice for LOS assessment.
- Chapter 3: Summary of Indicators and Measures for Template Development presents the highlights of Appendix B material on recommended LOS indicators and measures for template development.
- Chapter 4: Level of Service Template presents each asset class and outcome, and associated definitions, indicators, measures, and recommended thresholds for the LOS A through F scale.
- Chapter 5: Implementation Guide describes, for DOT users, how to implement and use the template.
- Chapter 6: Implementation Considerations provides additional insight on template implementation from a state DOT perspective.
- Appendix A: State-of-the-Practice Research (available on the accompanying CD-ROM) presents the results of the state-of-the-practice research regarding measurement and reporting of highway LOS.
- Appendix B: Development of Levels of Service for the IHS (available on the accompanying CD-ROM) describes the process and results of developing levels of service, applying them to the demonstration states, and refining them through the LOS workshop.

1.5 Definition of Terms

To ensure clarity and understanding of the subject matter, the following definitions of the principal terms used throughout this report are provided:

Asset Class—An asset class is a group of similar roadway or roadside assets, such as bridges, pavements, or drainage.

Asset Element—An asset element is a characteristic of an asset that is evaluated to determine the asset's condition. By applying a performance measure to the asset element, the LOS for that element can be determined.

Asset Management—As noted in previous studies, AASHTO defines asset management as follows:

> 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 decisionmaking based upon quality information and well-defined objectives.[1]

Condition Assessment—Condition assessment is the process of applying performance measures to asset elements to establish levels of service.

Deficiency Criteria—Deficiency criteria are the characteristics of a LOS indicator that identify whether it should be counted or measured (e.g., "the traffic sign's message is not visible to motorists").

Level of Service (LOS)—In the context of asset management, this term is synonymous with service level. Although there is the potential of confusion with the identical term used in traffic studies (i.e., traffic levels of service), highway maintenance agencies have been using the term "level of service" for many years to describe the condition of roadway and roadside assets and the quality of maintenance services. Although "level of service" and "service level" can be used interchangeably, level of service (or LOS) will be used throughout this report. The term is nearly synonymous with performance measure, but there is a subtle difference

[1]Cambridge Systematics, Inc., et al., *NCHRP Report 632: An Asset Management Framework for the Interstate Highway System,* Transportation Research Board (2009).

in usage. In practice, LOS is used to characterize the performance measure by assignment of a letter grade or score to a specific performance measure or range of measures. In this report, letter grades are used to describe the LOS of specific assets (e.g., the statewide average performance of traffic signs on the IHS might be described as having an LOS of "B," which means that the performance measure is between 5 and 10 percent of traffic signs deficient).

LOS Indicator—An LOS indicator describes the condition or type of deficiency, of an asset or asset element in general terms (e.g., "not functioning as intended" or "damaged").

LOS Measure—Synonymous with performance measure, an LOS measure defines how the deficiency criteria are determined and expressed (e.g., "5 percent of traffic signs are deficient").

LOS Target—An LOS target is a desired condition of an asset element, an asset, or an asset class. Targets may be established in a variety of ways, including preservation needs, safety considerations, customer input, or management decisions. LOS targets are often used to identify maintenance and improvement needs and to develop work programs and budgets. The difference between actual and target LOS can be used to determine the incremental adjustment needed in the annual work program to meet the target.

Performance Measure—*NCHRP Report 551: Performance Measures and Targets for Transportation Asset Management* defines performance measurement as follows:

> Performance measurement is a way of monitoring progress toward a result or goal. It is also a process of gathering information to make well-informed decisions. Transportation agencies have used performance measures for many years to help track and forecast the impacts of transportation system investments, monitor the condition of highway features, and gauge the quality of services delivered by an agency.[2]

In the context of highway asset management, a performance measure can be an actual measurement, such as linear feet of deficiency, or a count, such as number of signs deficient. It can also be a more subjective rating, such as an observed condition state of a bridge element. Performance measures are often expressed as a percentage (e.g., percentage of signs deficient, calculated by dividing the quantity that is deficient by the total quantity).

Service Level—Service level is synonymous with level of service (LOS).

Threshold Levels of Service—Threshold levels of service are the boundary values that define the minimum and maximum performance measures for a given LOS. In the example shown in the LOS definition, 5 and 10 percent are the threshold values for the "B" LOS.

[2]Cambridge Systematics, Inc., PB Consult Inc., and Texas Transportation Institute, *NCHRP Report 551: Performance Measures and Targets for Transportation Asset Management,* Transportation Research Board (2006).

CHAPTER 2

Summary of the State of the Practice

2.1 Overview

A state-of-the-practice review was performed to identify approaches used by the federal government and state departments of transportation to measure and report highway LOS. This included identifying approaches used to aggregate facility-level data to report level of service by functional class and/or distinguishing between highways within metropolitan boundaries and outside those boundaries.

For the most part, a scan of secondary sources was used to establish the state of the practice, particularly the following research reports:

- *NCHRP Report 551: Performance Measures and Targets for Transportation Asset Management,* NCHRP Project 20-60, 2006 and
- *NCHRP Report 632: An Asset-Management Framework for the Interstate Highway System,* NCHRP Project 20-74, 2009.

In addition to the published research, the research team members were personally familiar with relevant practices in about a dozen state DOTs. Much of this knowledge is not published and was particularly helpful for the assets other than pavements and bridges, such as drainage features, traffic control devices, and roadside features.

Members of the research team also attended the Second National Maintenance Quality Assurance Peer Exchange, held in Raleigh, NC, September 22–23, 2008.

The project workshop, held in October 2009 and attended by project panel members and representatives from the three demonstration states (Florida, Mississippi, and Washington), provided additional insight on LOS practices. This group included representatives from eight state DOTs, a county road agency, AASHTO, and the academic and consulting communities.

These sources provided a firm basis for establishing the state of the practice.

2.2 Framework for Research Results

The earlier research (*NCHRP Report 632*) defined several broad categories of national objectives for LOS measurement that were helpful for categorizing the research results. These objectives or outcome areas are as follows:

- Preservation—Research on this outcome area was related to preservation of assets, sometimes referred to as preservation of investment. LOS measurement practices were found to be in wide use for most assets, including pavements, bridges, drainage, traffic control devices (active and passive), and a few other roadside assets on the IHS.
- Mobility—Research on this outcome area, sometimes referred to as "operations reliability," found that most LOS measures were related to traffic congestion.
- Safety—The safety outcome area covers the systematic monitoring and reporting of fatalities, injuries, and crashes on the highway system. LOS measures for this outcome area are usually expressed in terms of a rate based on vehicle miles of travel.
- Environment—State DOTs may refer to this outcome area as environmental quality, environmental protection, environmental preservation, or environmental stewardship (for this project, the latter term was preferred). Although all states routinely perform environmental assessments of their programs and projects, and undertake various mitigation measures, there was very limited data on LOS measurement and reporting for this area.

Since the purpose of asset management is to help transportation agencies better achieve their policy goals, the policy goals of the three demonstration states used in this study (Florida, Mississippi, and Washington) were reviewed to ensure that any LOS measures developed for IHS application would support these goals. Table 2-1 was developed from information found on the DOT web sites for these states.

Table 2-1. Policy goals of the demonstration states.

Florida	Mississippi	Washington
Economic Prosperity	Economic Development	(No equivalent goal)
Environmental Preservation	Environmental Stewardship	Environmental Protection
Mobility	Accessibility & Mobility	Mobility
Preservation	Maintenance & Preservation	Preservation
Safety	Safety	Safety & Security
(No equivalent goal)	(No equivalent goal)	Stewardship (Quality, Effectiveness, Efficiency)

The goals of preservation, mobility, safety, and environmental stewardship were common to all demonstration states and are aligned well with the core service-level categories proposed in Table 2.2 of *NCHRP Report 632* for grouping asset performance measures. These four policy goals will be aligned with the recommended performance measures in Chapter 3 of this report.

Economic development, or economic prosperity, mentioned by two of the states, was not included since that goal is much broader in scope and influenced by many factors other than IHS LOS.

The same could also be said for environmental stewardship, except that some states have incorporated specific environmental mitigation measures into their highway planning, design, construction, maintenance, and operational practices. For example, Washington DOT installs culverts such that the water flow will not restrict fish passage. Some states also monitor compliance with environmental agreements and mitigation measures. Although there are no specific LOS measures as such, a few states use a simple checklist approach to ensure that environmental issues are not overlooked. Accordingly, environmental stewardship was included mainly to serve as a reminder that it should not be overlooked during asset management considerations. However, at present, the state of the practice offers no specific guidance on performance measures that would be applicable to the IHS.

2.3 Asset Classes

The state-of-the-practice research led the research team to disaggregate IHS assets into the following logical asset classes. For each asset class or outcome area listed below, a recommended LOS framework was developed based on the state-of-the-practice research.

2.3.1 Pavement

The pavement asset area includes roadways, shoulders, ramps, and other paved areas. The state-of-the-practice review finds strong evidence that a national framework for measuring and reporting system-level LOS for the nation's Interstate pavements can be implemented that builds on the data collection and reporting performed through HPMS. Such measurement can address ride quality and distress.

Several conclusions can be reached from the literature review of state highway agency pavement management practices, including

- All agencies collect pavement roughness information, typically expressed in the form of the International Roughness Index (IRI).
- All agencies collect pavement distress information as a means of identifying structural deficiencies.
- Most agencies develop a distress index scale that is used to provide an overall measure of pavement condition.

Table 2-2 shows the state-of-the-practice research results for pavement assets.

2.3.2 Structures

The structures asset class focuses on bridges, but also includes large culverts (span greater than 20 ft), overhead sign and signal structures, and retaining walls. The state-of-the-practice review finds strong evidence that a national framework for measuring and reporting system-level LOS for the nation's Interstate bridges can be implemented that builds on the following two ongoing and related efforts to improve the measurement and reporting of the performance of the nation's bridges:

1. The use of the AASHTO Guide for Commonly Recognized (CoRe) Structural Elements to provide data to establish a common Health Index (first developed by Caltrans) and
2. Computing the Health Index using data collected by all 46 states that are currently using Pontis to manage their bridge inspection data.

Table 2-2. Pavement state of the practice.

Asset Class	Asset Elements	Level of Service		
		Condition	Indicator	Measure
Pavement	Travel Lanes: Functional/ Structural	Ride quality/ structural capacity	International Roughness Index, rutting, faulting, fatigue cracking, and transverse cracking	Mean Roughness Index, average rut depth, average fault, % fatigue type cracking, and length of transverse cracking (ft/mi)
	Ramps: Functional/ Structural	Ride quality/ structural capacity	International Roughness Index, rutting, faulting, fatigue cracking, and transverse cracking	Mean Roughness Index, average rut depth, average fault, % fatigue type cracking, and length of transverse cracking (ft/mi)
	Shoulders	Functioning as designed	Adequate/inadequate, potholes, edge raveling	Extent of shoulders inadequate (percent)

Tunnels were not included as an asset class for LOS purposes because they are not included in the CoRe elements by AASHTO and they occur in relatively small numbers on the IHS.

Table 2-3 shows the results of the structures state-of-the-practice research.

2.3.3 Other Interstate Assets

Many states collect condition data on roadway assets as a part of their MQA programs. The aim of these programs is to establish LOS ratings for each of those assets for performance evaluations and, in some cases, to develop a performance-based maintenance budget. These assets typically include drainage, traffic control devices, and other roadside features, as follows:

- Drainage—The different surface and subsurface drainage assets within the IHS drainage systems are culverts and pipes, ditches, drop inlets and catch basins, and other drains. Culverts are drainage structures 20 ft or less in span length, measured in the direction of travel. Pipes may

Table 2-3. Structures state of the practice.

Asset Class	Level of Service		
	Condition	Indicator	Measure
Structures	Structural and functional condition of decks, superstructure, substructure, and culverts	Deck rating: superstructure rating; substructure rating; culvert rating; clearances (horizontal and vertical)	Average National Bridge Inspection (NBI) condition rating
	Load-carrying capacity	Superstructure rating; substructure rating; traffic volume and composition; load rating	Structural evaluation; NBI Load Rating
	Overall structural and functional condition	Structural adequacy and safety; serviceability and functional obsolescence; essentiality for public use	Sufficiency rating
	Element level structural condition	CoRe element condition states	Health Index; element average condition state

Note: Asset elements would be defined to be consistent with the agency's current bridge management practices.

provide lateral or transverse drainage and may be described as cross, side, or outfall drains. Ditches can be unpaved or paved to prevent erosion and improve flow. Drop inlets and catch basins are drainage structures that collect storm water surface runoff and transport it to a culvert or storm water sewer system. Edge drains and under-drains are located under the roadway and along the edge of a shoulder or curb.

- Roadside—The roadside asset class is the area between the outside edges of the shoulder and the right-of-way line. For the IHS, this is best defined as all non-paved areas within the Interstate right of way, and includes slopes, mowable areas, brush and tree areas, and fences. Rest areas are also included in this class and include all roadside facilities where parking is permitted, such as visitor centers, information kiosks, picnic areas, scenic vistas, and historic monuments.
- Traffic Control and Management Devices (Active)—This category includes all of the equipment installed on and along the roadway and in control centers that is used for active traffic management, including signals and what is generally referred to as Intelligent Transportation Systems (ITS). However, the state of the practice has not reached the point where LOS measures have been developed and applied in sufficient numbers to serve as a guide for national application. Furthermore, these devices are generally not found in rural areas that make up most of the Interstate mileage. At present, active traffic control devices are not recommended for Interstate LOS assessment.
- Traffic Control and Management Devices (Passive)—Traffic control devices in this category are signs, pavement markings, delineators, guardrails, and other devices used to regulate, warn, or guide traffic. They may be placed on, over, or adjacent to the highway. The purpose of such devices is to move vehicles safely and efficiently by guiding traffic movement, controlling vehicle speeds, and warning drivers of potentially hazardous conditions.

Highway lighting was considered for inclusion in the "other IHS assets" category for LOS assessment. However, this item was not included for practical reasons. For lighting to be adequately addressed for LOS purposes, a separate nighttime inspection would be needed, at considerable additional effort and cost. The research team concluded that the additional cost of nighttime data collection outweighed any benefit to be gained.

Table 2-4 through Table 2-6 show the state-of-the-practice research results for drainage, roadsides, and passive traffic control devices.

2.3.4 Other Outcome Areas

The outcome areas of mobility, safety, and environment are not directly related to specific asset classes or asset LOS, but are related to how well the assets are being managed to meet the objectives of mobility, safety, and environmental stewardship. Mobility and safety are particularly well suited as IHS LOS indicators, since the IHS was originally conceived and constructed to provide safe, high-speed travel over long distances. State-of-the-practice results for these outcome areas are summarized below.

2.3.4.1 Mobility

This category describes how well the transportation network is performing its basic function of supporting transport, often expressed in terms of throughput and congestion. Previous research efforts, including NCHRP Projects 20-74 and 20-60, concluded that state practices vary widely. Definitions, goal areas, and data collection and analysis techniques create difficulties for meaningful comparison of LOS measures between states. *NCHRP Report 632* (Project 20-74) recommended only two mobility indicators (i.e., travel time and delay) derived from measures that are currently available in the HPMS.

Although the state-of-the-practice research did not find much commonality among the states to allow a concise statement of practices, there were sufficient measures and data available to warrant development of a few key LOS indicators and measures for mobility, as shown in Table 2-7.

Table 2-4. Drainage state of the practice.

Asset Class	Asset Elements	Level of Service Condition	Level of Service Indicator	Deficiency Criteria	Level of Service Measure
Drainage Systems	Point features: Drop Inlets/Catch Basins	Functioning as designed	Blocked/damaged	Percent blocked/damaged	Percentage of elements blocked/damaged (number of elements deficient divided by total number of surveyed elements)
	Linear features: All cross and side drainage structures, and ditches				

Table 2-5. Roadside state of the practice.

Asset Class	Asset Elements	LOS Condition	LOS Indicator	Deficiency Criteria	LOS Measure
Roadside	Front and Back Slopes	Functioning as intended	Erosion, slides	Depth of washouts, depth of accumulated material	Percent of slopes deficient (measured longitudinally along roadway)
	Right-of-Way Fences	Functioning as intended	Missing/damaged	Height reduction, openings	Percent of length deficient
	Vegetation Management	Condition of mowable areas	Motorist visibility, aesthetics	Height of vegetation in mowable areas	Average height of vegetation (inches)
	Rest Areas	Open and functioning as intended	Closed; damaged facilities; non-functioning facilities; not sanitary; unsightly	Rest area rating	Average rest area rating (five-point scale)

Table 2-6. Traffic control and management devices (passive) state of the practice.

Asset Class	Asset Elements	LOS Condition	LOS Indicator	Deficiency Criteria	LOS Measure
Traffic Control & Management Devices – Passive	Point features: All signs, delineators, hazard markers, impact attenuators, pavement symbols & legends	Functioning as designed	Non-reflecting/ missing/ damaged/ obstructed	Quantity deficient	Percentage of elements deficient
	Linear features: All pavement stripes and markings, guardrails, barriers				

Table 2-7. Mobility state of the practice.

Outcome Area	Units of Analysis	Service Level Condition	Service Level Indicators	Deficiency Criteria	LOS Measures
Mobility	Statewide, metropolitan planning organization (MPO) area, non-MPO area	Mobility, operations reliability	Delays, congestion	Frequency of on-time arrivals; frequency of congested travel; traffic volume versus capacity	Percent on-time arrival, percent heavily congested travel, volume/capacity ratio

2.3.4.2 Safety

A well-developed state of the practice exists for measuring and reporting safety outcomes at the national and state levels. Transportation safety has long been a policy priority, with the systematic monitoring and reporting of crashes, fatalities, and injuries on the highway system. The U.S.DOT and state DOTs all monitor and report safety performance. The federal government and state agencies have broadly consistent approaches to reporting safety outcomes, especially for fatalities, with LOS measures that are applicable to the IHS. The state-of-the-practice research results are shown in Table 2-8.

2.3.4.3 Environment

Environmental outcomes typically are not addressed by state DOTs in terms of LOS measures. Most of the policy statements and performance measures currently in use, such as air and water quality measures, are specific to other agencies. The measures are not applicable to the IHS as a unit of analysis distinct from other highways or other sources. Some practices currently used by a few DOTs—such as checklists to ensure compliance with environmental agreements and mitigation measures—while effective at the managerial level, are generally state-specific and would not be transferable to other states. The research team concluded that the current state of the practice does not provide sufficient guidance from which to develop environmental LOS measures for the IHS or for attempting to isolate the IHS from other highway systems or from other sources. Furthermore, the state of the practice does not provide guidance on differentiating the contributions to environmental quality from the IHS, other highway systems and other sources.

In some respects, the LOS measures included in the mobility outcome area are related to environment quality associated with IHS operations. For example, measures such as traffic volumes, delays, and congestion have a relationship to air and water quality and noise levels. But, how these measures should be treated in an environmental LOS context is beyond the current state of the practice.

2.4 Findings

Our state-of-the-practice research provided the following findings:

- All state highway agencies are currently collecting pavement and bridge condition data and safety-related data, with varying degrees of sophistication. Common to all are the data items collected as part of national inspection and reporting requirements (i.e., HPMS, the NBI program, and FARS).
- Based on the literature search and the research team's experience in various states, over 30 state highway agencies are currently collecting condition data on selected other assets, including drainage and roadside features, traffic control devices, and rest areas. There is considerable variation between the states in their practices, although there is much commonality in the use of the data.
- Although there are some technical issues to be resolved, such as standardization of measurements and rating criteria, none of these issues appear to be insurmountable.
- There are no known technology limitations that would prevent any state from embarking on a comprehensive LOS assessment program—in fact, there are several technologies currently available that make the task easier (e.g., instrumented vans for pavement data collection and video logging, GPS-capable handheld data collection devices, handheld laser rangefinders for measuring lengths and distances, GIS applications to assist in analyzing and presenting the data, and commercial off-the-shelf software applications for managing the data).
- FHWA has already established a precedent for nationwide collection of standardized highway asset data (i.e., the HPMS that has been in operation for over 20 years). Although changes in HPMS reporting requirements are planned for 2010, the data will continue to serve the same purpose.
- It is technically possible to establish an IHS LOS system. Key elements of the system already exist nationwide for pavements, bridges, and safety, and for some of the other asset classes in about 60 percent of the states. Nationwide standard practices have been established in a number of areas (e.g.,

Table 2-8. Safety state of the practice.

Outcome Area	Area of Analysis	LOS Condition	LOS Indicator	Deficiency Criteria	LOS Measures*
Safety	Statewide, MPO area, non-MPO area	Safe travel	Traffic fatalities	Frequency of traffic fatalities	Fatality rate (fatalities/100 MVMT)
			Traffic crashes	Frequency of traffic crashes	Crash rate (crashes/MVMT)

* Million vehicle-miles of travel (MVMT).

HPMS, NBI, traffic control devices per the Manual on Uniform Traffic Control Devices [MUTCD]), and the FARS.

2.5 Conclusion

The research team finds that it is feasible to establish an IHS LOS system without placing burdensome data collection requirements on state DOTs, at least for the major asset classes of pavements and bridges and the mobility and safety outcome areas. For some state DOTs, implementation would require new data collection processes for some assets and, in some cases, changes in existing data collection practices. Considerable outreach and promotion would be required to ensure "buy-in" and the implementation of a successful nationwide LOS framework.

Based on the research findings, the research team recommends a set of indicators and measures that describe the LOS of IHS assets, as detailed in the remainder of this report. The recommended measures either exist in current data collection systems or can readily be developed to define ratings and thresholds for categorizing IHS asset performance.

CHAPTER 3

Summary of Indicators and Measures for Template Development

One of the tasks for this study was to develop a template to facilitate implementation of LOS assessments on the IHS. Development of the template was based on a synthesis of the following:

- Research into LOS practices in three demonstration states that were selected to represent a cross-section of best practices among highway agencies;
- A workshop with the NCHRP panel and the demonstration states;
- Review of relevant literature, including NBI requirements, HPMS (including Reassessment for 2010), and *NCHRP Reports 551* and *632*; and
- The collective professional experience of the project team, with firsthand knowledge of LOS practices in about a dozen state DOTs.

The asset classes and elements that are recommended for inclusion in the template are summarized in Table 3-1. The relationship to agency policy goals is also shown in the table.

3.1 Level of Service Ratings

The proposed levels of service are based on the fact that many states currently collecting LOS data are using a five-point scale to express LOS for their assets. Some nationally used indices also use five-point scales, e.g., Present Serviceability Rating (PSR) and Bridge Element Condition States (although a few elements use a three or four-point scale). Many of the DOT—including Alabama, Arizona, Louisiana, Mississippi, North Carolina, Washington, and the West Virginia Turnpike (I-77)—are using letter grades to describe LOS.

Generally, the LOS rating scale developed during this study can be interpreted as follows:

- A—Excellent (like new or nearly perfect);
- B—Good;
- C—Fair (mediocre condition);
- D—Poor; and
- F—Very poor (failed, unacceptable).

Although the ratings can be applied to individual assets or elements, they are primarily intended to allow regional, statewide, or national assessment of asset conditions based on average LOS values. This allows various technical LOS measurements and ratings to be presented in nontechnical terms for nontechnical reviewers, similar to a "report card" format. People with nontechnical backgrounds may not fully comprehend the meaning and significance of the individual measures and rating practices (e.g., bridge inspections and pavement surveys), but they can easily relate to the rating scale previously shown.

3.2 Notes on Research Results

A full discussion of each of the asset classes and elements is presented in Appendix A (which is available on the accompanying CD-ROM). Following is a summary of the key findings and considerations. The template is presented in Section 4.

3.2.1 Bridges

LOS measures for the bridges asset class, listed in Table 3-1, are designed to take advantage of data already being collected under FHWA's NBI program. The elements include deck condition, superstructure and substructure condition, deck geometry and under-clearances, approach alignment, load-carrying capacity, channel condition, and culvert condition (for culverts with span length greater than 20 ft).

Initially, a composite structural condition category was envisioned, which was based on the lowest NBI condition rating of a variety of structural elements, including deck, superstructure, substructure, and culverts. After additional consideration, it was deemed more useful to simply use the condition ratings for the separate elements, since this would permit more detailed

Table 3-1. Asset classes and elements for interstate LOS assessment.

Agency Goals	Asset Class	Asset Elements
Preservation	Bridges	Deck Condition Deck Geometry, Vertical & Horizontal Superstructure Condition Substructure Condition Under-Clearances, Vertical & Horizontal Approach Alignment Load-Bearing Capacity Channel Condition Culvert (>20 ft) Condition
	Drainage	Cross/Side Drains Ditches/Channels Drop Inlets/Catch Basins
	Pavement	Fatigue Cracking (AC & Composite) Fatigue Cracking (Continuously Reinforced Concrete Pavement [CRCP]) Fatigue Cracking (Jointed Concrete Pavement [JCP]) Faulting (JCP) Rutting (Asphalt Concrete [AC] & Composite) Surface Roughness
	Roadside	Rest Areas Slopes Vegetation Management
	Traffic Control and Management – Passive Devices	Delineators/Object Markers Guardrail Pavement Markings/Symbols/Legends Pavement Striping Raised Pavement Markers Signs
	Traffic Control and Management – Active Devices	Signals and ITS Devices (not recommended for inclusion)
Mobility		Congestion Reliability Volume versus Capacity
Safety		Annual Traffic Fatalities
Environmental Stewardship		Agency-specific checklists on environmental commitments and permit requirements

analysis. Also, since large culverts are numerous and not accounted for elsewhere in the LOS measures, a separate category for culverts was considered important.

The NBI structurally deficient flags and the structurally obsolete flags were not included in the template because, after further consideration, these flags are set based on the condition of the various structural elements, which are already included in the template. Adding these flags would be a duplication of performance measures.

The Average Sufficiency Rating was initially considered as an option to indicate the overall sufficiency of bridges to remain in service, considering both structural and functional conditions. It provided a single, overall number to describe bridge conditions. However, after discussions with workshop participants, the research team decided not to include the Average Sufficiency Rating, since it is was decided only to use structural condition.

The details of the individual bridge elements included in the template are fully defined in FHWA's *Bridge Inspector's Reference Manual* (latest edition dated December 2006).[3]

3.2.2 Drainage

There are no standards or requirements for rating common drainage features that are found along the highway, such as ditches, pipes, and drop inlets. Several states currently collect such data as part of their maintenance quality assessment programs, and the proposed drainage elements in Table 3-1 are modeled after those practices.

3.2.3 Pavement

Although most states practice some form of pavement management, there is no standard for the elements to be measured or for how they should be measured. The current FHWA HPMS is being revised[4] and will include a few pavement distress indicators for fatigue cracking, faulting, and rutting. These items have been included in the template on the assumption that they will soon become a national reporting requirement. They are also very visible distresses from the viewpoint of the road user and are considered appropriate for inclusion in a national Interstate LOS assessment program.

The IRI was included to provide an overall indication of ride comfort. States that collect roughness data typically use this index. The statewide weighted average is referred to as Mean Roughness Index (MRI) and is the number used to determine an LOS letter grade in the template.

3.2.4 Roadside

As with drainage, there are no recognized standards for assessing LOS for roadside features that are typically maintained by highway agencies. As shown in Table 3-1, three items were selected that either represent potential safety issues (slopes) or consume considerable resources of the highway agency as well as impact road user perceptions of roadside aesthetics (rest areas and vegetation management). Several states are already collecting LOS data on these elements.

[3]See http://www.nhi.fhwa.dot.gov/training/course_detail.aspx?num=FHWA-NHI-130055&num=130055.

[4]See HPMS Reassessment 2010 at http://www.fhwa.dot.gov/policy/ohpi/hpms/2010/index.cfm.

3.2.5 Traffic Control Devices (Passive)

There are no standards for assessing the LOS of traffic control devices. The *Manual on Uniform Traffic Control Devices* (MUTCD) sets the standards for design and installation of such devices, but offers no guidance for LOS assessments. Since these devices play a fundamental role in providing a safe operating environment for road users, the main asset elements include most of the commonly used devices, as shown in Table 3-1. Most of the states that are currently collecting LOS data include these asset types.

3.2.6 Traffic Control Devices (Active)

Initially, both active and passive traffic control devices were considered for inclusion. However, LOS measures for active devices, such as ITS equipment, are not recommended at this time, for the following three reasons:

1. No states were known to be actively collecting and reporting LOS data on such devices (except for signals, which are rarely found on the IHS); only routine inspections for maintenance and repair purposes were being performed.
2. There are a number of different technologies involved, and individual items are difficult to isolate and evaluate since they are often an integral part of a complex system involving sensors, signals, variable message signs, underground cables or fiber optics, wireless communications, and remotely located, centralized computer systems.
3. These systems are mainly found in large urbanized areas or high traffic locations and are rarely found on rural Interstate highways that make up most of the Interstate mileage. Since the number of installations is small compared to other highway assets, the cost versus benefit of establishing and operating a nationwide LOS measurement system for ITS devices is questionable.

3.2.7 Mobility

After consideration of the research team's findings and the suggestions of LOS workshop participants, the following three mobility LOS measures are recommended for common application and are included in Table 3-1:

- Percent of heavily congested travel.
- Percent on-time arrival.
- Volume to capacity ratio (V/C).

The definitions of these measures are given in Appendix B.8.

3.2.8 Safety

Due to the high volumes of traffic and high operating speeds on the IHS, the fatality rate was selected as the most useful, and most widely available, indicator of the overall level of safety provided by the IHS. Fatalities are currently reported to NHTSA and are expressed as fatalities per 100 million vehicle miles of travel (MVMT). The rationale for establishing the LOS scale for fatalities was to set the C level at about the national average, which is currently around 1.3 fatalities per 100 MVMT. The other grades were set up in equal increments on either side of the C range.

The second widely used indicator of safety is the crash rate, expressed as traffic crashes per MVMT. However, as noted in Appendix B.9, there is considerable variation from state to state in how crashes are reported and which crashes are reported. Furthermore, there is no standard for reporting crashes and no requirement to do so. For these reasons, use of the vehicle crash rate is not recommended as a LOS measure for the IHS.

3.2.9 Environmental Stewardship

As noted in Section 2.3 and Appendix B.10, there are currently few processes and no significant body of data in place among the state DOTs to support the concept of LOS assessment for environmental stewardship associated with the IHS or any other highway system. There is no existing model or best practice to serve as a guide to begin to establish such a process.

Accordingly, the recommendation by the research team is to not attempt to develop and implement a LOS assessment process for environmental stewardship at this time. As state practices in this area evolve, the subject should be revisited and perhaps addressed with additional research.

CHAPTER 4

Level of Service Template

The proposed template for Interstate LOS assessment is shown in Table 4-1. The template lists all asset classes and elements that are needed to ensure a comprehensive assessment of IHS LOS. The table includes a definition of each element, along with the indicators and measures for each. The recommended threshold values are given for the five-point scale that is used to describe the level of service. A detailed description of each asset, asset element, and LOS measure is presented in Appendix B.

Each asset element's LOS measure shown in the template is the average of all measures for that element in the dataset, whether the dataset is for individual IHS routes, IHS routes in a region of the state (e.g., a district), for the entire state or the entire nation. As suggested in Section 6.2, a sampling methodology should be used in each state to obtain statistically significant results while reducing the cost of data collection.

Once an average value for an LOS measure has been determined for an element, that value may be compared to the threshold values on the LOS scale to obtain an LOS rating for the element. This will be expressed as a letter grade, A through F. For example, if a traffic control device had an LOS measure of 11 percent deficient, it would be given an LOS grade of "C." If desired, plus and minus letter grades may be assigned by dividing each letter-grade range into thirds. Using that technique, the traffic control device used in the above example would be given an LOS grade of "C+." This technique is not recommended unless the sampling and measurement methodologies provide a sufficient level of accuracy to justify the finer level of detail.

Generally, the asset classes, elements, and measures for most asset classes in the template are readily available from existing data sources, such as pavement and bridge management systems, traffic surveys, and maintenance LOS surveys. For states that are not currently conducting maintenance LOS surveys, it would be necessary for them to implement a process that would capture the data required for drainage, roadside, and traffic control devices.

Most states that are currently collecting LOS data for roadway and roadside assets have a detailed data collection manual available and most conduct training sessions for data collectors. These practices are recommended to ensure accuracy and consistency in data so that all stakeholders may be assured that they have a true representation of IHS LOS.

Establishment of thresholds for LOS measures is not an "exact science," but there are some general guidelines that can be followed. Generally, the "A" level represents conditions that are like new (i.e., asset elements are in good condition needing little or no maintenance or repairs). The "F" level represents the point at which the asset element condition is unacceptable for service and in need of immediate maintenance service or major repair or replacement, depending on the type of asset. The intermediate thresholds for "B," "C," and "D" are usually divided into equal increments between the "A" and "F" values. In several states, LOS thresholds were established by a committee of knowledgeable in-house and consultant subject matter experts.

In some cases, minor adjustments have been made to the LOS thresholds after reviewing the results of the initial LOS field surveys. For example, if current conditions are considered to be an average LOS and should be rated as a "C," but the initial thresholds resulted in a "B" or "D" rating, then the thresholds would be adjusted accordingly.

Customer opinion surveys may be used to help validate in-house LOS assessments. Several states have hired professional survey firms to obtain road user impressions of current and desired levels of service for various asset classes and elements. The surveys usually consist of thousands of telephone interviews followed by several focus group sessions to better understand public opinions on various issues. When the results are compared with the in-house LOS assessments, some LOS thresholds may be revised as a result of these comparisons.

The thresholds shown in Table 4-1 represent a synthesis of practices from several states that have active MQA programs and the opinions of the subject matter experts on the project research team. In the case of structures, federal guidelines for bridge inspection and rating were helpful in setting upper and lower limits for certain elements. For example, an NBI rating of 4 or less was used as the "F" LOS for some CoRe elements, because that rating generally indicates a poor or failed condition.

Table 4-1. Template for level-of-service assessment on the Interstate Highway System.

Asset Class	Element	Definition	Indicators	Measure	Level of Service Thresholds				
					A	B	C	D	F
Bridges	Deck Condition	This element applies to the riding surface of the bridge where live loads are directly applied (NBI Item No. 58).	Cracking, spalling, holes, or other signs of deterioration.	Average NBI condition rating	9.0 - 7.0	6.9 - 6.0	5.9 - 5.0	4.9 - 4.0	< 4.0
	Deck Geometry	This element refers to the curb-to-curb bridge roadway width and the minimum vertical clearance over the bridge roadway (NBI Item No. 68).	Horizontal clearances less than travelway width, or vertical clearances less than 16 ft.	Average NBI condition rating	9.0 - 8.0	7.9 - 6.0	5.9 - 4.0	3.9 - 2.0	< 2.0
	Superstructure Condition	This element refers to that component of the bridge that supports the deck, as well as the loads applied to the deck (NBI Item 59).	Section loss or fatigue cracks in steel, shear cracks in concrete, or other signs of deterioration in structural elements.	Average NBI condition rating	9.0 - 7.0	6.9 - 6.0	5.9 - 5.0	4.9 - 4.0	< 4.0
	Substructure Condition	This element refers to all the components of the bridge which support the superstructure and transfer the load to the foundation (NBI Item No. 60).	Section loss or fatigue cracks in steel, shear cracks in concrete, scouring under foundations, or other signs of deterioration in structural elements.	Average NBI condition rating	9.0 - 7.0	6.9 - 6.0	5.9 - 5.0	4.9 - 4.0	< 4.0
	Under-Clearances, Vertical and Horizontal	This element refers to the minimum vertical and horizontal clearances of the through roadway under the structure (NBI Item No. 69). (Note that clearances	Horizontal clearances less than travelway width, or vertical clearances less than 16 ft.	Average NBI condition rating	9.0 - 8.0	7.9 - 6.0	5.9 - 4.0	3.9 - 2.0	< 2.0

(continued on next page)

Table 4-1. (Continued).

Asset Class	Element	Definition	Indicators	Measure	Level of Service Thresholds				
					A	B	C	D	F
Bridges (continued)		over navigable waterways are not considered for the purposes of determining LOS.)							
	Approach Alignment	This element refers to the alignment of the bridge approaches compared to the alignment of the roadway section on which the bridge is located (NBI Item No. 72).	Changes in vertical or horizontal alignment between the roadway and bridge approaches, such that a reduction in vehicle operating speed occurs.	Average NBI condition rating	9.0 - 7.0	6.9 - 6.0	5.9 - 5.0	4.9 - 4.0	< 4.0
	Load-Carrying Capacity	This element is the NBI-defined Inventory load rating (NBI Item 66). Note that the posting status of the bridge (NBI Item 70) is also considered.	Load level that can safely utilize an existing structure for an indefinite period of time.	NBI Items 66 and 70	NBI Item 66: ≥ 91 metric tons (about 200,000 lb)	NBI Item 66: 90 - 54 metric tons (<200,000 to 120,000 lb)	NBI Item 66: 53 - 36 metric tons (<120,000 to 80,000 lb)	NBI Item 66: 35 - 27 metric tons (<80,000 to 60,000 lb)	NBI Item 66: < 27 metric tons (< 60,000 lb) or NBI Item 70: < 5
	Channel Condition	This element refers to the physical conditions associated with the flow of water through the bridge, such as stream stability and the condition of the channel, riprap, slope protection, or stream control devices, including dikes (NBI Item No. 61).	Excessive water velocity that is undermining slope protection, eroding banks, and realigning streambeds; or accumulation of drift and debris.	Average NBI condition rating	9.0 - 7.0	6.9 - 6.0	5.9 - 5.0	4.9 - 4.0	< 4.0
	Culvert (>20 ft) Condition	This element refers to the condition of the culvert	Deterioration, cracking, leaching, or spalls on	Average NBI condition rating	9.0 - 7.0	6.9 - 6.0	5.9 - 5.0	4.9 - 4.0	< 4.0

Table 4-1. (Continued).

Asset Class	Element	Definition	Indicators	Measure	Level of Service Thresholds				
					A	B	C	D	F
Bridges (continued)		with a total length of 20 ft or more, including the alignment, settlement, joints, structural condition, scour, and other items associated with culverts, such as wing walls (NBI Item No. 62).	concrete or masonry walls and slabs; distortion, deflection, corrosion, pitting, or perforation of metal culverts; scouring or erosion around walls or pipes.						
Drainage	Side/Cross Drains	These elements are drains that normally cross under a roadway, generally perpendicular to the direction of travel, or are drains located by the side of the road, generally parallel to the direction of travel, and which generally begin or end in an open roadside ditch or channel. This category includes pipe and culvert installations with span lengths less than 20 ft.	Openings blocked (flow restricted) and/or structure damaged.	% of drains more than 25% blocked or damaged	0 - 4.9	5.0 - 9.9	10.0 - 14.9	15.0 -19.9	≥ 20
	Ditches/ Channels	These elements are water channels on the side of the road that collect runoff water from the road surface and convey it to storm drains, other drainage	Openings blocked (flow restricted) and/or structure damaged.	% of drains more than 25% blocked or damaged	0 - 4.9	5.0 - 9.9	10.0 - 14.9	15.0 -19.9	≥ 20

(continued on next page)

Table 4-1. (Continued).

Asset Class	Element	Definition	Indicators	Measure	Level of Service Thresholds				
					A	B	C	D	F
Drainage (continued)		structures, retention ponds, or waterways. They may be paved or unpaved and include both roadside and outfall ditches and channels.							
	Drop Inlets/ Catch Basins	These elements include all drop inlets, catch basins, and junction boxes, found in curbed and gutter sections, ditch bottoms (paved or unpaved), and other storm drains that collect water runoff and convey it to connected drainage systems.	Openings blocked (flow restricted) and/or structure damaged.	% of inlets and basins more than 25% blocked or damaged	0 - 4.9	5.0 - 9.9	10.0 - 14.9	15.0 -19.9	≥ 20
Pavement	Fatigue Cracking (Asphalt and Composite Pavement)	This element refers to load-associated cracking of the pavement surface.	Cracking of the pavement surface best described as an area feature rather than a linear feature. Includes alligator cracking, patching, and potholes.	% of surface area with fatigue cracking	0 - 4.9	5 - 9.9	10.0 - 14.9	15.0 - 34.9	≥ 35.0
	Fatigue Cracking (Continuously Reinforced Concrete Pavement)	This element refers to load-associated cracking of the pavement surface.	Cracking of the pavement surface best described as an area feature rather than a linear feature. Includes punch-outs and patching.	% of surface area with fatigue cracking	0 - 0.4	0.5 - 1.4	1.5 - 2.4	2.5 - 14.9	≥ 15.0

Table 4-1. (Continued).

Asset Class	Element	Definition	Indicators	Measure	Level of Service Thresholds				
					A	B	C	D	F
Pavement (continued)	Fatigue Cracking (Jointed Concrete Pavement)	This element refers to load-associated cracking of the pavement surface.	Cracking or patching of the pavement slabs. Includes corner breaks, transverse cracking, and longitudinal cracking.	% of slabs with fatigue cracking	0 - 1.9	2.0 - 4.9	5.0 - 9.9	10.0 - 34.9	≥ 35.0
	Faulting (Jointed Concrete Pavement)	This element refers to vertical displacements of the pavement surfaces on each side of a joint or crack.	Difference in elevation across joints or cracks.	Average fault height (inches)	< 0.125	0.125 - 0.24	0.25 - 0.49	0.5 - 0.74	≥ 0.75
	Rutting (Asphalt and Composite Pavement)	This element refers to longitudinal depressions of the pavement surface along vehicle wheel paths.	Longitudinal surface depressions in wheel paths.	Average rut depth (inches)	< 0.125	0.125 - 0.24	0.25 - 0.49	0.5 - 0.74	≥ 0.75
	Surface Roughness	This element refers to the vertical irregularities of the pavement surface that affect ride comfort, as expressed by the International Roughness Index.	Rough surface, ride discomfort.	Mean Roughness Index (MRI) (inches/mile)	0 - 45	46 - 74	75 - 120	121 - 200	> 200
Roadside	Rest Areas	This element includes all welcome centers, rest areas, picnic areas, scenic overlooks, and historical monuments with parking areas on the roadside.	General condition and appearance of grounds, buildings, and janitorial services.	% of facilities with average condition rating greater than 1	0 - 4.9	5.0 - 9.9	10.0 - 14.9	15.0 -19.9	≥ 20

(continued on next page)

Table 4-1. (Continued).

Asset Class	Element	Definition	Indicators	Measure	Level of Service Thresholds				
					A	B	C	D	F
Roadside (continued)	Slopes	This element includes roadside front and back slopes, between edge of shoulder and right-of-way line.	Washouts or slope slippages.	% of shoulder miles with washouts or buildups greater than 6 in	0 - 4.9	5.0 - 9.9	10.0 - 14.9	15.0 -19.9	≥ 20
	Vegetation Management	This element includes the mowable area on roadsides and medians on both the main roadway and ramp areas.	General appearance of roadside mowable areas.	Average height of mowable roadside vegetation (inches)	4 - 7.9	8.0 - 11.9	12.0 - 15.9	16.0 -19.9	< 4 or ≥ 20
Traffic Control Devices - Passive	Delineators/ Object Markers	This element includes all roadside delineators and object markers, including reflective posts and barricades and reflectors mounted on guardrails, barrier walls, and bridge railings.	Non-reflective/ missing/ damaged/ obstructed.	% of elements deficient	0 - 4.9	5.0 - 9.9	10.0 - 14.9	15.0 -19.9	≥ 20
	Guardrail	This element includes all types of traffic guide rails, including all types of guardrail (W-Beam, cable, wood, etc.) and New Jersey barrier, and end treatments.	Damaged or missing.	% of length deficient	0 - 4.9	5.0 - 9.9	10.0 - 14.9	15.0 -19.9	≥ 20
	Pavement Striping	This element includes lane and edge lines, both solid and "skip" lines, and both painted and thermo-plastic.	Faded, missing.	% of length deficient	0 - 4.9	5.0 - 9.9	10.0 - 14.9	15.0 -19.9	≥ 20

Table 4-1. (Continued).

Asset Class	Element	Definition	Indicators	Measure	Level of Service Thresholds				
					A	B	C	D	F
Traffic Control Devices – Passive (continued)	Pavement Markings/ Symbols/ Legends	This element includes any pavement markings, other than line striping, such as exit-lane and through-lane arrows, route numbers, and symbols.	Faded, missing.	% of elements deficient	0 - 4.9	5.0 - 9.9	10.0 - 14.9	15.0 -19.9	≥ 20
	Raised Pavement Markers	This element consists of reflective devices placed on the pavement to mark travel lanes and pavement edges, as well as ramp lanes and gore areas.	Non-reflective/ missing/ damaged.	% of elements deficient	0 - 4.9	5.0 - 9.9	10.0 - 14.9	15.0 - 19.9	≥ 20
	Signs	This element consists of all types of traffic signs, including regulatory and warning signs, guide and informational signs, regardless of the type of mounting (roadside posts, overhead sign structures, or attached to bridge structures).	Non-reflective/ missing/ damaged.	% of elements deficient	0 - 4.9	5.0 - 9.9	10.0 - 14.9	15.0 -19.9	≥ 20
Mobility	Congestion	This item indicates the amount of congestion experienced by a traveler. It is expressed as the ratio of congested segment person-hours of travel to the total person-hours of travel.	Heavily congested travel.	% heavily congested travel	0 - 20	21 - 40	41 - 60	61 - 80	81 - 100

(continued on next page)

Table 4-1. (Continued).

Asset Class	Element	Definition	Indicators	Measure	Level of Service Thresholds				
					A	B	C	D	F
Mobility (continued)	Reliability	This item indicated the reliability of travel by estimating the percentage of trips for which a traveler arrives on time, based on an accepted lateness threshold. The recommended lateness threshold is 10% above the average travel time.	On-time travel.	% on-time arrival	100 - 80	79 - 60	59 - 40	39 - 20	19 - 0
	Traffic Service	This element relates to the mobility of vehicles using the highway during the peak hour of travel and the degree to which freedom of movement is restricted.	Traffic volume versus highway capacity.	Average peak hour volume/ capacity ratio (V/C), as defined in the Highway Capacity Manual (HCM)	0 - 0.29	0.30 - 0.49	0.50 - 0.74	0.75 - 0.89	≥ 0.90
Safety	Traffic Safety	This is the annual number of traffic fatalities as reported to NHTSA Fatality Analysis Reporting System (FARS) for the Interstate Highway System (Rates and VMT published annually in FHWA *Highway Statistics*, Tables FI-10 and VM3).	Annual Traffic Fatality Rates (Fatalities/ 100 MVMT).	Ratio of state-to-national fatality rate	< 0.40	0.40 - 0.79	0.80 - 1.19	1.20 - 1.59	≥ 1.60

CHAPTER 5

Implementation Guide

The importance of the IHS to the nation's economy and transportation system, and to those of individual states, is beyond question. The benefits of an LOS approach for managing assets on the IHS have been well documented in previous reports.[5–6] To assist state DOTs with developing and implementing an LOS assessment process, an Implementation Plan and User Guide are presented in the following sections. The Implementation Plan is intended to assist administrators responsible for asset management in the agency. The User Guide is intended for the data collection and analysis personnel who will be responsible for day-to-day operation of the LOS assessment process.

5.1 Implementation Plan

The following steps are suggested for developing and implementing the LOS assessment process for the IHS:

1. A good starting point for any activity related to managing assets on the IHS would be to develop an Asset Management Plan, as outlined in Section 2.4 of *NCHRP Report 632.* This report suggests the following topics for the plan:
   a. Significant aspects of the IHS in the state,
   b. Assets included,
   c. Performance measures,
   d. Funding,
   e. Risk management,
   f. Investment strategies, and
   g. Provision for plan updates.
2. State DOT administrators will need to review their existing data collection and reporting requirements to ensure that they have all the necessary data. An action plan should be developed for obtaining, processing, and reporting the LOS data shown in the template in Table 4-1. For some assets, especially pavements and bridges, the data may already exist in various databases within the agency, and only extraction and possible conversion may be needed. For other assets, a field data collection process may need to be established and conducted.
3. Responsibilities for collecting, analyzing, maintaining, and reporting the data will need to be established and assigned. Since several different sources for the data may exist, the responsibilities may extend to more than one person in more than one unit in the agency. However, it will be desirable to have one person or one unit responsible for the overall process. This will ensure timely and consistent processing and reporting.
4. Once the agency's policy has been clearly established, training of data collectors should be conducted to ensure that accurate and consistent practices are instilled early in the process. The training should consist of both classroom and field exercises. It would be desirable to have one statewide team collecting the data for consistency reasons, but there are practical considerations for why this is not always done (e.g., travel time and costs). In addition to the data collection team, some states use a quality assurance team to ensure accuracy and uniformity of results by checking a small percentage of the samples, often in the range of 5 to 10 percent of the total. This is definitely a recommended practice.
5. The LOS measures will need to be averaged for each geographic region of the state. Some of the desired roll-ups might include routes, districts, MPO/non-MPO, rural/urban, and statewide. Several types of report formats have been used effectively to summarize the LOS data, including dashboard-style displays[7] and tabular and graphical reports.

[5]Cambridge Systematics, Inc., et al., *NCHRP Report 632: An Asset Management Framework for the Interstate Highway System,* Transportation Research Board (2009).

[6]Cambridge Systematics, Inc., PB Consult Inc., and Texas Transportation Institute, *NCHRP Report 551: Performance Measures and Targets for Transportation Asset Management,* Transportation Research Board (2006).

[7]See Cambridge Systematics, Inc., et al., *NCHRP Report 632: An Asset Management Framework for the Interstate Highway System,* Transportation Research Board (2009), Figure 5.3, page 38.

Table 5-1 and Table 5-2 show example formats similar to those that have been used successfully by several states (Louisiana, Mississippi, North Carolina, Washington, and the West Virginia Turnpike). Table 5-1 shows an example of the actual LOS measures recently obtained in one state, while Table 5-2 presents the same data in a report card format. It should be noted that these tables are only suggesting a possible format, not specific assets and elements for the IHS. Note that terms used by this state are equivalent to those used in this report (i.e., "group" equates to "asset class" and "feature" equates to "element"). Also, note that this state chose to interpret the LOS measures such that a grade level could be expressed with a plus or minus, by dividing the range for each grade into three equal parts. This

Table 5-1. Example of service level reporting—detail format.

District Interstate Routes - 2008									
Group	Feature	Units	Level of Service		LOS Grade Thresholds				
			Measure	Grade	A	B	C	D	F
Asphalt Pavement	Potholes	No./Ln Mi	2.2	D+	0	1	2	3	>3
	Rutting Depth	Inches	0.14	C+	0	0.125	0.250	0.500	>0.50
	Stripping (Raveling)	% of Area	0	B+	0	5	10	20	>20
	Alligator Cracking	% of Area	0.4	B+	0	10	20	30	>30
	Area Cracking	% of Area	0.4	B+	0	10	20	30	>30
	Longitudinal/Transverse Cracking	Lin Ft/Ln Mi	97.4	A	250	500	1000	2500	>2500
	Edge Raveling	Lin Ft/Ln Mi	0	A+	25	100	300	500	>500
	Shoving	Sq Ft/Ln Mi	0	A	0	10	25	50	>50
	Sweeping	% of Sh Mi	1.6	A+	5	10	15	25	>25
Concrete Pavement	Spalling	Lin Ft/Ln Mi	0	A	0	2	5	10	>10
	Faulting Height	Inches	0.14	C+	0	0.125	0.250	0.500	>0.50
	Joint Sealing	% Deficient	0	A	0	5	10	15	>15
	Cracking	Lin Ft/Ln Mi	3.7	B+	0	1500	3000	5000	>5000
	Punch-Outs	No./Ln Mi	0.6	B	0	1	2	3	>3
	Pumping	No. Slabs/ Ln Mi	0	A	0	5	10	15	>15
	Sweeping	% of Sh Mi	0	A+	5	10	15	25	>25
Paved Shoulders	Potholes	No./Sh Mi	1.2	B	0	2	4	6	>6
	Edge Raveling	Lin Ft/Sh Mi	35	B+	0	125	250	500	>500
Unpaved Shoulders	Drop Off	Lin Ft/Sh Mi	378	B-	0	500	1000	2500	>2500
	High Shoulder	Lin Ft/Sh Mi	1602	D	0	500	1000	2500	>2500
Drainage	Side Drains	% of Pipes	0	A	0	2	5	10	>10
	Cross Drains	% of Pipes	6.6	D+	0	2	5	10	>10
	Edge Drains	% of Drains	41	F	0	10	20	30	>30
	Unpaved Ditches	% of Ditch	0.9	B+	0	5	10	15	>15
	Paved Ditches	% of Ditch	13.7	D-	0	5	10	15	>15
	Drop Inlets	% of Inlets	29.2	F	0	5	10	15	>15

Table 5-2. Example of service level reporting—report card format.

District Interstate Routes - 2008 LOS Ratings						
Asset	**Feature**	**A**	**B**	**C**	**D**	**F**
Asphalt Pavements	Potholes				D+	
	Rutting			C+		
	Stripping (Raveling)		B+			
	Alligator Cracking		B+			
	Block Cracking		B+			
	Linear Cracking	A				
	Edge Raveling	A+				
	Shoving	A				
	Sweeping	A+				
Concrete Pavements	Spalling	A				
	Faulting			C+		
	Joint Sealing	A				
	Crack Sealing		B+			
	Punch-Outs		B			
	Pumping	A				
	Sweeping	A+				
Paved Shoulder	Potholes		B			
	Edge Raveling		B+			
Unpaved Shoulder	Drop-Off		B-			
	High Shoulder				D	
Drainage	Side Drains	A				
	Cross Drains				D+	
	Edge Drains					F
	Unpaved Ditches		B+			
	Paved Ditches				D-	
	Drop Inlets					F

practice should only be used where the sampling practices provide sufficient accuracy to justify the finer distinctions in the grade levels.

6. It may be desirable for the LOS results to be published at the state level and submitted to a national agency. Ultimately, the state DOTs will have the responsibility for recognizing any shortcomings and making improvements on a priority basis.
7. The objective of collecting and analyzing LOS data for the IHS is to determine the LOS being provided and make informed decisions about where and how the LOS may need to be improved. Typically, this is done by establishing target LOS values for each asset or asset element and comparing actual results with the targets. Ideally, these comparisons are made in advance of the budgeting cycle so that the results can influence budget decisions. Target LOS values may be set based on several considerations, including professional judgment regarding preservation, mobility and safety, budget constraints, and customer survey results.

8. The difference between a target and actual LOS represents an incremental adjustment needed to a specific portion of the state's previous work program to reach the target LOS in the next budget year. With appropriate conversion factors and inventories of the various assets' elements, the difference in target and actual LOS measures can be expressed as an incremental adjustment to a specific work activity in an activity-based work program. Two of the demonstration states and several others are known to use this technique (e.g., Louisiana, Mississippi, Washington, and West Virginia). One state (Alabama) is developing this approach, with implementation planned within the next year.
9. By monitoring LOS data from year to year, trends in LOS can be detected and matched against expenditure levels, allowing appropriate budgeting and operational actions to be taken. (Washington State DOT recently used this technique to show a downward trend in LOS over the past 5 years and was able to convince the legislature to provide additional funding.)

5.2 Users Guide

The following steps are suggested for conducting the LOS assessment for the IHS:

1. The first step is to decide on the lowest administrative level or geographic area for which LOS data for the IHS will be reported. This may be at a district or regional level within the state, and may be further subdivided by rural and urban, or by MPO and non-MPO areas. (This will be the level at which sampling procedures should be designed to be statistically significant, as discussed in a later step.)
2. Interstate mileage will be needed for each of the areas identified in Step 1. For some Interstate routes, the physical traveled ways (i.e., roadbeds) may be widely separated, or median barriers may exist, such that it is generally desirable to treat each direction of travel as a separate roadway for condition assessment purposes. For example, if a highway district has 50 mi of Interstate centerline mileage, for sampling purposes it would be considered as 100 mi of roadway. In general, the sample population may be considered as twice the centerline mileage. In some cases, there may be collector-distributor lanes parallel to the through lanes that are considered to be part of the Interstate and should be included in the total mileage. However, frontage roads are not considered to be part of the Interstate mileage for the purposes of LOS assessment.
3. Once the areas and mileages have been established, the most recent existing data for the Interstate assets and elements shown in Table 4-1 should be collected. For example, relevant data may be obtained from pavement management surveys, bridge inspections, maintenance quality assurance surveys, and traffic and crash statistics. The objective is to obtain an average value for each LOS measure for each geographic area in the state (e.g., each district).

   In some cases, such as for pavement data, the surveys may have been collected on homogeneous sections of unequal length, based on surface types. In such cases, the LOS measure for each section will need to be weighted based on section length (either roadway miles or lane miles, depending on how the pavement survey was conducted) to obtain an overall average for each element in that area of the state. In some states and for some elements, the data are collected on sections of standard length (e.g., 500 ft). In those cases, a straight average may be used. Generally, asphalt and concrete pavements are considered separately since different indicators may be used. For example, rutting usually applies to asphalt and faulting usually applies to concrete pavements.

   For both bridges and pavements, the data may be up to 2 years old, depending on when the last inspections were performed. However, the most recent assessment of asset condition should be used and reported each year.

   The pavement data will need to be separated by surface type for analysis, because asphalt and concrete pavements have somewhat different LOS measures and rating scales (see Table 4-1).

   Typically, the bridge inspection data will need to be separated into two groups, bridges and large culverts (length of 20 ft or more), since the rating elements are different and some elements do not apply to culverts (e.g., underclearances). Then, the ratings for similar elements within each group may be averaged (e.g., decks).

   For the Safety LOS measure, both fatalities and vehicle miles of travel will be needed for Interstate routes in each area of the state. Also, the most recent national fatality rate will be needed to establish the state-to-national fatality ratio.

   For some elements, such as drainage features, traffic control devices, and roadside features, condition data may not exist. In such cases, a data collection process will need to be implemented, as described in the next step.
4. If LOS measurements for some elements are not being collected, a condition survey will need to be conducted. This will usually be the case for states that are not conducting periodic maintenance quality assurance surveys on drainage features, traffic control devices, and roadside features. In such cases, a sampling process is recommended, using the formula presented in Section 6.2 to determine the number of samples required.

   To establish the number of samples required, all of the Interstate mileage for each area of the state should be visualized as one continuous route arranged from end to end. For example, if a district has one Interstate route that is 10 mi long (20 mi for both directions) and another that is 30 mi long (60 mi in both directions), the analyst should visualize one continuous route, extending from virtual milepoints 0.0 to 80.0. The first 40 mi would consist of all those segments in the direction of increasing mileposts and the last 40 mi would consist of the segments in the direction of decreasing mileposts. That length represents a sampling population of 800 segments of 0.1-mi each. To determine the number of samples required, use the formula in Section 6.2 with the suggested values of z=1.96, p=0.8, e=0.07 and N=800. The resulting number of samples is 109 (rounded up), which will provide 95 percent confidence that results will be within plus or minus 7 percent of the true values. If a precision of 5 percent were used, the required number of samples would be 189 in this example, representing an increase of 73 percent more samples and the associated additional time and cost of data collection and processing, which is an important consideration when developing budgets.

5. To determine the sample locations, generate a list of random numbers between 0.0 and 1.0 equal to the sample size that was determined in the previous step, rejecting any duplicates. Using that example, 109 random numbers would be required. Multiply these numbers by 80.0 (the total mileage in our sample area) to obtain virtual milepoints to the nearest tenth of a mile. Then, convert these virtual milepoints back into the actual milepoints for the sample locations on the various routes involved. In the field, count or measure each element present and each element that is deficient in each sample area.
6. When LOS data have been collected from all sources and surveys, calculate the average LOS measure for each element. For bridges, for example, this will be the average NBI rating for each group of elements, such as the average deck condition or the average superstructure condition. For pavements, this may be the average percent of surface area with fatigue cracking, or other measured distress.
7. When the average LOS measures have been determined for each element, the threshold scales in Table 4-1 may be used to assign an LOS rating, or letter grade, to each of the elements. Results may be summarized as shown in the examples in Table 5-1 and Table 5-2. A report may be developed for each Interstate route, each area of the state, and for the entire state. At the national level, similar reports may be developed, showing the average LOS for each of the asset elements.

If a single LOS grade is desired for an asset group (e.g., drainage), an overall letter grade may be determined by using the approach outlined in Section 6.5 for aggregation of letter grades.

The resulting reports will provide a clear indication of the LOS being provided by the IHS in a region of a state, statewide, and nationwide. Furthermore, the results will be comprehensible and useful to both technical and nontechnical people for decisionmaking.

CHAPTER 6

Implementation Considerations

The following sections provide additional insights on certain aspects of an effective LOS assessment program, including frequency of LOS surveys, sampling techniques, analysis approaches, weighting and aggregation of data (roll-ups), and implementation considerations.

6.1 Frequency of LOS Surveys

Two of the three demonstration states, and many other states, conduct LOS surveys once per year. Florida DOT was the exception with three surveys per year. The rate of change in asset conditions must be weighed against the costs and benefits of data collection. Annual surveys for most assets are considered to be sufficient. Bridge inspections are done on a 2-year cycle in most cases (bridges with structural deficiencies may require more frequent inspections). Pavement surveys are often conducted on a 1- or 2-year cycle.

Although annual surveys are desirable, especially if they are used to influence annual budget cycles, collecting pavement and bridge data on an annual basis may be cost prohibitive for some states. Rather than change the frequency of pavement and bridge data collection, it is recommended that states report on whatever LOS data are available on an annual basis. In some cases, that may mean that LOS data for certain asset classes may be repeated in the "off-years" of survey cycles that are longer than 1 year. This practice is not considered to present a significant problem for the purposes of IHS LOS assessment.

6.2 Data Collection

The state of the practice shows that random sampling methods are used to collect data that in turn determine the LOS provided by the various elements of the drainage system asset class.

In the three demonstration states, condition data of all the elements within the drainage system asset class on the IHS are collected using a random sampling methodology as opposed to collecting data on the entire inventory. The specifics of the random sampling techniques, such as the formula used to calculate the number of samples required, varies among the states, but the data collected by all three states is significant at a 95 percent confidence level.

Data are collected by dividing the total number of centerline IHS miles in each of the states into 0.1-mi segments. These segments constitute the sampling universe. A statistically significant number of sample segments is randomly generated from within these total number of 0.1-mi segments and condition data for the elements present in those particular segments are subsequently collected. In Florida, the samples are significant at the county, maintenance area, and district levels; in Mississippi they are significant at the maintenance district level; and in Washington they are significant at the regional level.

Several states (Alabama, Louisiana, Mississippi, and the West Virginia Turnpike [I-77]) use the following formula to determine a statistically significant number of 0.1-mi sample segments at a maintenance district level:

$$n = \frac{(z^2)(p)(1-p)}{e^2 + \dfrac{(z^2)(p)(1-p)}{N}}$$

where

n = Sample size (e.g., number of 0.1-mi increments needed);

N = Population size (e.g., total number of 0.1-mi increments);

z = Standard normal deviate (i.e., number of standard deviations for desired level of confidence);

p = Proportion of the population that meets a specified criteria (a value of 0.8 is suggested for Interstate highways);

$1 - p$ = Remaining proportion of the population; and

e = Allowable sampling error (or precision), expressed as a decimal (a value of 0.07 is suggested; using a value of 0.05 will increase the number of samples required by about 75 percent).

The expression "$p(1 - p)$" in the above formula may be replaced with the variance "σ^2" (where σ is the standard deviation), if desired. In either case, the percent of the population meeting the passing criteria, or the variance of the population, may be estimated based on a review of the early sampling results.

The formula may be examined in more detail by referring to various textbooks on statistical sampling.[8]

In Washington, an online calculator[9] is used to determine the statistically valid number of sites at the regional level. These numbers are then prorated out per area, and then section, based on the percentage of centerline miles in each area and section. They are also prorated out per type of roadway (e.g., if half the centerline miles in a section are functional Class 5 [freeway], approximately half of their survey sites will be on freeways).

Washington's formula is similar to the one shown above, except that it does not include the adjustment for population size (i.e., the term containing "N" in the above formula). For large populations, say 30,000 or more (i.e., 3,000 or more miles of Interstate using 0.1-mi samples) Washington's formula will yield results very similar to results obtained from the formula shown above. However, for small populations, as may be the case with the IHS in some of the smaller states and the District of Columbia, the above formula will yield more reasonable results.

Florida uses a manual method, rather than a formula-based method, to determine a statistically valid number of samples.[10] After stratifying the road network by district and road class, they select 30 samples (0.1-mi each) from each road segment longer than 10 mi and a 30 percent sample from segments shorter than 10 mi. The sampling methodology was initially designed to provide a confidence level of 95 percent, with a precision of approximately ± 3 percent. In practice, the precision varies by a percentage point or more, depending on the size of the sample population in the various districts.

Random sampling methodology, as opposed to collecting data on the entire inventory, has been adopted in the three demonstration states and is in general agreement with the state of the practice. At the same time, these states use different formulae to determine the statistically significant number of samples. Although all are significant at a 95 percent confidence level, irrespective of the formulae used, it would be desirable for all states to use the same methodology for determining sample sizes for Interstate LOS assessment. Since the formula presented above is already in use by several states (Alabama, Louisiana, Mississippi, and the West Virginia Turnpike) and includes an adjustment for population size, it is recommended for national use.

For most assets, data collection can be done on a sample basis. However, for assets with very small population sizes (e.g., rest areas), a 100 percent sample is recommended.

For those elements collected as part of the HPMS program, the various LOS measures should be obtained as a weighted statewide average, based on the length of each homogeneous section, as described in the HPMS manual.

For other elements, a simple average of the data accumulated on randomly selected 0.1-mi sections should be used. In most cases, a percentage is calculated by dividing the number or length of deficient elements by the number of elements in the sampled population.

6.3 Pass/Fail versus Quantitative Approach for LOS Analysis

There are two commonly used approaches for LOS for highway assets. One is generally referred to as the "pass/fail approach." The other, although not formally named as such, will be referred to as the "quantitative approach."

In both cases, LOS indicators are defined and deficiency criteria are established. For an asset like "guardrail," the LOS indicator might include a statement like "damaged or missing," for both cases. The deficiency criteria also may be similar to the extent that the severity of deficiencies may be described in some detail, such as "damaged to the extent that structural integrity is reduced."

Also, in both cases, the LOS measure is often expressed in terms of "percent deficient," such as "percent of guardrails deficient," or as a measurement such as "linear feet of deficiency per shoulder mile," or conversely, in terms of "percent sufficient." Results may be summarized in terms of measures like "linear feet of deficiency per shoulder mile," or "percent deficient."

A significant difference with the pass/fail approach is that a deficiency is typically defined by a minimum extent before it is considered a deficiency. For example, statements like "more than 10 percent of the length deficient" may be used to define a deficiency, which means that any guardrail section with deficiencies less than 10 percent of the section length would not be considered deficient.

The advantage of the pass/fail approach is that data collection is relatively quick and easy. Consider, for example, 100 sample sites in which each had guardrail, which in total amounted to 50,000 ft. Furthermore, consider that no more than 10 percent of any guardrails in the sample areas were deficient. If the minimum extent rule mentioned above

---

[8]Hamburg, M. and Young, P., *Statistical Analysis for Decision Making,* 6th ed, Dryden Press, Harcourt Brace College Publishers, Orlando, FL, 1994, p. 297.

[9]http://www.surveysystem.com/sscalc.htm#ssneeded

[10]Zahn, D., Wu, S. M., and Stein, J. *Assessment and Improvement of the Maintenance Rating Program,* Florida Department of Transportation, August 1996.

were applied, the inspectors could simply count the number of installations and the number that were deficient (in this example, 100 and 0, respectively). A time-consuming measurement would not be necessary unless the extent of deficiency in some locations was questionably near 10 percent.

One of the disadvantages of the pass/fail approach is that the resulting LOS statement does not accurately reflect actual amounts of deficient conditions of the assets. In the above example, up to 10 percent of the guardrail could be deficient, yet the resulting LOS would show 100 percent as passing.

Another disadvantage of the pass/fail approach is that the results can not reliably be used for maintenance planning and budgeting. In the above example, there is no indication of the quantity of guardrail repair work that may be needed, and not even an indication that some work might be required. The only conclusion that can be reached is that somewhere between 0 and 5,000 ft of guardrail may need to be repaired.

Still another disadvantage of the pass/fail approach is the legal aspect. The highway agency might be considered "negligent" in a liability lawsuit should someone hit a damaged guardrail section that was rated as "passing."

The advantage of the quantitative approach is that all deficiencies are counted or measured, regardless of the extent of each. In the above example, each deficient length of guardrail would be measured and compared to the total length. The resulting average LOS measure might be, for example, 5 percent deficient, which reflects the actual extent of deficiencies in the sample population.

Another advantage of the quantitative approach is that the result can immediately be converted into a work quantity for maintenance forces. In the above example, it is clear that 2,500 ft (i.e., 50,000 * 0.05) of guardrails needs maintenance attention.

A disadvantage of the quantitative approach is the additional time required to collect the data, since each asset and the extent of deficiency of each asset needs to be measured or counted. The data are more accurate and more useful, but the level of effort and cost to obtain it is somewhat higher.

These pros and cons will need to be considered when establishing a policy for LOS assessment. The recommendation of the research team is to use the quantitative approach.

6.4 Data Weighting Issues

There are three circumstances where weighting of the LOS measures may be necessary or desirable.

First, some types of data may be collected on homogeneous road sections of unequal length, as is the case with HPMS data and some pavement surveys. In these cases, the measures for each homogeneous section will need to be weighted based on the length of the section to obtain meaningful averages. This is generally not necessary for data collected on sample sections of uniform length.

Second, weighting will be necessary when rolling up results from district level to statewide level or from statewide to national level. This type of weighting is necessary to present data on a comparable basis. Otherwise, data from smaller regions or smaller states would be given equal weight as larger regions or larger states and would not be a true representation of the overall LOS for the IHS as a whole. The LOS measures should be weighted based on the Interstate mileage represented by each element.

Third, in cases where a single LOS measure is desired for a group of assets (e.g., the drainage or roadside asset class), it may be desirable to assign weights to the average LOS measure for each asset element, based on the perceived level of importance of each element. Some elements, for example, may be safety related, and may warrant a higher weight than others that have less impact on safety, such as vegetation management. These decisions will depend largely on the policies and perceived importance of the various assets in individual states. Establishment of a national policy for weighting the importance of individual asset elements is not viewed as desirable by the research team. There is no rational basis for doing so at the present time, and it is doubtful that any two states would agree on what the weights should be. In fact, when analyzing data at the national level, it would be better to work with unweighted data. Then, if the importance of certain elements is of interest, weights can be applied at the national level on a consistent basis.

6.5 Aggregation of LOS Measures

When describing overall Interstate LOS at the state or national level, it may be desirable to show one aggregate rating for a group of assets (e.g., drainage or traffic control devices) or for the system as a whole. The challenge with aggregation is that the performance measures may be different for different assets, but the problem is not insurmountable.

For a group of assets in which all have the same LOS measure, say "% deficient," and the same thresholds for the various letter grades, the measures for the individual assets could be averaged to obtain an overall LOS for the group. This approach would work for the drainage and traffic control devices shown in Table 4-1. However, it would not be applicable to the other asset categories, some of which have different measures and different thresholds. Furthermore, this approach would not be suitable for determining an overall rating for the IHS.

Table 6-1. Conversion factors for aggregating letter grades.

	Letter Grade Conversions												
LOS Grade	A+	A	A-	B+	B	B-	C+	C	C-	D+	D	D-	F
Numerical Value	13	12	11	10	9	8	7	6	5	4	3	2	1

Another approach is to assign numerical values to the letter grades, as shown in Table 6-1.

Each letter grade is converted to a numeric value using Table 6-1. The numeric values can be averaged for a group of assets, for all assets in the region or state, or for a nationwide average. The average value can be converted back to a letter grade using the same table.

The advantage of this approach is that it can be applied to any asset or group of assets regardless of the measurement units involved.

Appendices

The appendices are not printed with this report but are included on the accompanying CD-ROM and are titled as follows:

- Appendix A: State-of-the-Practice Research
- Appendix B: Development of Levels of Service for the IHS

Bibliography

2006 Status of the Nation's Highways, Bridges, and Transit: Conditions and Performance, report to Congress, U.S. Department of Transportation, Federal Highway Administration, Federal Transit Administration, 2006.

Arizona Department of Transportation, *Strategic Highway Safety Plan,* August 2007.

Arnoult, J. D., *Culvert Inspection Manual: Supplement to the Bridge Inspector's Training Manual,* Report FHWA-IP-86-002, Federal Highway Administration, McLean, Va., July 1986.

Cambridge Systematics, Inc., et al., *NCHRP Report 618: Cost-Effective Performance Measures for Travel Time Delay, Variation, and Reliability,* Transportation Research Board, 2008.

Delaware Department of Transportation, *Delaware Transportation Facts,* 2006.

Federal Highway Administration, Highway Statistics, Table VM-2.

Florida Department of Transportation, *Draft Issue Paper, Improving Florida's Transportation Planning and Design Analysis Time Period Process,* February 2009.

Florida Department of Transportation, *Florida's Mobility Performance Measures Program,* December 2000.

Florida Department of Transportation, *Quality/Level of Service Handbook,* 2009.

Iowa Department of Transportation, Results Iowa, accessed August 2008.

Maine Department of Transportation, *Transportation Indicators Report,* April 2002.

Manual on Uniform Traffic Control Devices for Streets and Highways, 2003 ed, U.S. Department of Transportation, Federal Highway Administration, December 2007.

Maryland Department of Transportation, *Annual Attainment Report on Interstate System Performance,* 2007.

Minnesota Department of Transportation, *Minnesota Statewide Transportation Plan,* 2003.

Missouri Department of Transportation, *Tracker: Measures of Departmental Performance,* April 2008.

National Highway Traffic Safety Administration, *Traffic Safety Performance Measures for States and Federal Agencies,* August 2008.

Nebraska Department of Roads, *Performance Measures,* September 2007.

Nevada Department of Transportation, *Draft Statewide Long-Range Transportation Plan 2008–2028,* 2008.

Texas Department of Transportation, *2009–2013 TxDOT Strategic Plan,* 2008.

Texas Transportation Institute, *2007 Urban Mobility Report.*

Transportation Asset Management Case Studies, Culvert Management Systems: Alabama, Maryland, Minnesota, and Shelby County, Office of Asset Management, Federal Highway Administration, U.S. Department of Transportation, Washington D.C., May 2007, http://www.fhwa.dot.gov/infrastructure/asstmgmt/tamcs_cms.cfm.

U.S. Department of Transportation, *Performance and Accountability Report, FY 2007.*

U.S. Government Accountability Office, GAO-08-843R, *Surface Transportation,* July 2008.

Washington Department of Transportation, *Transportation Benchmarks 2006 Report.*

Washington State Department of Transportation, *Gray Notebook Edition 31, Measuring Delay and Congestion—2008 Annual Update,* September 30, 2008.

Washington State Department of Transportation, *WSDOT Maintenance Customer Survey: Summary Report,* November 2005.

Washington State Department of Transportation, *WSDOT's Congestion Measurement Approach,* January 2008.

Wisconsin Department of Transportation, *Wisconsin State Highway Plan 2020,* February 2000.

Wyant, D. C., *NCHRP Synthesis 303: Assessment and Rehabilitation of Existing Culverts,* Transportation Research Board, Washington D.C., 2002.

Acronyms

ACP	Asphaltic Concrete Pavement
CoRe	Commonly Recognized
CRCP	Continuously Reinforced Concrete Pavement
DOT	Department of Transportation
FARS	Fatality Analysis Reporting System
HCM	Highway Capacity Manual
HPMS	Highway Performance Monitoring System
IHS	Interstate Highway System
IRI	International Roughness Index
ITS	Intelligent Transportation Systems
JCP	Jointed Concrete Pavement
LOS	Level of Service
MPO	Metropolitan Planning Organization
MQA	Maintenance Quality Assurance
MRI	Mean Roughness Index
MUTCD	Manual on Uniform Traffic Control Devices
MVMT	Million Vehicles Miles of Travel
NBI	National Bridge Inspection
PSR	Present Serviceability Rating
V/C	Volume to Capacity

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
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation