

Managing Selected Transportation Assets: Signals, Lighting, Signs, Pavement Markings, Culverts, and Sidewalks

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NCHRP SYNTHESIS 371

**Managing Selected
Transportation Assets:
Signals, Lighting, Signs,
Pavement Markings,
Culverts, and Sidewalks**

A Synthesis of Highway Practice

CONSULTANT

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Teaticket, Massachusetts

SUBJECT AREAS

Bridges, Other Structures, and Hydraulics and Hydrology, Maintenance, Safety and Human Performance

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.
2007
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FOREWORD

*By Staff
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Highway administrators, engineers, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and unevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

There is information on nearly every subject of concern to highway administrators and engineers. Much of it derives from research or from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the entire highway community, the American Association of State Highway and Transportation Officials—through the mechanism of the National Cooperative Highway Research Program—authorized the Transportation Research Board to undertake a continuing study. This study, NCHRP Project 20-5, “Synthesis of Information Related to Highway Problems,” searches out and synthesizes useful knowledge from all available sources and prepares concise, documented reports on specific topics. Reports from this endeavor constitute an NCHRP report series, *Synthesis of Highway Practice*.

This synthesis series reports on current knowledge and practice, in a compact format, without the detailed directions usually found in handbooks or design manuals. Each report in the series provides a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems.

PREFACE

This synthesis was designed to gain a better understanding of the state of the practice for managing transportation infrastructure assets other than pavements and bridges, identify best practices, and document gaps in knowledge and areas for further study. It examines key aspects of asset management related to selected infrastructure assets (traffic signals, lighting, signs, pavement lane striping and other markings, drainage culverts and pipes, and sidewalks), including primary sources of technical guidance for management; basic approaches to budgeting for and conducting preservation, operation, and maintenance; organizational responsibilities for ongoing maintenance; measurement of asset condition and performance, including methods and frequencies of data collection; estimates of service lives (or deterioration models) for key components of the selected assets, accounting for the different materials used; information technology capabilities available to help agencies manage these selected assets; and perceptions of the transportation objectives that are served by maintaining selected assets in good condition.

Information for the study was acquired through a review of U.S. and international literature and by a survey of state, provincial, county, and city transportation agencies in the United States and Canada. Follow-up communications with selected survey respondents provided additional information.

Michael J. Markow, Consultant, Teaticket, Massachusetts, collected and synthesized the information and wrote the report. The members of the topic panel are acknowledged on the preceding page. This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

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MANAGING SELECTED TRANSPORTATION ASSETS: SIGNALS, LIGHTING, SIGNS, PAVEMENT MARKINGS, CULVERTS, AND SIDEWALKS

SUMMARY Transportation agencies at all levels of government have in recent years investigated and applied the concepts, methods, and tools of asset management. These applications have typically focused agencies' strongest capabilities on pavements and bridges, key items in an agency's capital program and budget. They are often at the center of decisions on investment priorities and program tradeoffs, and their performance is highly visible to motorists and the public at large. Relatively sophisticated management systems and other analytic tools enable agencies to track the condition and performance of pavements and bridges and to identify "optimal" investment strategies for these assets. Data on current condition, performance, and remaining service life are developed through detailed, comprehensive periodic inspections. Broader technical knowledge of pavements and bridges is sustained through research programs; technological innovation by public and private industry organizations; and information dissemination through publications, conferences, and courses.

Similar methods, tools, and forums for information exchange are typically not as widely available or deployed for other surface transportation assets in the United States, at least not to the scale seen for pavements and bridges, although there are notable individual exceptions. The objectives of this synthesis were to gain a better understanding of the state of practice for managing transportation infrastructure assets other than pavements and bridges, to identify best practices, and to document gaps in existing knowledge and needs for further research. The study focused on the assets listed here, although unique or innovative management methods for other assets were also included whenever identified. The six types of assets that were the primary subjects of this study—referred to as "selected infrastructure assets" or simply "selected assets"—included:

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

This synthesis study examined several key aspects of asset management related to the selected infrastructure assets, including primary sources of technical guidance for management; basic approaches to budgeting for and conducting preservation, operation, and maintenance; organizational responsibilities for ongoing maintenance; measurement of asset condition and performance, including methods and frequencies of data collection; estimates of service lives (or deterioration models) for key components of the selected assets, accounting for the different materials used; information technology capabilities available to help agencies manage these selected assets; perceptions of the transportation objectives that are served by maintaining selected assets in good condition; and major gaps in knowledge that impede better asset management, with recommendations for future research. These data were gathered through a review of U.S. and international literature, and a survey of state, provincial, county, and city transportation agencies in the United States and Canada.

The literature review indicated that management of these assets can be complicated in several ways.

- From an engineering and technical standpoint, selected assets comprise a number of components and materials, serve in many different environments across the United States and Canada, and are subject to many different types of deterioration. Developing models that adequately explain these deterioration mechanisms and that can predict service lives for the complete range of possible conditions is a major challenge.
- From a human factors perspective, the selected assets that affect mobility and safety can have complicated impacts that are still being researched among different population groups of drivers and pedestrians.
- From an organizational, institutional, and procedural view, selected assets present challenges in management, coordination, and data compilation, given the typically diffused responsibility for their operation and maintenance.

The survey questionnaire, developed with the advice of the Topic Panel, was presented in seven parts: six related, respectively, to the six classes of infrastructure assets listed earlier. A seventh part addressed the broader issues of asset management and knowledge gaps and needs. The survey was distributed to the contact individuals for asset management within each state department of transportation or state highway agency, as identified by AASHTO. Distribution to U.S. cities and counties was assisted by FHWA's Local Technical Assistance Program network. Distribution to provinces and cities in Canada was facilitated by the Transportation Association of Canada. A total of 35 agencies responded to this questionnaire.

Those agencies that responded to the survey were clearly interested in the management of these selected assets. Several have already developed management systems specifically directed at one or more of these classes of infrastructure. Others have incorporated these selected assets within agency-wide asset management systems or enhanced maintenance management systems. Others are now in the process of developing an asset management approach for these assets, although they are not yet completed. At a minimum, agencies rely on existing maintenance management systems or other analytic and data gathering tools such as spreadsheet workbooks and paper log books to track and manage these selected assets.

Agencies that responded to the survey agreed substantially on why these selected assets should be managed. Many provided exactly the same or very similar rankings of the transportation goals served by these assets. However, estimates of technical data such as asset service life varied across agencies. Although there is a basic pool of information that could form the nucleus of an asset management approach, these agencies reported that additional work is needed in a number of areas.

- State of knowledge—current state of knowledge regarding the performance and service life of selected assets needs to be improved to reduce variability and increase consistency and completeness.
- Inventory—lack of a complete, accurate, and current inventory of these selected assets was viewed by many agencies as one of the key issues to address. The main challenge is to keep the inventory complete and current over time.
- Management capabilities and information—although research continues on understanding and modeling the service life of selected assets and implications for performance, participating agencies identified several additional capabilities and types of information that are needed to improve management. These included a need for greater standardization in how asset service life is measured and reported; the need to evaluate service life under field conditions; additional modeling tools and related information; and simple, practical, and streamlined analytic tools to aid decision making without the need for substantial data gathering.

- Beyond physical condition—these selected assets demonstrate performance impacts that go beyond physical condition and service life. Measures of performance and life expectancy need to be broadened to encompass concepts such as energy consumption and functional, rather than physical, obsolescence of electronic components. Performance also needs to be understood in terms of impacts to the general public, not just motorists.
- Dynamic commercial environment—new technology is continually evolving for these selected assets. Although these advances provide many benefits to transportation agencies and users, they complicate an agency's ability to remain current regarding the performance and compatibility of new versus existing products.
- Institutional factors—maintenance responsibilities for these selected assets tend to be shared among public- and private-sector entities. Although these arrangements may make efficient use of resources, they complicate information awareness and enforcement of maintenance standards.
- New technology—several ideas were proposed by participating agencies for new technology that could aid in the management and repair of selected assets.
- Better communication of priority—participating agencies identified the need for stronger communication of the priority of selected assets.

INTRODUCTION

BACKGROUND

Modern road transportation systems comprise many physical components, or *assets*, that enable them to fulfill the public's expectations to travel to their destinations safely, conveniently, in reasonable time, and at reasonable cost. Roadway pavements and bridges are among the most visible and highly valued elements of highways, roads, and streets. These aspects of road links are essential to providing smooth, safe, efficient, and cost-effective movement of people and goods. Many other assets in highway, road, and street networks however also play important roles in ensuring the structural integrity as well as the orderly, safe, convenient, and efficient mobility expected in a well-functioning and cost-effective transportation system. These additional assets are located above, below, and alongside the roadway proper; encompassing items such as signs, signals, lighting, centerline or median barriers, guardrails, crash attenuators, lane and edge striping, and other pavement markings, sidewalks, roadside delineators, pavement subsurface drains, drainage inlets and catch basins, culverts and drainage ditches, retaining walls, and fencing.

The importance of these “other assets” should not be underestimated. They are critical to an orderly and safe movement of vehicles and people in several ways:

- They help guide vehicles (signs, lane striping, and delineators) and avoid conflicts at intersections (signs and traffic signals).
- They help prevent collisions with other vehicles (striping and centerline barriers) and with roadway and roadside objects (guardrails, warning signs, and crash attenuators).
- They alert motorists to situations requiring heightened attentiveness (warning signs, signals, and pavement markings) and increase overall awareness at night (roadway lighting and retroreflective signs, pavement markings, and delineators).

Assets such as drainage structures and pipes, retaining walls, and fences enable roads to serve properly in their natural setting and to protect the public from natural threats such as floods and slides. They help maintain the integrity of the roadway foundation by collecting and diverting water from the road surface and subsurface, and transporting natural watercourses safely along and across the right-of-way

(drainage inlets, subsurface drains, culvert pipes, box culverts, and ditches). They enable the construction and preservation of an optimal road alignment and profile in hilly or mountainous terrain, and in urban areas where open land is scarce (retaining walls and reinforced earth structures), while protecting motorists as well as the natural environment (fallen-rock barriers, gabions, and fish passages). They prevent unwanted incursions within the transportation right-of-way by people and animals (signs, fences, and cattle guards).

These types of assets enable highway, road, and street networks to serve several transportation modes simultaneously, both motorized and nonmotorized. They delineate reserved lanes and loading areas (e.g., for buses, taxis, delivery trucks, and cyclists), separate the traffic streams of different modes (e.g., pedestrian sidewalks, bicycle paths, and lanes), and help organize the movement of conflicting modes where they must cross (e.g., signs, signals, and pavement markings at crosswalks). They provide important warnings and regulatory controls on traffic at critical locations; for example, in school zones, at busy intersections, and near housing for the elderly or people with special needs. Often these assets are used in combination with one another for maximum effectiveness; for example, signs, signals, markings, and lighting.

STUDY OBJECTIVES

The objectives of this synthesis were to gain a better understanding of the state of practice for managing transportation infrastructure assets other than pavements and bridges, to identify best practices, and to document gaps in existing knowledge and needs for further research. The study focused on the assets listed here, although unique or innovative management methods for other assets were also included whenever identified. The following six types of assets were the primary subjects of this study, and are referred to in this report as “selected infrastructure assets” or simply “selected assets”:

- Traffic signals, including structural components;
- Lighting, including structural components;
- Signs, both ground-mounted (or roadside) and overhead, including structural components;
- Pavement lane striping and other markings;
- Drainage culverts and pipes (but not bridges); and

- Sidewalks, including the walkway itself, curbs, and corners on urban roads and streets (corner curbs, and curb cuts and ramps if present).

The synthesis was designed to address a number of issues related to these selected assets, including:

- Agency management approaches for each asset;
- Methods to determine condition of the asset;
- Methods to determine where an asset is in its life span;
- Methods to forecast future resource needs for preserving and/or achieving a service-level objective;
- Service-life models or assumptions that are used to forecast maintenance, rehabilitation, and replacement;
- Methods and technologies used to collect, analyze, predict, map, and maintain asset information;
- Major knowledge gaps and research needed to improve the validity of service-life estimates for the six selected transportation assets; and
- Other non-pavement, non-bridge assets for which unique or innovative management approaches have been developed.

STUDY APPROACH

This synthesis study examined these and other aspects of asset management related to the selected infrastructure assets, including primary sources of technical guidance for management; basic approaches to budgeting for, and conducting, preservation, operation, and maintenance; organizational responsibilities for ongoing maintenance; measurement of asset condition and performance, including methods and frequencies of data collection; estimates of service lives (or deterioration models) for key components of the selected assets, accounting for the different materials used; information technology capabilities available to help agencies manage these selected assets; perceptions of the transportation objectives that are served by maintaining selected assets in good condition; and major gaps in knowledge that impede better asset management, with recommendations for future research.

These data were gathered through a review of U.S. and international literature and a survey of state, provincial, county, and city transportation agencies in the United States and Canada. The survey questionnaire was developed with the advice of the Topic Panel and was presented in seven parts: six related to the six classes of infrastructure assets listed previously, and a seventh that addressed broader issues of asset management and knowledge gaps and needs. The survey questionnaire is included in Appendix A. Follow-up communications with selected survey respondents provided additional information. The survey was distributed to the contact individuals for asset management within each state department of transportation (DOT) or state highway agency (SHA), as identified by AASHTO. The FHWA's Local

Technical Assistance Program network assisted with the distribution to U.S. cities and counties. Distribution to provinces and cities in Canada was facilitated by the Transportation Association of Canada (TAC). A total of 35 state DOTs, SHAs, highway and transportation (H&T) organizations, provincial ministries of transport, and transportation or public works departments in cities and counties responded to this questionnaire and are listed in Appendix B. These 35 jurisdictions provided 39 sets of completed questionnaires, as the results for Colorado were submitted individually by Colorado DOT region.

Not all respondents completed all parts of the questionnaire. The number of responses with useable data therefore varied by survey part. When subsequent chapters refer to "reporting agencies" or "responding agencies," the numbers of responses for each asset type are as given by the following counts: signals (31), lighting (32), signs (36), markings (33), culverts (30), and sidewalks (23).

This report discusses the survey findings fully, reflecting the breadth and detail of the questions as posed. Comments and additional information that were provided by survey participants are paraphrased following the graphical and tabular compilations of responses. The report also cites the findings of additional surveys that have been conducted by other researchers in earlier studies.

There is a considerable body of literature associated with each of the six selected assets. This synthesis reviews the portions of that literature that most directly explain and illustrate to what degree agencies have applied good asset management practice to the six selected assets. This review includes considerations such as service-life estimation, supporting data collection, applications of information technology, relevant human factors issues, gaps in current knowledge, and needs for research. The number, detail, and types of sources of this literature are not uniform across the six types of assets, however, which has also been observed by other researchers (e.g., Zwahlen et al. 2005). For example, there are considerable numbers of references addressing the physical and chemical performance of culvert materials and pavement markings, respectively; explanations of how these assets degrade over time are technically complex. Other assets, such as traffic signals and roadway lighting (excluding supports), exhibit performance based on a different set of organizing principles that are rooted in electrical/electronic systems and communications rather than physical material abrasion, deformation, and corrosion; the literature related to the asset management of these systems in a transportation context is not as extensive. Applications of asset management to roadway lighting and examples of innovative lighting technology are prevalent in the international literature. Sidewalk asset management plans are almost exclusively in the domain of local governments rather than state DOTs, at least in U.S. practice. These differences are one of the key reasons for addressing the six assets individually in

chapters two through seven. At the same time, the importance of viewing asset management comprehensively is a major reason for consolidating findings across assets and describing strategic agency management approaches in chapter eight.

PRACTICAL ASSESSMENTS OF ASSET MANAGEMENT

General

Asset management is a strategic approach to managing transportation infrastructure that aims to get the best results or performance in the preservation, improvement, and operation of infrastructure assets given the resources available. According to the AASHTO *Transportation Asset Management Guide*, good asset management approach is policy-driven and performance-based, considers alternatives or options, evaluates competing projects and services based on cost-effectiveness and the anticipated impact on system performance, considers tradeoffs among programs, employs systematic and consistent business processes and decision criteria, and makes good use of quality information and analytic procedures (Cambridge Systematics, Inc. et al. 2002). During the development of the *Guide* in NCHRP Project 20-24(11), site visits to several DOTs indicated that all agencies likely practice at least some elements of good asset management, but none are likely to have fully implemented all potential aspects. Today, asset management is seen as applicable to transportation agencies at all levels of government, and the concept has been applied internationally among selected national, provincial, and municipal agencies for many years.

Although asset management is a fundamental idea that applies in concept to any significant facility or item of infrastructure, there has been a tendency in the United States until now to associate it most closely with pavement and bridge management. One purpose of this synthesis is to identify how asset management concepts and techniques have been, or can be, applied to other transportation assets such as the six selected assets that are the focus of this study. This objective will first be addressed for each of the six assets individually, considering results from agencies that have participated in the synthesis survey, plus findings of the international literature review. Results across the six selected assets will then be consolidated to develop general findings on how agencies manage their transportation assets other than pavements and bridges. It will also highlight leading efforts by individual agencies to develop improved information-gathering techniques, management procedures, and decision-support systems for their non-pavement, non-bridge assets. It will contrast these state-of-the-art examples with the wide range of current practices that now exist within the broader population of transportation agencies at various levels of government worldwide.

Maturity of Asset Management Development

Although “asset management” relates to many facets of an agency’s business processes and decisions, it is possible to provide brief, descriptive examples that help to identify where an agency is in its asset management development. Table 1 presents such a “maturity diagram” for three levels of development.

- Basic infrastructure management, which is based not on an initial awareness of asset management, but continuing decision making that is largely focused on individual assets. Asset management needs are typically addressed by engineering-based solutions. An asset inventory may exist, but, if so, it is not integrated with a corporate data warehouse.
- Growing application of asset management, where policy, processes, and staffing are all working to integrate an agency’s decision making for long-term, mid-term, and immediate needs.
- State-of-the-art asset management, which represents a comprehensive application of good practices across assets and programs, and broad organizational buy-in with commitment from top management. The agency adopts positions and decision processes based on funding asset needs in a sustainable manner, subject to resource constraints. Decision making is no longer asset-centric. Data and decisions reflect confidence levels so that communities and stakeholders can knowledgeably weigh in on preferred and affordable levels of services. Asset management is seen as a business management philosophy, not a program.

The information in Table 1 has been developed from several sources: the *Transportation Asset Management Guide* (Cambridge Systematics, Inc. et al. 2002), the *International Infrastructure Management Manual* (IIMM, or “I²M²”) issued by the National Asset Management Steering Group (2006), *NCHRP Report 551: Performance Measures and Targets for Transportation Asset Management* (Cambridge Systematics, Inc. et al. 2006), the FHWA report *Roadway Safety Hardware Asset Management Systems: Case Studies* (Hensing and Rowshan 2005), and a general knowledge of the evolution of pavement management and bridge management, which are often cited as examples of transportation asset management in practice. Points to note are:

- Table 1 compares progressive stages of infrastructure asset management development. It is intended as a template. More complete and authoritative information on the concepts and implementation of asset management is provided in the references cited in the preceding paragraph.
- Asset management is really continuous process improvement and is not developed in discreet stages. The use of three stages of development in Table 1 is

TABLE 1
ASSET MANAGEMENT MATURITY CRITERIA

Aspect of Infrastructure Management	General Stages of Infrastructure Management Maturity		
	Basic Infrastructure Management	Growing Application of Asset Management	State-of-the-Art Asset Management
Overall Description of Agency Practice	<ul style="list-style-type: none"> Investment and management decisions reflect current public policy objectives and good standard engineering practice. Thinking and decision making tend to be organized around specific programs, projects, and technologies, with little cross-program interaction. Management is to some degree reactive to current condition and performance. Research and information exchange likewise focus on specific assets or technologies. 	<ul style="list-style-type: none"> Business processes and decisions show increasing sophistication and cross-program, cross-disciplinary involvement, and an increasing ability to understand long-term as well as short-term implications of decisions. There is a greater capability to account for factors affecting asset performance, costs, and impacts across a wide range of situations, supported by strengthened analytic tools and data. Better information means that sources and degrees of risks are better understood and better addressed, enabling more proactive approaches. 	<ul style="list-style-type: none"> Transportation asset management is aligned with public policies and priorities, agency strategic business plans, transportation long-range plans, and transportation financial and construction program plans. Business processes and decisions reflect principles in the <i>Transportation Asset Management Guide</i>, and represent an integrated, multi-disciplinary, and transparent approach to solving problems.
Policy Guidance	<ul style="list-style-type: none"> Agency practices conform to applicable federal, state, and local statutes; local public policy; governing engineering standards and practices; and agency policies and procedures. Public outreach is largely project-specific. Early human-factors research focuses on minimum acceptable asset performance. 	<p>Preceding capabilities plus:</p> <ul style="list-style-type: none"> Guidance moves beyond wish lists ” to provide clear governmental priorities among competing goals, objectives, and initiatives. Agency begins to integrate this guidance within aspects of its investment and management decision-making processes; e.g., in ranking and prioritization criteria, and performance-measure targets. Human factors understanding of asset-performance requirements extends to different population groups. 	<p>Preceding capabilities plus:</p> <ul style="list-style-type: none"> Long-range planning, agency strategic planning, and decisions on program funding and resource allocation are fully integrated horizontally (across agency units) and vertically (top management, managerial, and technical levels) under the umbrella of this guidance. Public outreach extends to identifying governmental priorities at a broad program level.
Asset Life-Cycle Focus	<ul style="list-style-type: none"> Project engineering decisions tend to focus on selection of materials and technology, initial cost and service life comparisons, and required impacts studies across alternatives. Maintenance and operations management decisions are largely detached from those for design and construction. 	<ul style="list-style-type: none"> Agencies apply life-cycle analysis techniques to compare total long-term performance, costs, benefits, and other impacts of project alternatives. Agencies increasingly integrate design and construction, maintenance, and operations considerations when analyzing performance, costs, benefits, and other impacts of project options. 	<ul style="list-style-type: none"> Project decisions are based on maximization of life-cycle benefits or minimization of life-cycle costs, plus consideration of other (nonquantitative) impacts. Life-cycle impacts to the public are considered in decisions on management options. The life-cycle framework enables analysis of certain tradeoffs (e.g., capital-maintenance, benefits-to-costs).

(continued)

TABLE 1 (continued)

Aspect of Infrastructure Management	General Stages of Infrastructure Management Maturity		
	Basic Infrastructure Management	Growing Application of Asset Management	State-of-the-Art Asset Management
Asset Performance and Costs	<ul style="list-style-type: none"> Asset performance is understood in basic terms such as estimated service life and measures of condition and reliability, based largely on historical data, engineering judgment, and manufacturer’s recommendations. Predictive models of asset deterioration are simple (if they exist at all), and causal factors (effects of different operating environments) are imperfectly understood. 	<ul style="list-style-type: none"> Causal factors affecting asset deterioration are reasonably well understood based on published research and the agency’s own experience. This knowledge is captured within predictive deterioration models, which may be joined with life-cycle decision-support methods (e.g., optimization, heuristics, decision trees) in management systems to forecast needs for treatments, associated costs, and improvement in asset condition or extension of service life. Management systems are applied to identify strategies for attaining performance targets within available resources. 	<p>Preceding capabilities plus:</p> <ul style="list-style-type: none"> Models yield information on asset performance and cost that can be easily processed or summarized for use by different agency organizational units and levels, as well as for external accountability reporting and public information. Understanding of asset performance—in terms of current condition, stated objectives and targets, resulting investment needs, and performance tracking—is vertically integrated and understood by the agency, executive, and legislative stakeholders.
Impacts of Asset Performance	<ul style="list-style-type: none"> Impacts are understood and communicated in basic, qualitative terms (e.g., high-moderate-low effects). Quantitative information and capability to predict impacts for different investment options are limited. 	<ul style="list-style-type: none"> More comprehensive, detailed, quantitative information on impacts of asset performance on mobility, accessibility, safety, preservation of asset investment, etc., is available through research and agency experience. This knowledge is captured within predictive models used in decision support (e.g., management systems). 	<ul style="list-style-type: none"> Agency has attained or acquired a body of research on impacts of asset performance in different situations, climates, road classes, etc. Predictive models of impacts are fully incorporated in life-cycle procedures to optimize decisions on construction, rehabilitation, and maintenance.
Resource Allocation, Budgeting, and Project Selection	<ul style="list-style-type: none"> Budget development conforms to applicable law, funding eligibility, and agency planning and programming guidelines. Various approaches may be used in setting target program budget amounts; e.g., past year’s budget plus inflation and other adjustments, percent of total budget designated for each program, percent of inventory addressed annually, and level-of-service-based budgeting. Ranking of projects in each program is based on a defined method; e.g., a scoring approach or a combination of objective and subjective criteria. 	<p>Preceding capabilities plus:</p> <ul style="list-style-type: none"> Budget development emphasizes more explicitly the relationship between proposed budget and target level of service or performance, with implications for achieving defined policy objectives. Ranking or prioritization criteria are closely aligned with policy objectives and performance targets. Level of service considers customer needs and perceptions, in addition to other public-policy and agency priorities. Budgeting results and forecast program impacts are communicated to stakeholders and the public. 	<p>Preceding capabilities plus:</p> <ul style="list-style-type: none"> Cross-program tradeoffs are explicitly considered, in addition to prioritization of projects within each program. Resource allocation and budgeting process is fully vertically aligned, with project prioritization criteria, tradeoff analyses, and performance measures and targets in full agreement with policy goals and objectives. Devices such as geographic information system-based maps and dashboards are used to communicate budget results and program impacts to stakeholders and the public.

(continued)

TABLE 1 (continued)

Aspect of Infrastructure Management	General Stages of Infrastructure Management Maturity		
	Basic Infrastructure Management	Growing Application of Asset Management	State-of-the-Art Asset Management
Organization	<ul style="list-style-type: none"> Decision making occurs in silos, and information is not readily accessible across an agency. Awareness of asset management occurs at professional conferences or through literature. 	<ul style="list-style-type: none"> Role of asset management is assigned; cross-functional asset management teams exist. Occasional training is attended by asset managers. 	<ul style="list-style-type: none"> Cross-functional asset management responsibility exists; briefs top management on status. Recognition and commitment to sustainable management of assets among employees, management, and elected officials. Hiring for asset manager role is explicit and training and asset management training occurs regularly and reaches all employees, managers, and elected officials. Succession planning takes into account the role of asset managers.
Performance Measurement	<ul style="list-style-type: none"> Performance is understood in basically engineering terms; e.g., asset condition and work outputs. Performance measures may include research results on impacts to road users (e.g., serviceability measures). Measures may comprise a mix of quantitative and qualitative indicators. Agency tracks customer comments and complaints. 	<p>Previous capabilities plus:</p> <ul style="list-style-type: none"> Asset performance is understood in engineering, economic, and customer-oriented terms. There is greater consideration to customer-oriented outcomes (consistent with greater attention to impacts in other items above), and may be supplemented by customer surveys. There is increasing use of quantitative measures, establishment of target values, and application of predictive models to evaluate investment options against targets. 	<ul style="list-style-type: none"> Body of performance measures is well-established and incorporated in business and decision processes as the basis for accountability reporting internally and externally, and to support policy formulation, prioritization and tradeoff analyses, resource allocation, and public feedback. Measures are expressed in various forms for different audiences, including reports, trend lines, dashboards, maps, and other devices.

(continued)

TABLE 1 (continued)

Aspect of Infrastructure Management	General Stages of Infrastructure Management Maturity		
	Basic Infrastructure Management	Growing Application of Asset Management	State-of-the-Art Asset Management
Information Technology (IT) and Data Collection and Processing	<ul style="list-style-type: none"> Models and engineering relationships discussed in previous items are incorporated within IT tools such as simple programs, spreadsheet workbooks, or legacy management systems (typically stand-alone, asset-specific, managing own data). Performance and impacts may include a mix of objective (quantitative) and subjective (qualitative) data. Asset inspections may be scheduled, periodic, occasional, or on-demand (i.e., following a complaint or asset failure). Data collection tends to be conducted for particular assets and programs by individual agency units, with resulting potential duplication of coverage and potentially contradictory values. 	<p>Preceding capabilities plus:</p> <ul style="list-style-type: none"> IT tools have evolved to more sophisticated management systems, incorporating engineering and economic models, life-cycle concepts, and decision-support procedures (e.g., optimization, heuristics, decision rules, or trees). More refined and controlled data collection protocols are used on defined frequencies of inspection, with an increasing trend toward data integration and sharing throughout the agency and across asset classes. Sampling techniques may also be employed. Where appropriate, there is increasing use of automation in data collection and processing (e.g., global positioning system locations, bar code readers, automated measuring devices). 	<p>Preceding capabilities plus:</p> <ul style="list-style-type: none"> Asset management systems are organized on an integrating platform (e.g., geographic information system or web-based portals) for internal and possibly external access to information. The agency maintains complete, current, and accurate data on asset inventory, condition, performance, cost, and work accomplishment. Data are updated on a predetermined schedule or by established criteria. Data supporting infrastructure asset management are fully integrated within a unified scheme. Techniques such as data warehousing may support reporting to various agency levels and stakeholders. There is an appropriate mix of data collection technology (e.g., visual, physical, and automated measurement, remote sensing) to ensure high-quality data and cost-effective coverage. Information on customer perceptions is updated regularly through surveys, focus groups, complaint tracking, or other methods.

convenient but arbitrary. For example, the AASHTO *Transportation Asset Management Guide* gives more detailed examples of state-of-the-art practice and compares typical current practices with equivalent practices with good asset management. The IIMM provides two levels of asset management attainment, a “core” level and an “advanced” level. The important point is understanding the potential span of improvement that is possible with asset management, rather than the specific number of development levels used to track that improvement.

- Entries in Table 1 highlight examples of typical practices at each stage in the U.S. transportation context, and should not be taken too literally for any one agency. Agencies differ in their management ap-

proaches and cultures for many reasons, and practices that may be viewed as “basic” by one agency may be regarded as “advanced” by another. Again, the purpose of Table 1 is to provide broad, general comparisons.

- In practice, every transportation agency displays examples of excellent asset management in some aspects of its work, and no agency has a “perfect asset management score”—there is always room for improvement. Any one agency will therefore represent a blend of practices from two or three stages in Table 1.

Based on the technical findings for each asset in chapters two through seven, the guidelines in Table 1 will be applied in chapter eight to evaluate how current management

practices for selected assets compare with the benchmarks set for good asset management. The result will be an assessment of the range of practices now in use, identification of gaps and potential research needs regarding management of the selected assets, and a focus on those agencies that are “at the front of the curve” regarding their management of the selected infrastructure assets.

Demonstrating the Importance of Selected Assets

One of the hallmarks of good asset management practice is to be able to justify asset-related expenditures on the basis of worthwhile investment and value for dollar spent. Pavement management and bridge management systems are often cited as examples of how the principles, decision criteria, and quality of data associated with good asset management can be embodied within practical, well-understood tools for managers. A key issue regarding the six selected assets is the lack of a strong history in quantifying and demonstrating the benefits that these assets provide to the public, and in using that information to identify needs, prioritize projects, and demonstrate accountability for expenditures. The value of a properly functioning set of traffic signals, roadway lights, road signs, pavement markings, drainage culverts, and sidewalks is understood technically during design. Broader impacts of these assets on road users, pedestrians, and the general public can be, and often are, expressed descriptively. However, agencies’ capabilities to manage selected assets with the same level of data availability and analytic sophistication that are now employed for pavement and bridge management vary widely and often fall short of the benchmark set by well-developed pavement and bridge management systems.

As an example, one of the questions in the survey conducted for this study asked agencies about the quantity of their inventory, and their level of expenditures for new installation and subsequent maintenance and rehabilitation, for each of the six selected assets. The question elicited one of the lowest response rates in the survey, with many partial or blank responses. Moreover, the data that were reported were highly inconsistent. From the results that were received, it was evident that (1) not all agencies maintain inventories of selected assets, and of those that do, agencies structure their inventories quite differently and express them in different units of measure; and (2) data on expenditures for the six selected assets are incomplete and difficult to compare reliably, either among agencies or in compiling annual expenditures for new installations versus those for maintenance and rehabilitation. Limited information on estimated expenditures for selected assets is available from other sources, and is cited in the chapters for those assets. As a general statement, however, many agencies do not have a good understanding of the quantity of selected assets that they manage or how much they spend on these assets.

Several other themes emerged from this study regarding how agencies manage these assets, and how they view the importance of selected assets:

- The wide range in management practices across agencies—These variations were evident in several areas; for example, in an agencies’ acquisition of basic information such as expected service life; methods of data collection and analysis; measures of asset performance and failure; criteria and threshold values for repair, rehabilitation, and replacement; ability to predict asset condition, performance, and life-cycle costs; and analytic methods and tools to help manage these assets.
- Different perspectives on the role of selected assets—There is a basic question among agencies as to whether the selected assets are indeed “assets” or merely “features” or “hardware” associated with some larger component of infrastructure; for example, are traffic signals or signalized intersections the asset of interest? Decisions on questions such as this play an important role in shaping how selected assets are viewed within an agency and in determining what level of effort will be devoted to gathering and organizing information on their status and cost.
- The lack of a perceived problem in current management of these assets—Agencies apply a number of management approaches to selected assets, including periodic inspections, programmed replacements, and quick responses to customer complaints. These methods appear to work—so long as no crisis develops. Given existing funding pressures, agencies may resist more frequent and focused attention, more advanced management approaches, and strengthened investment priority for these assets.
- Difficulty in demonstrating and communicating the importance of selected assets to the overall public good—Failures of selected assets can have serious (and in severe cases, catastrophic) consequences to mobility, safety, and public welfare. However, these consequences are not widely communicated, and are therefore poorly recognized and appreciated. Part of the reason is the lack of adequate analytic tools and more comprehensive performance information, which, if they were available, could demonstrate a performance-based relationship between selected asset condition or performance and resulting impacts to the public. Other factors, however, also come into play:
 - The need to consider *operational performance* as opposed to just *physical condition* of assets (e.g., proper signal timing; hydraulic performance of culverts; effect of pavement glare on visibility of pavement markings; and role of human factors in driver perceptions of roadway lighting, traffic signs, and pavement markings).
 - The need to consider the *combined effects* of several selected assets working together; for example, the combined roles of pavement markings, lighting,

signs, and signals at intersections and crosswalks; and the combined roles of roadway lighting and pavement marking conditions in ensuring adequate nighttime visibility of centerline, lane, and edge striping.

- The need for a *system-level* view of selected asset performance; for example, the role of signal systems in providing safe, efficient movement of traffic along a length of roadway rather than just through a single intersection; and the ability of traffic signals, roadway lighting, road signs, pavement markings, and sidewalks to serve adequately different segments of the population and different types and configurations of vehicles.
- The need for a *long-term* view of selected asset performance; for example, the ability of signal systems to respond to changes in long-term traffic volume and composition, as well as short-term

interruptions in normal traffic patterns; and the ability of a culvert system to provide ongoing protection against flooding given land-use changes and highway expansion that may have occurred after many years.

ORGANIZATION OF SYNTHESIS

Chapters two through seven discuss the synthesis findings for each of the six selected assets: chapter two, traffic signals; chapter three, roadway lighting; chapter four, road signs; chapter five, pavement markings; chapter six, drainage culverts; and chapter seven, sidewalks. Chapter eight summarizes cross-cutting findings and themes among the six selected assets. It presents several examples from agencies in the United States and internationally that have implemented or are now looking at ways to manage selected assets better. Chapter nine presents the conclusions.

TRAFFIC SIGNALS

OVERVIEW

Traffic signals help manage intersecting streams of automobile and truck traffic, pedestrians, cyclists, and other road and transit vehicles by assigning the right-of-way to individual streams in turn. They are placed where the volumes of traffic or crash histories justify their need, where crossings near schools require signal control, or signal installation is needed as part of a coordinated signal plan to ensure a smooth, progressive flow of vehicle platoons. The *Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD 2003)* establishes standards and warrants for signal installation and operation, as well as general guidance on responsibility for maintenance. The Code of Federal Regulations (23 CFR 655.603) recognizes the *MUTCD* as the national standard for traffic control devices, including signals, on all public highways, streets, and bicycle trails in the United States. It further requires that any supplementary manuals or guidelines issued by other federal and state agencies shall substantially conform to the national *MUTCD*. Traffic control devices must also conform to standards issued or endorsed by the FHWA (*MUTCD 2003*).

The study survey asked agencies to identify their key sources of technical guidance for management of traffic signals. The purpose of the question was to understand perceptions of what are the important drivers of engineering and management decisions regarding traffic signals, rather than to cite a complete list of legal and engineering authorities. Figures 1 and 2 present these results for two key aspects of asset management: new construction and installation, and maintenance and rehabilitation, respectively. The importance of individual agency guidelines as well as national standards such as the *MUTCD* is evident. AASHTO (*A Policy on Geometric Design of Highways and Streets 2004*; *Guide for the Planning, Design, and Operation of Pedestrian Facilities July 2004*), TRB's *Highway Capacity Manual (HCM 2000)*, and the Institute of Transportation Engineers (Giblin et al. 1989) provide additional guidelines regarding signal and lamp characteristics; recommended geometric characteristics of intersections; methods to compute the capacity of signalized intersections; pedestrian signal timing, phasing, and warrants; and recommended preventive maintenance schedules. AASHTO has published *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals (2001)*, and the *Roadside Design Guide (2002)* for locating and installing signal supports in the roadside, particularly regarding

safety in cases where vehicles run off the road. Building on the AASHTO specifications, subsequent studies have developed updated, more comprehensive information on several technical aspects of structural supports for signals (e.g., Dexter and Ricker 2002; Fouad et al. 2003). Individual agencies may address signalization as part of their intersection design guides (e.g., *Florida Intersection Design Guide . . . 2002*). The city of Edmonton noted corresponding Canadian guidance by TAC, the Canadian *MUTCD*, the International Municipal Signal Association, the Canadian Standards Association, and the TAC Chief Engineers' Council for new installations; and the International Municipal Signal Association and Chief Engineers' Council for maintenance and rehabilitation. The Saskatchewan H&T mentioned that another source of guidance it complies with is the requirements of the municipality with which the provincial agency partners in managing its signals in this urban area.

The *MUTCD* cites a number of potential benefits of correct signal installation: the orderly and efficient movement of what would otherwise be potentially conflicting traffic streams, improved safety, and increased intersection capacity. From an asset management perspective, maintaining signals in a state of good repair can serve these and other transportation objectives. The agencies participating in the study survey ranked several factors in order of perceived importance, as shown in Table 2. Although safe, efficient traffic movement was at the top of the list, the survey results also confirmed the importance of very responsive maintenance policies in reducing the lifecycle costs of managing these traffic control assets. The particular ranking shown in Table 2 received very strong majorities among the responses of agencies at all levels of government from the United States and Canada. This importance of signal systems to effective transportation operations has been recognized in several quarters, including this comment by the General Accounting Office [now General Accountability Office (GAO)] as cited in a report by the National Transportation Operations Coalition (NTOC):

Properly designed, operated, and maintained traffic control signal systems yield significant benefits along the corridors and road networks on which they are installed. They mitigate congestion and reduce accidents, fuel consumption, air pollutants, and travel times. These benefits are documented in numerous evaluations, provided to us (the GAO) by the Federal Highway Administration (FHWA), states, cities and other sources that compared before-and-after results when signal systems were installed, expanded, or retimed (U.S. General Accounting Office, Mar. 1994, as reported in NTOC 2005a, p. 3).

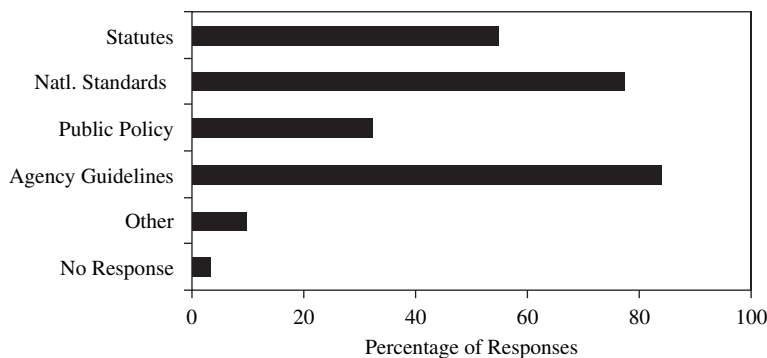


FIGURE 1 Technical management guidance for new construction and installation of signals.

Notwithstanding this consensus on the importance and the value of traffic signals, reviews of current practice by others have identified shortcomings. An earlier NCHRP synthesis study considered good-practice system engineering techniques as applied to traffic signals, including the use of a structured analysis, identification of goals and problems to be addressed, project management approach, alternatives evaluation and project evaluation, specific topics within traffic signal systems engineering (e.g., need for signals, signal timing, signal coordination, and coordination of traffic control systems), communication system engineering, local intersection control (e.g., local actuation strategy, signal priority, railroad and emergency vehicle preemption, and transit signal priority), signal procurement, operations and maintenance, and training (Gordon 2003). Responses to the survey conducted in that study indicated that although certain systems engineering techniques are well known and widely applied (e.g., evaluation of need for signals, signal timing, emergency vehicle and railroad preemption, maintenance, and training), several of the other available engineering methods are not widely or frequently used by practitioners, for the following reasons (Gordon 2003):

- Practitioners are unfamiliar with the methods or lack a user-friendly format or tool for easy application.
- Agency guidelines and standard specifications may limit designer choices among alternatives and represent

preference or selection criteria different from those assumed in the available engineering methods.

- Resource constraints and compatibility requirements with existing systems or equipment may further limit choices among design alternatives and favor simple, easy-to-maintain equipment.

In 2005, NTOC provided a report card on the nation’s traffic signal systems (NTOC 2005a,b). The objectives of this exercise were to:

- Determine the current state of signal system operation in six areas and create an awareness of signal status,
- Strengthen the understanding of the congestion-reducing benefits of good traffic signal operation,
- Build a case for more attention and additional investment in signal systems, and
- Provide a benchmarking tool for agencies to assess their own performance.

This report card was developed by a self-assessment incorporating responses from 378 state, county, and local agencies across the United States, representing agencies having signal system inventories ranging from fewer than 50 signals to more than 1,000. The self-assessment was organized and prepared by AASHTO, APWA, Institute of Transportation Engineers, Intelligent Transportation Society

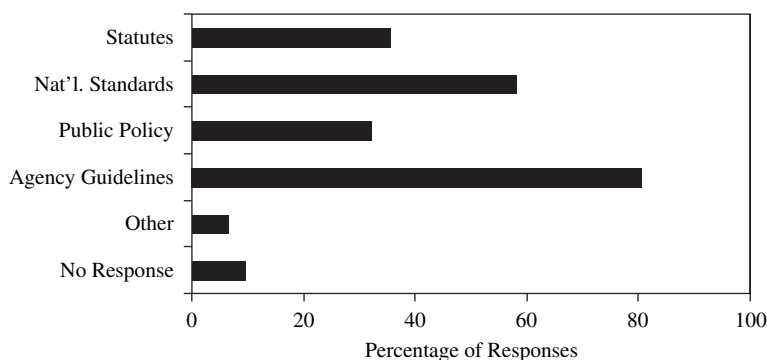


FIGURE 2 Technical management guidance for maintenance and rehabilitation of signals.

TABLE 2
PRIORITY OF TRANSPORTATION OBJECTIVES SERVED
BY TRAFFIC SIGNALS

Rank	Factor
1	Public safety; accident and accident risk reduction
2	More efficient travel; maintain intended flow and operating speed; reduce travel time
3	Preservation of existing road infrastructure; reduced agency life-cycle costs
4	Comfort and convenience of the traveling public (motorists, pedestrians, cyclists)
5	Road aesthetics and appeal

of America, and the FHWA. It considered signal operation in five areas (a sixth area received a small number of responses and was therefore not graded), and aggregated these results to produce an overall national rating. The report card grades assigned to the five areas and the overall national result were as follows: proactive management (F), coordinated systems (D–), individual intersections (C–), detection (F), maintenance (D+), and overall national results (D–).

These low grades do not mean that signals across the country are failing to display green–yellow–red. Rather, they point to deficiencies in *system* operation and integration, a limited degree of proactive management, and the effect of resource constraints. Additional findings of the NTOC survey are presented in later sections.

A survey of 120 state and local agencies with traffic signal responsibility was recently conducted by the FHWA as part of its signal systems asset management review of state of the practice (“Signal Systems Asset Management . . .” n.d.). These results reinforce some of the findings of the NTOC survey.

- Respondents were asked to ascribe high, medium, or low priority to a number of signal system operational improvements. The improvements that received the greatest number of high-priority responses (i.e., by more than 40% of respondents) included adjusting and upgrading existing signals, integrating signals within one’s own jurisdiction, improving system capabilities, and establishing or upgrading a traffic management center.
- Other system-related improvements, including signaling more intersections, coordinating with other jurisdictions, complying with Intelligent Transportation System architecture, and upgrading system software, received fewer high-priority responses; generally less than 30%.
- Participants were also asked about their priorities for physical signal system repair. Only repair and replacement of equipment received a high priority from more than 50% of respondents. Upgrading communications, reducing responsive repair costs, and standardizing components were rated as a high priority by at least 30% of respondents.

Agencies participating in the FHWA signal system asset management survey also reported a range of estimated annual budget amounts for signal systems, considering funding from all sources (federal, state, and local) (“Signal Systems Asset Management . . .” n.d.).

- Regarding annual construction budgets for new signal installations and upgrades of existing systems, agencies divided almost uniformly among four annual cost ranges: less than \$0.5 million; \$0.5 to \$1.0 million; \$1 to \$2 million; and more than \$2 million. These levels of expenditure were roughly correlated with the size of the signal system, ranging from small systems (fewer than 300 signals) to large systems (more than 1,000 signals).
- Regarding annual maintenance budgets for preventive and emergency work, reporting agencies were again distributed almost uniformly among the four expenditure levels. However, there was little apparent correlation between the level of expenditure and system size.
- Regarding annual operations budgets for items such as signal timing plans, almost half the responding agencies reported annual budgets of less than \$0.5 million. The remaining agencies were divided almost uniformly among the other expenditure categories. Again, there was little correlation between annual expenditure and system size.

MANAGEMENT PRACTICES

Synthesis and AASHTO–FHWA Survey Findings

Maintenance of traffic signals is often characterized by a sharing of responsibility among public and private organizations, as indicated in Figure 3 based on the study survey. Although some DOTs, local agencies, and provincial ministries are solely responsible for both overall management as well as conduct of signal maintenance, many agencies enlist other groups in this work through outsourcing to private contractors (by all levels of government) and partnerships or intergovernmental agreements with other levels of government (e.g., state and provincial agencies in arrangements with counties or municipalities). When other levels of government

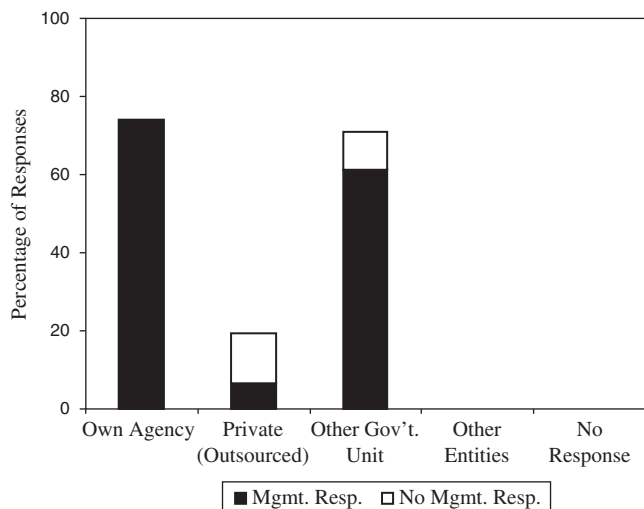


FIGURE 3 Responsibility for maintaining signals once in service.

are involved, they typically exercise management responsibility for their work. By contrast, in the majority of cases where private firms maintain signals, they are not given management responsibility.

The Pennsylvania DOT (PennDOT) described its statewide signal management arrangement in which traffic signals, including those on state highways, are owned, operated, and maintained by the municipality in which they are located.

PennDOT is responsible for approving the installation, revision, or removal of traffic signals. PennDOT issues a traffic signal permit to the local municipality, which outlines the design and operation of each specific signalized intersection. The municipality is responsible for operating and maintaining the signal in

accordance with the permit. PennDOT also maintains statewide standards, specifications, lists of approved materials, and maintenance guidelines.

— Pennsylvania DOT (PennDOT)

Saskatchewan noted that its sharing of maintenance responsibility affects management practice and available information about these assets.

Our department does not have an inventory or budget for traffic signals. The department usually [enters] into a cost-shared agreement with the municipality for installation. The urban municipality is normally responsible for maintenance after initial installation.

— Saskatchewan H&T

Other aspects of asset management practice are revealed through an agencies' methods of budgeting for preservation, operation, and maintenance of traffic signals, and their approaches to preserving and maintaining signals (including re-timing) once in service. The options that were presented to surveyed agencies are listed in Tables 3 and 4, accompanied by abbreviated descriptions used to describe the survey responses in Figures 4 and 5, respectively. Because agencies could choose more than one response in each of these topics, and many did so, the percentages in Figures 4 and 5 do not sum to 100%.

Regarding methods of budgeting, a large number of responding agencies at all levels of government chose the "Previous Budget Plus Adjustments" option and the "Staff Judgments, Political Priorities, and Citizen Demands" options as best describing their processes. These two were often selected in combination and sometimes in conjunction with one or more of the other options shown in Figure 4 as well. The "Other" methods indicated in Figure 4 specify that, for one agency, traffic signals are rated in its safety improvement

TABLE 3
SURVEY DESCRIPTIONS OF BUDGET METHOD OPTIONS

Budget Method Options—Full Description	Abbreviated Description
Budget recommendations based on the cost to achieve a performance target for assets (i.e., target drives budget)	Target Drives Budget
Budget recommendations maximize the asset performance target that can be achieved for the available funding (i.e., budget drives target)	Budget Drives Target
Budget recommendations based on addressing a percentage of the inventory each year	Percent Inventory Annually
Budget recommendations based on previous year's budget plus inflation and other adjustments	Previous + Adjustments
Budget recommendations based on staff judgments, political priorities, and citizen demands	Judgment, Politics
Budget recommendations based on a percentage of the total anticipated budget	Percent of Total Budget
Other approach (describe briefly)	Other
No specific approach	No Specific Approach

TABLE 4
SURVEY DESCRIPTIONS OF PRESERVATION AND MAINTENANCE OPTIONS

Approaches to Asset Maintenance and Preservation—Full Description	Abbreviated Description
Preventive maintenance carried out on a set schedule	Preventive—Schedule
Immediate—repairs carried out as soon as possible after damage or failure is reported	Corrected Immediately
Corrective—repairs prioritized and scheduled to meet performance targets subject to resource constraints	Prioritized—Avail. Res.
“Worst-first”—limited number of repairs each year, but backlog exists	Worst First
Deferred maintenance—little or no work performed annually	Deferred Maintenance
This agency does not maintain traffic signals	No Maintenance Responsibility
Other	Other

program for purposes of budgeting. For two other agencies, this option was chosen because signals are maintained by local governments.

The survey results in Figure 4 show that the number and target performance of assets are used to a degree in budgeting, but are not the primary drivers of budget processes among survey respondents. Approaches based on Target [Asset Performance] Drives Budget, Budget [Asset Performance] Drives Target, and Percent of Inventory Budgeted Annually each were identified in less than 20% of responses. By contrast, methods based on Adjustments to the Previous Budget and those that involve Staff Professional Judgment, Political Priorities, and Citizen Demands each garnered roughly 40% of the responses (bearing in mind that agencies could select more than one approach). The general thrust of these results was complemented by a January 2000 AASHTO survey of roadway safety hardware reported by the FHWA (Hensing and Rowshan 2005). When asked whether asset inventory and asset condition were used as the basis of funding allocation, 11 of 39 states (28%) responded

affirmatively for signal inventory, and 15 of 39 (38%) for signal condition—again, less than a majority in each case. The corresponding results for supports for signs, signals, and lighting in this AASHTO survey were 6 of 39 states (15%) responded affirmatively that funding allocation is based on supports inventory, and 11 of 39 (28%) that allocation is based on supports condition.

A related question in the January 2000 AASHTO survey (Hensing and Rowshan 2005) asked whether state DOTs have a separate budget line item for *maintenance* of signals. Twenty-one of 39 agencies (54%) responded affirmatively. The corresponding result for maintenance of sign, signal, and lighting supports was 8 of 39 agencies (21%) responding affirmatively. Although there was no corresponding question for budgeting of *new* signal installations, the survey did address tracking and updating of asset inventory. These additional responses are reported later in this chapter.

Multiple selections were often made as well by agencies describing their approaches to preserving and maintaining

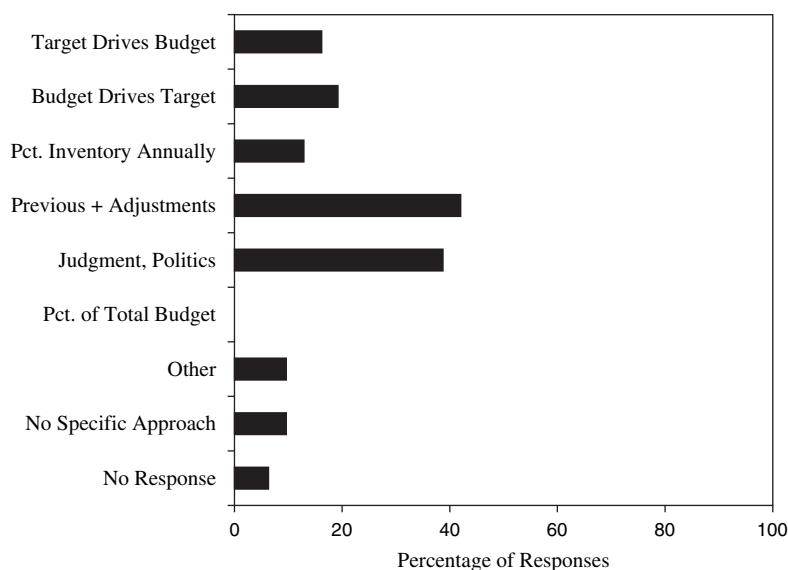


FIGURE 4 Annual budgeting method for signal preservation and operation.

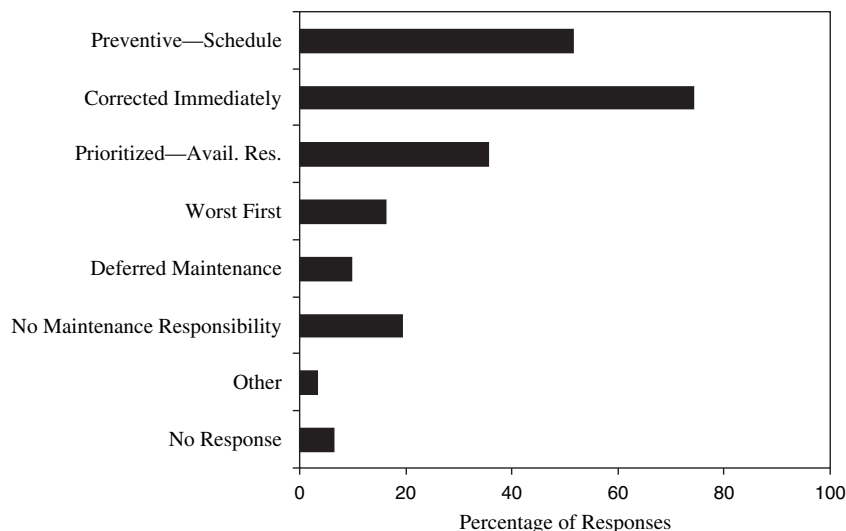


FIGURE 5 Approach to maintaining and preserving signals.

signals. Immediate correction of problems was the most prevalent response, as shown in Figure 5, reflecting the importance of signals to safety, good traffic movement, and the other transportation objectives discussed earlier. A preventive approach and a priority approach subject to resource constraints were also selected by many agencies. The shared responsibilities for signal maintenance discussed earlier are also reflected in the responses.

The FHWA survey of state and local agencies that was conducted as part of its state-of-practice review for signal system asset management asked respondents about their use of signal performance data for decision making (“Signal Systems Asset Management . . .” n.d.). At least half of the respondents reported using performance data for several kinds of decisions. The most prevalent uses (more than 70% of responses) were to identify needs for signal coordination and for improvement. These were followed by the identification of changes needed in traffic control, need for periodic signal timing, real-time signal timing, and planning for equipment replacement.

Comments by several agencies, which are paraphrased here, provided additional details on other methods of signal management and why they describe signal maintenance and preservation often with multiple approaches:

[“Other” approach]: We conduct audits of existing roadways on a 3- to 5-year cycle and make any signal-timing changes needed as part of these reviews. We also look at signal timing when requested.

— Kansas DOT

[Evolving approach]: While now following an Immediate approach, we are now moving in the direction of preventive maintenance.

— New York State DOT (NYS DOT)

[Multiple approaches]: Preventive Maintenance: limited, but occurring; Immediate: agency does address signal trouble calls;

Worst first: capital reconstruction dollars are prioritized this way.

— City of Portland, Oregon

National Transportation Operators Coalition Report Card Findings

The NTOC report card (NTOC 2005a) emphasized signal system management and operations, and identified a number of best practices that were used to benchmark the grading of responses:

- Proactive management, including documentation of agency procedures and their communication to employees; availability of technical personnel outside of normal business hours; communication with the public regarding problems such as signal outages, excessive delays, incidents and work zone closures, and other signal-related conditions affecting travel; coordination with outside groups such as special-event organizers, law enforcement agencies, and emergency service providers; easy access by the public to report/complaint centers; and internal policies and encouragement to agency staff to obtain relevant licenses, certificates, and degrees.
- Coordinated signal management, including reviews of traffic signal timing every 3–5 years, or more frequently as needed; development and implementation of new citywide or corridor timing plans within one year of initial identification of need; use of effective data collection, analysis, and field testing procedures in developing and implementing timing plans; development of plans for different traffic patterns and contingencies (e.g., special events, incidents, road work, and inclement weather); and coordination of signal timing with adjacent jurisdictions.
- Signal operation at individual intersections, including a documented process identifying factors that will trigger

reviews of timings; a documented, centrally accessible, current inventory of approved signal phasing and timing for each intersection; analyses of appropriate information supporting timing reviews, such as turning movement counts, pedestrian volumes, accident histories, complaint histories, field observations of clearance intervals, and checks on any geometric changes to the intersection since the last review; and quick implementation of timing plans once developed (within two working days).

- Specialized operation of traffic signals, which addresses unique locations that require frequent study and adjustments, such as railroad crossings, light-rail corridors, reversible lane and ramp-metering locations, and locations that experience incident response and emergency vehicle access. Best practices include an inventory of signals within 200 ft of grade crossings and signals operated by others; installation of signal preemptions at those grade crossings with and without adaptive controls in place; and regular measurement of the number of train movements and speeds as well as vehicular traffic volumes and speeds, noting changes therein.
- Detection systems, including an established process for gathering data on intersection traffic volumes and turning movements; use of this information in computing signal timing; quality assurance procedures to check the accuracy of surveillance data; and basic quality checks such as physical inspection of detectors and communications links.
- Signal system maintenance, including adequate organizational staffing (30–40 intersections per technician recommended); on-going funding commitment to signal system repair, upgrade, and replacement; inclusion of needed repair or replacement of signal system components damaged by road maintenance or utility work, as part of the project; training programs on signal maintenance, including latest equipment and procedures; regular inspections and assessments of signal control equipment condition and operation, and a semi-annual comprehensive assessment of all operating conditions; near-real-time monitoring and emergency response, including the computer and communications technology to provide reports of failure to maintenance personnel within 5 min of detection; use of a maintenance management system that supports preventive maintenance policies and tracking of equipment performance histories to identify unreliable equipment; and establishment of agency policies, procedures, and criteria to prioritize among competing problems and define appropriate response times.

The NTOC report card provided these best practices as a guide for agencies to improve their signal system management scores. Specifically, the NTOC recommended strengthened investment in traffic signal hardware, routine updates to signal timing, and good maintenance to help reduce traffic delays, fuel consumption, and harmful vehicle emissions. Particular shortcomings in the several aspects of current

agency practice that were identified by the NTOC in responses to its report card questionnaire are as follows (NTOC 2005a):

- Issues in proactive management—NTOC’s report observes that its most noteworthy finding is the very poor grade attributed to proactive management:

. . . 68 percent of respondents [either have] no documented management plan for their traffic signal operation or they are managing their signals on an ad hoc basis.

Travelers use the transportation system 24 hours every day and traffic signals need to perform efficiently during that entire time; however, 71 percent of the agencies do not have staff resources committed for other than typical working hours, even if peak periods occur outside these hours. Even in the largest signal systems (more than 450 signals), less than half (42 percent) reported good progress in this area.

— NTOC 2005a, p. 10

- Issues in signal operations in coordinated systems—Although reviews of traffic signal timing are critical to optimal system operation and smooth traffic movement, 57% of report card respondents reported that they do not conduct these reviews routinely every 3 years or that their procedures in this area are ad hoc. Once the need for retiming is identified, 55% reported that they take more than 18 months to complete the task. Fewer than half of the reporting agencies coordinate signal timing with neighboring jurisdictions and only approximately one-quarter indicated that they adjust timings for revised traffic flows during special events.
- Issues in signal operations at individual intersections—Routine reviews of signal timing at individual intersections are not generally done, with 77% of respondents reporting “only ad hoc or no such process.” Survey results indicated that “little planning and organizational management of traffic signals updates are done. [Agencies’] resources are more likely to be allocated to deal with critical situations as they arise.” However, results also showed that when signal timing is ready to be addressed, more than 70% of the agencies stated that “they regularly update all aspects of the signal timing.”
- Issues with detection systems—Effective signal timing relies on good information regarding traffic counts and movements. However, 33% of the report card respondents, and 23% of those responsible for large systems of more than 450 signals, reported “no regular process for collecting data to support traffic signal timing. Again, this is a likely indicator of staffing deficiencies.”
- Issues in maintenance—Although good practice generally recommends a maintenance technician for every 40 or fewer traffic signals, 29% of respondents reported either a level of 60 or more signals per technician, or that they have not considered their staffing level at all. This finding was taken as a further indication of reactive signal maintenance in the face of resource constraints—that is, “putting out fires.”

- Overall issues—The low scores in the report card presented earlier are the result of resource constraints that inhibit more system-based actions and proactive management, and encourage agencies to resort to a “fire-fighting” mode. As a result, many agencies strive to meet only a basic level of service that provides safety and avoids liability. Although this solution may not be optimal from the perspective of vehicular and pedestrian traffic, in a technical sense the system is “working.” The low grades on the report card were “remarkably similar across the country and across jurisdictions,” suggesting that many signal systems “have the potential for greatly improved performance.”

MEASURING ASSET PERFORMANCE

Signal systems, encompassing support structures, the signal head and lamps, and electronic control and vehicle detection devices, may be characterized by many aspects of their performance. A number of options were listed in the study survey, categorized as follows:

- Physical condition—structural condition, corrosion, inoperable or nonfunctioning components, use- or time-related degradation (e.g., dirt accumulation), and other factors identified by responding agencies.
- Age of the system or asset.
- Hours in service.
- Operational performance—for example, proper signal timing.
- System reliability—for example, number of failures in a certain time interval.
- Performance or health index—a composite measure of condition or performance, the basis or computation of which agencies were asked to explain briefly.
- Qualitative ratings of condition—for example, good–fair–poor, and the basis on which they are developed.
- Asset value, in dollars.
- Customer-related measures—that is, data from customer surveys and number or frequency of customer complaints.
- Other factors identified by the agency.

For several of these categories, agencies were also asked to specify the frequency with which these assessments are made:

- More than once a year,
- Annually,
- Biennially, or
- Less frequently than biennially.

The information provided by agencies on performance measurement of traffic signals is summarized in Figure 6.

Many agencies use both physical and qualitative measures of structural condition, the age of the signal system, operational performance, system reliability, and customer complaints. Other measures have varying degrees of use; none of the responding agencies reported using hours in service, a signal-related performance index, or customer surveys (even though one agency reported conducting such a survey). In addition to the measures shown, North Carolina monitors the condition of anchor bolt nuts on posts, and the city of Portland (Oregon) reports a qualitative measure based on age. As a group, the physical measures of condition are the most widely used among survey respondents.

The frequencies with which these physical measures are assessed are shown in Figure 7. More than two-thirds of responding agencies monitor condition annually, and almost three-fourths at least biennially.

The FHWA review of state of practice in signal system asset management asked respondents about the data they maintain on different signal system components. Results are shown in Table 5. Although signal heads and controllers were identified by the greatest number of agencies, the FHWA reported “significant variation” among agencies as to the type of data maintained. Note in Table 5 that only five cells represent component/type-of-information combinations that were reported by more than half of the respondents (“Signal Systems Asset Management . . .” n.d.). The rate of responses for items such as asset age, physical condition, and nonfunctioning components are similar in Table 5 and Figure 6.

The FHWA survey also looked into the types of operational system performance data that agencies track. More than 75% of responding agencies identified intersection crashes, intersection fatalities, and traffic volume or throughput. More than 50% added traffic speed and customer complaints. Other items such as queue lengths, stops, and signal downtime were tracked by 30% or less of the reporting agencies. Transit performance as a function of signals was not selected by any of the reporting agencies (Harrison et al. 2004).

The methods used by responding agencies to assess signal condition and performance are reported in Figure 8. Visual inspections and customer complaints are by far the most common methods used, with other options reported by no more than one in five respondents. In the latter cases, few agencies mentioned the specific technologies or devices they employ to gather signal condition data. Under “Other” methods, North Carolina listed ground rod resistance and Meggar tests (tests of resistance between the loop and ground) for inductive loops; the Oregon DOT noted the use of standard drawings from the time when signal poles were originally installed; and the city of Edmonton included ultrasonic nondestructive tests of signal supports.

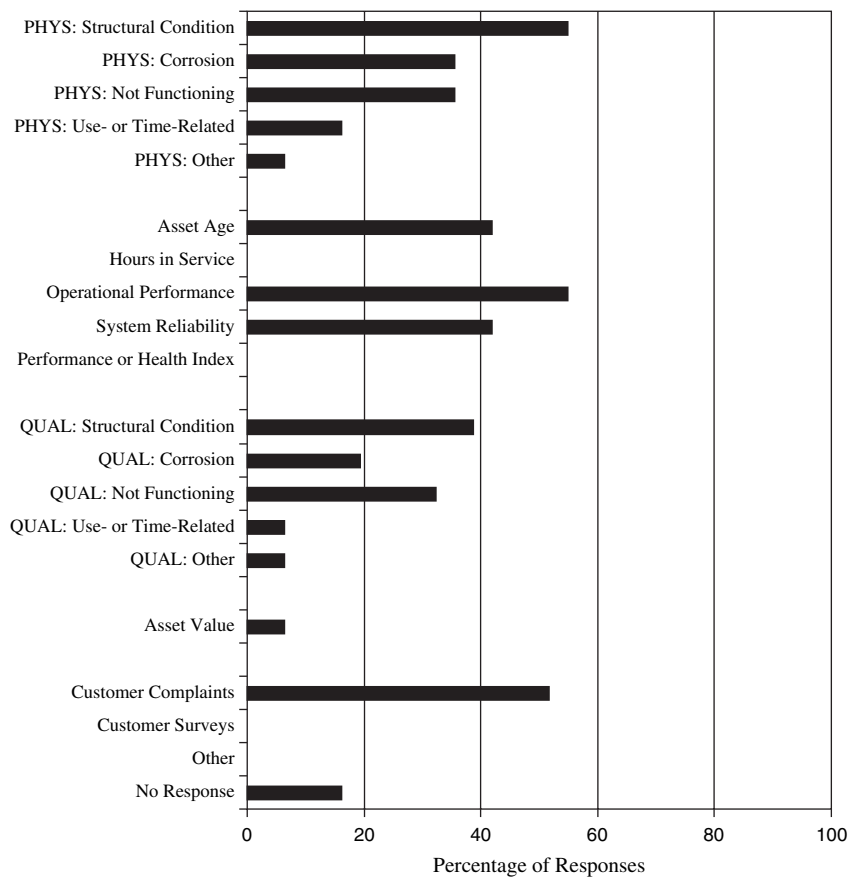


FIGURE 6 Measuring performance of traffic signals. PHYS = physical; QUAL = qualitative.

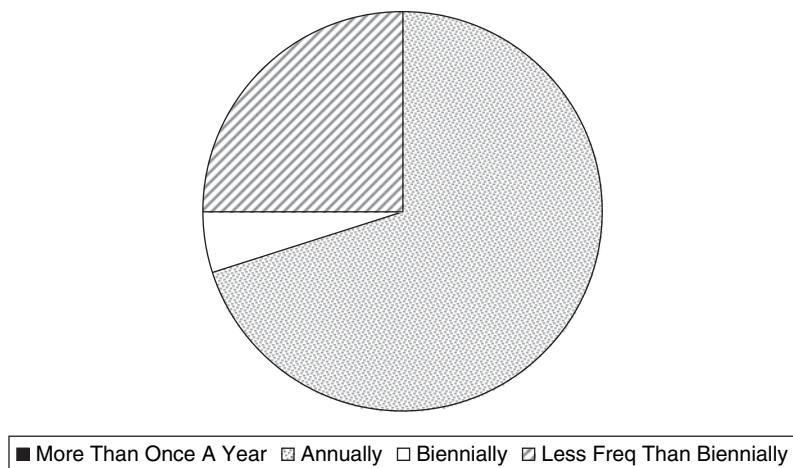


FIGURE 7 Frequency of physical condition assessments of signals.

TABLE 5
TYPE OF INFORMATION MAINTAINED FOR SIGNAL SYSTEMS

Type of Information	Signal				
	Heads (%)	Detectors (%)	Controllers (%)	Structures (%)	Communication Equipment (%)
General Characteristics (e.g., equipment models, functions, etc.)	46	46	62	35	50
Serial Numbers of Components	12	12	31	80	12
Maintenance Requirements	12	15	27	80	15
Maintenance History, Costs	42	38	46	35	38
Repair or Failure History	38	31	50	35	38
Age or Condition	19	27	46	23	31

Source: FHWA “Signal Systems Asset Management...” n.d. Data show percentage of respondents to FHWA survey.

ASSET SERVICE LIFE

Information on service life was obtained in the study survey for three major components of signal systems: the structural supports—poles and mast arms, the controller system, and signal display items—the signal heads and lamps. For each of these components, agencies were given the opportunity to report service lives for different materials that are typically used or for other materials that they employ. Survey participants were also asked to list the main sources they use to estimate service life.

Responding agencies rely on several methods to estimate these service lives, as shown in Figure 9. The activities in Figure 9 that can contribute to estimates of service lives include the following:

- Development of predictive models or management information systems to support management of these assets.
- Development and use of life-cycle cost analyses to compare the performance and costs of alternative components.
- Documented agency experience—for example, historical databases or other records of asset performance and service life.
- Literature describing service-life experience by others.
- Professional judgment of agency staff.
- Manufacturer’s performance data.
- Other sources of information identified by the respondents.

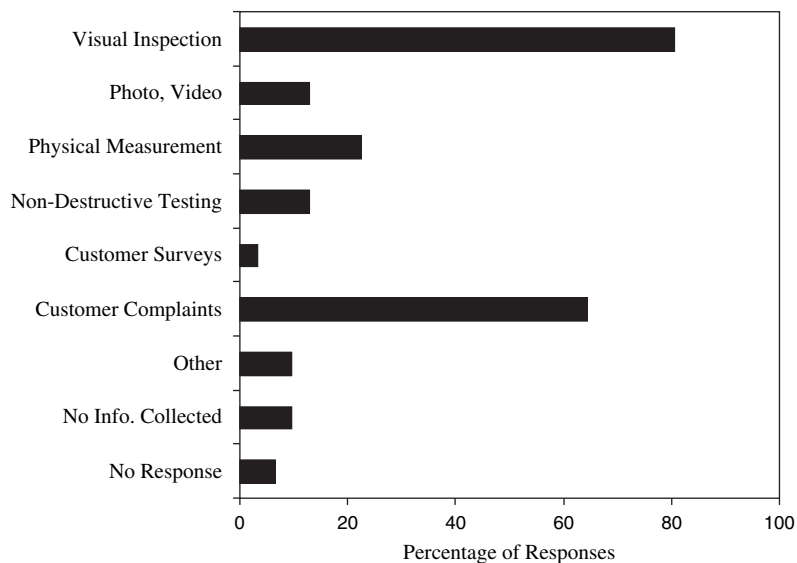


FIGURE 8 Data collection methods for signal condition and performance.

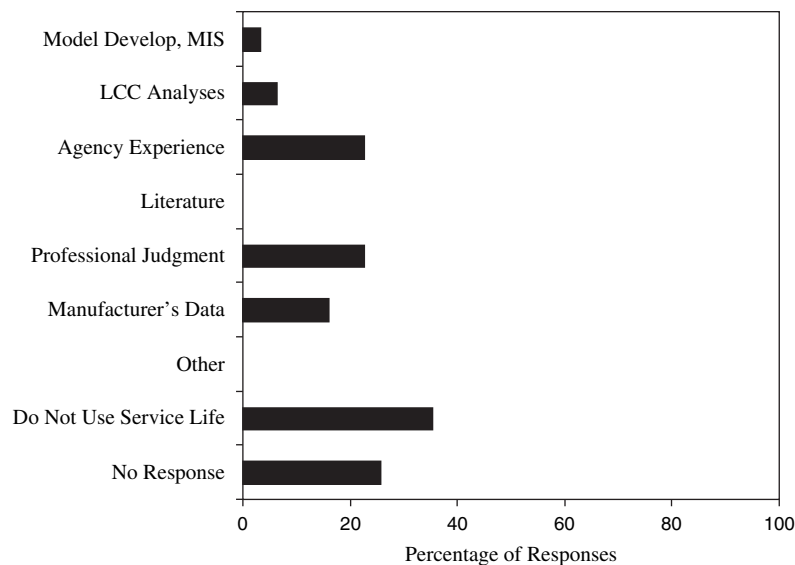


FIGURE 9 Sources for determining service lives of signal systems. MIS = management information systems; LCC = life-cycle cost.

Among the 40% of reporting agencies that identified at least one method, the emphasis was on collective agency knowledge, whether embodied in documented experience (e.g., a database of observed historical service lives) or in the professional judgment of their staffs. Manufacturers' data were also noted as an important source of information.

The agencies' estimates of service-life values are summarized in two ways. Table 6 presents statistical results in terms of the minimum and maximum values, and the three commonly used measures of central tendency—mean, median, and mode—for every component and type of material reported. The number of responses on which these statistical parameters is based is also given. The second method is a display of histograms for those components and materials that represented relatively large numbers of data points in the survey. Figures 10 through 13 show service-life distributions for several types of signal supports, Figure 14 for traffic controller cabinets, and Figures 15 through 17 for signal display components. The labels on the horizontal axis in these figures give the upper values of each range of service-life data. For example, if these labels are 0, 5, 10, 15, . . . , then the column labeled 5 shows the number of responses for estimated service life of zero to 5 years; the column labeled 10, the number of responses for estimated service life of more than 5 to 10 years; the column labeled 15, the number of responses for estimated service life of more than 10 to 15 years; and so forth. These graphics provide a clearer understanding of the shapes of the underlying distributions of estimated service life. It should be noted again that the data in Table 6 and Figures 10 through 17 may be derived in part from the professional judgment of agency personnel.

A related question is how agencies determine where signal components are in their respective service lives. Knowing how much life is consumed, and how much remains, is necessary in

applying the service-life concept. Agencies included in the survey were presented with a number of ways to determine the current status of an asset regarding its service life and asked to rank each method by relevance to their agency. The results are shown in Table 7. Note that two instances of tie values occurred in this particular ranking process.

The survey results in Table 7 reflect the importance reporting agencies assigned to quick maintenance response following asset damage or failure. This response is consistent with earlier findings regarding the importance of signals to customer safety and efficient movement, and the desirability of immediate correction of problems, particularly for signals at high-priority locations. An equally strong response, however, was to indicate that many reporting agencies do not use or monitor service lives in their management of traffic signals. It should be noted, however, that several agencies were able to provide data on estimated service lives of signal components, even though service life is not used within their current management procedures.

Although maintenance and rehabilitation are believed to extend service life, only 2 (of 31 total) responding agencies indicated that they take this into account, and only one provided an explanation. The city of Portland conducts partial intersection reconstructions in lieu of complete intersection replacements as the result of budget constraints. Work includes replacing only those poles, span wires, and signal heads that are in bad condition. The expectation is that this strategy extends the life of the signal system at the intersection for an additional 25 years.

Although service life is one dimension of performance, other aspects of signal system operation are also critical. The TRB Millennium Paper on traffic signal systems discusses several issues related to the complicated operational

TABLE 6
ESTIMATED SERVICE LIVES OF SIGNAL SYSTEM COMPONENTS

Component and Material	No. of Responses	Minimum (Years)	Maximum (Years)	Mean (Years)	Median (Years)	Mode (Years)
Structural Components						
Tubular steel mast arm	14	10	50	24.6	20	20
Tubular aluminum mast arm	7	20	35	24.3	20	20
Wood pole (and span wire)	9	2	30	15.1	15	15
Concrete pole (and span wire)	2	10	15	12.5	12.5	—
Steel pole (and span wire)	9	10	30	22.8	20	20
Galvanized pole and span arm	1	—	—	>100	—	—
Controller System Components						
Permanent loop detector	14	3	20	8.6	7.5	10
Non-invasive detector	12	5	20	10.4	10	10
Traffic controller	18	4	20	13.5	15	15
Traffic controller cabinet	17	10	30	17.5	15	20
Twisted copper interconnect cable	11	5	30	17.7	20	20
Fiber optic cable	7	20	30	23.6	20	20
Signal Display Components						
Incandescent lamps	15	0.5	3	1.4	1	1
Light-emitting diode lamps	18	5	10	7.2	6.5	5
Signal heads	15	7	30	18.8	20	15
Pedestrian displays	1	—	—	15	—	—

Notes: —, value is undefined for the particular distribution. When distribution is based on only one data point, its value is shown in the Mean column

environment in which modern signals may be expected to operate—for example, with advanced features such as closed-loop systems coordination, preemption by emergency vehicles, transit vehicle priority, and handling of bicycle traffic—as well as the need for system component compatibility and integrated, interoperable systems (Bullock and Urbanik 2000). As a specific example, the Ohio DOT has considered the safety aspects of substituting light-emitting diode (LED) lamps for incandescent lamps, given the electrical characteristics of existing signal hardware that detect when a lamp has failed and respond by placing the signal in a flashing mode. The study has concluded that the LED lamps that were tested are compatible with modern hardware in existing incandes-

cent systems (Gilfert and Gilfert 2002), although this topic may be researched further. The Ohio DOT report notes that whereas incandescent bulbs are replaced at 12-month or 18-month intervals, LED lamps should provide, based on current findings, service lives of at least 5 years.

The structural performance of signal supports has also been a topic of recent interest. Research has resulted in updated guidelines and specifications for structural supports (*Standard Specifications for Structural Supports . . .* 2001, updated 2003; Fouad et al. 2003). Investigations have also been conducted of premature structural failures in signal supports (Chen et al. 2002).

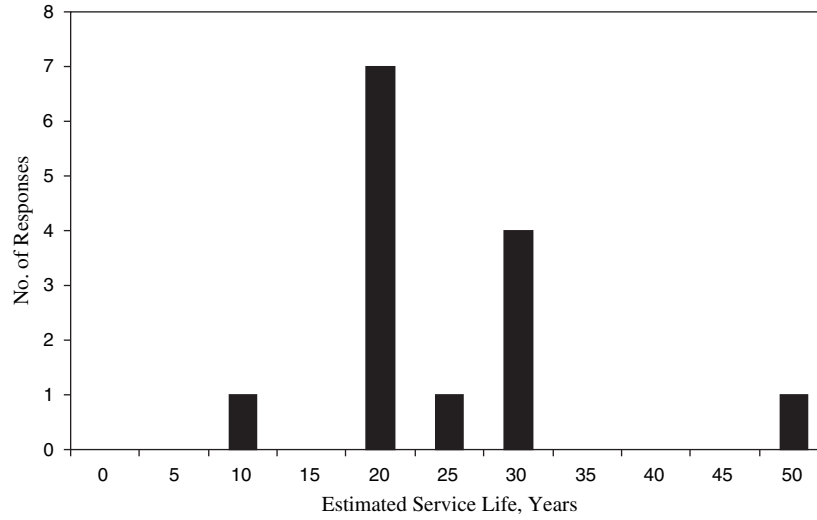


FIGURE 10 Estimated service life of tubular steel mast arms.

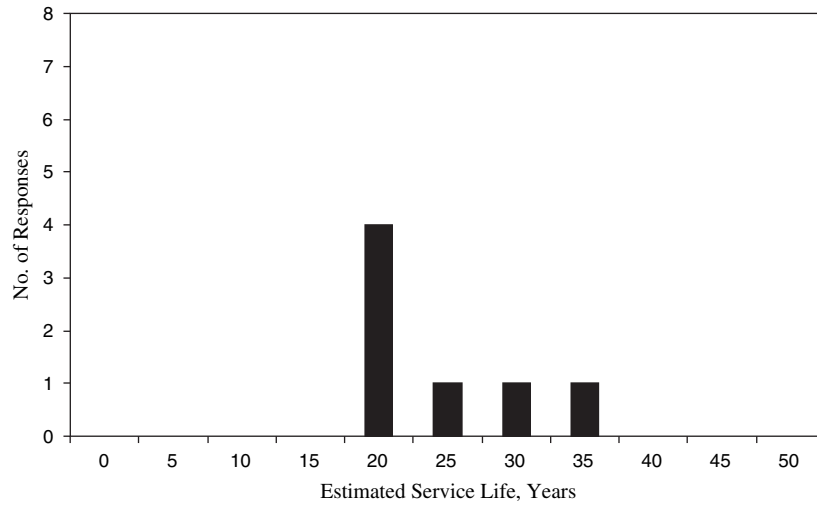


FIGURE 11 Estimated service life of tubular aluminum mast arms.

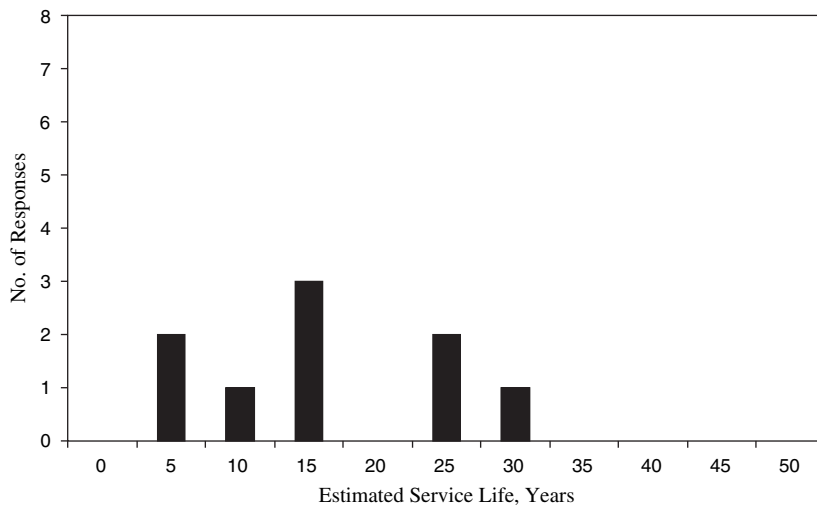


FIGURE 12 Estimated service life of wood pole and span wire supports for signals.

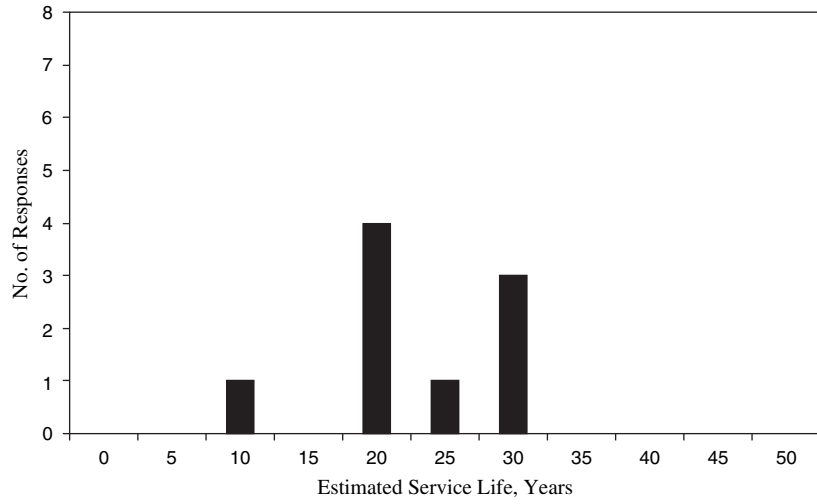


FIGURE 13 Estimated service life of steel pole and span wire supports for signals.

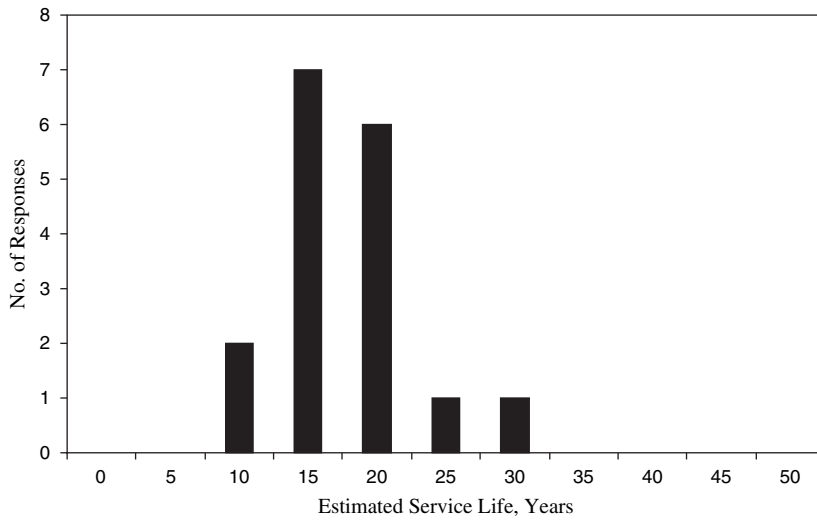


FIGURE 14 Estimated service life of traffic controller cabinets for signals.

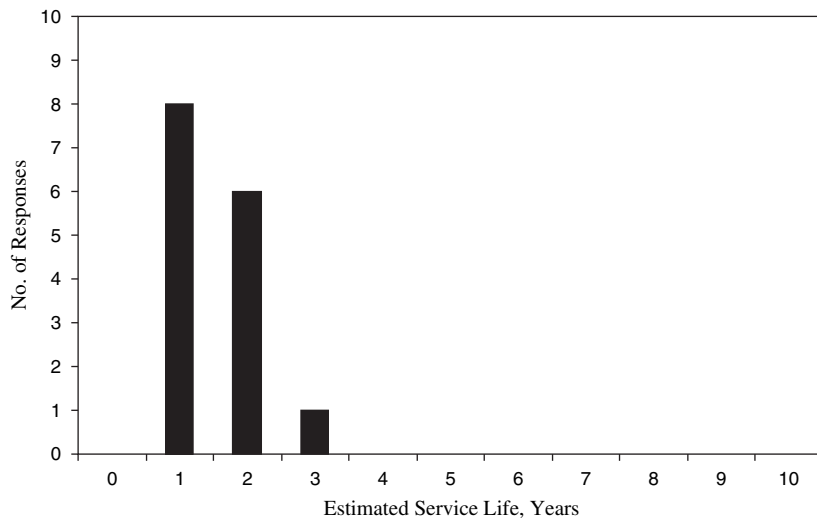


FIGURE 15 Estimated service life of incandescent lamps for traffic signals.

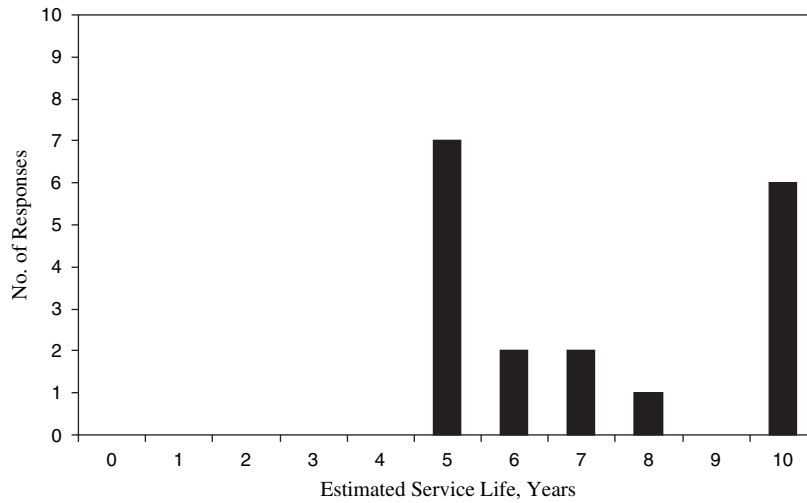


FIGURE 16 Estimated service life of light-emitting diode lamps for traffic signals.

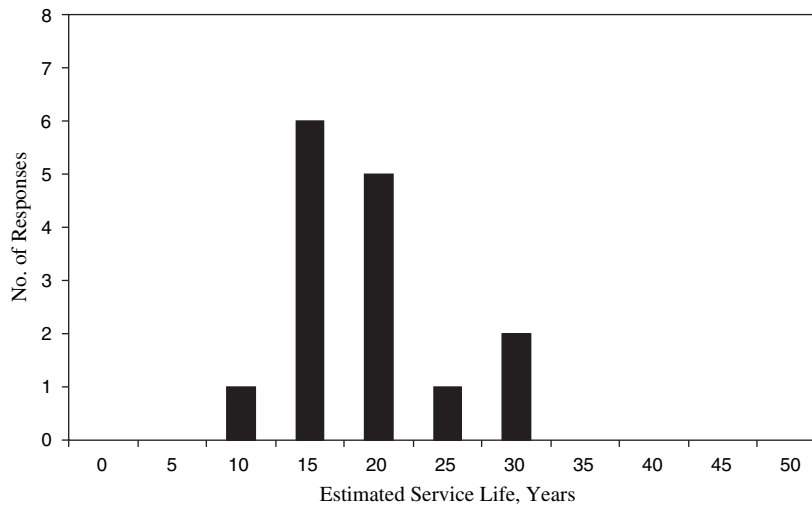


FIGURE 17 Estimated service life of traffic signal heads.

TABLE 7
RANKING OF METHODS TO DETERMINE WHERE TRAFFIC SIGNAL ASSETS
ARE IN THEIR SERVICE LIVES

Rank	Factor
1	Assets are repaired or replaced as soon as they fail without regard to service life
2	Service life is often determined more by functional obsolescence than by wear and tear
2	Compare current age of asset with the maximum age that defines service life
4	Monitor condition of the asset on a periodic schedule
5	Monitor condition of the asset occasionally
5	The agency does not use/does not monitor service life for this type of asset
7	Assets are replaced on a preventive maintenance schedule without regard to where they are in their service life
8	Apply deterioration models to estimate where the asset is on “the curve”
8	Compare service hours to date with the maximum number of service hours that defines service life

INFORMATION TECHNOLOGY SUPPORT

Synthesis and AASHTO–FHWA Survey Findings

As a practical matter, applying asset management to today’s transportation systems typically requires substantial information technology (IT) support. This support can be provided through a number of IT features for data processing, analytic modeling, decision support, communication of asset performance, and management accountability. Agencies participating in the study survey identified their key IT capabilities as shown in Figure 18. Many (but not all) agencies have an inventory of signal assets accompanied by information on location. Photographs, dates and recommendations of inspections, the age of assets, maintenance schedules, and tracking of public comments were reported by many agencies. One in five respondents noted that information on anticipated service life is available in their IT systems. No strong distinctions in the findings represented by Figure 18 were observed among levels

of government. By comparison, responses to the January 2000 AASHTO survey reported by the FHWA (Hensing and Rowshan 2005) indicated that 27 of 39 agencies (69%) had an inventory of signals, and 25 of 39 (64%) updated their inventory by some method, in most cases by manual survey.

In addition to these individual IT capabilities, agencies were asked to characterize the type of system(s) that they use to help manage signals. The categories of systems listed in the synthesis survey included the following:

- A dedicated traffic signal monitoring system;
- A broad-based management system such as a maintenance management system (MMS) or a comprehensive transportation infrastructure asset management system (TIAMS) that includes traffic signals as well as other assets;
- Simple programs that address traffic signals;

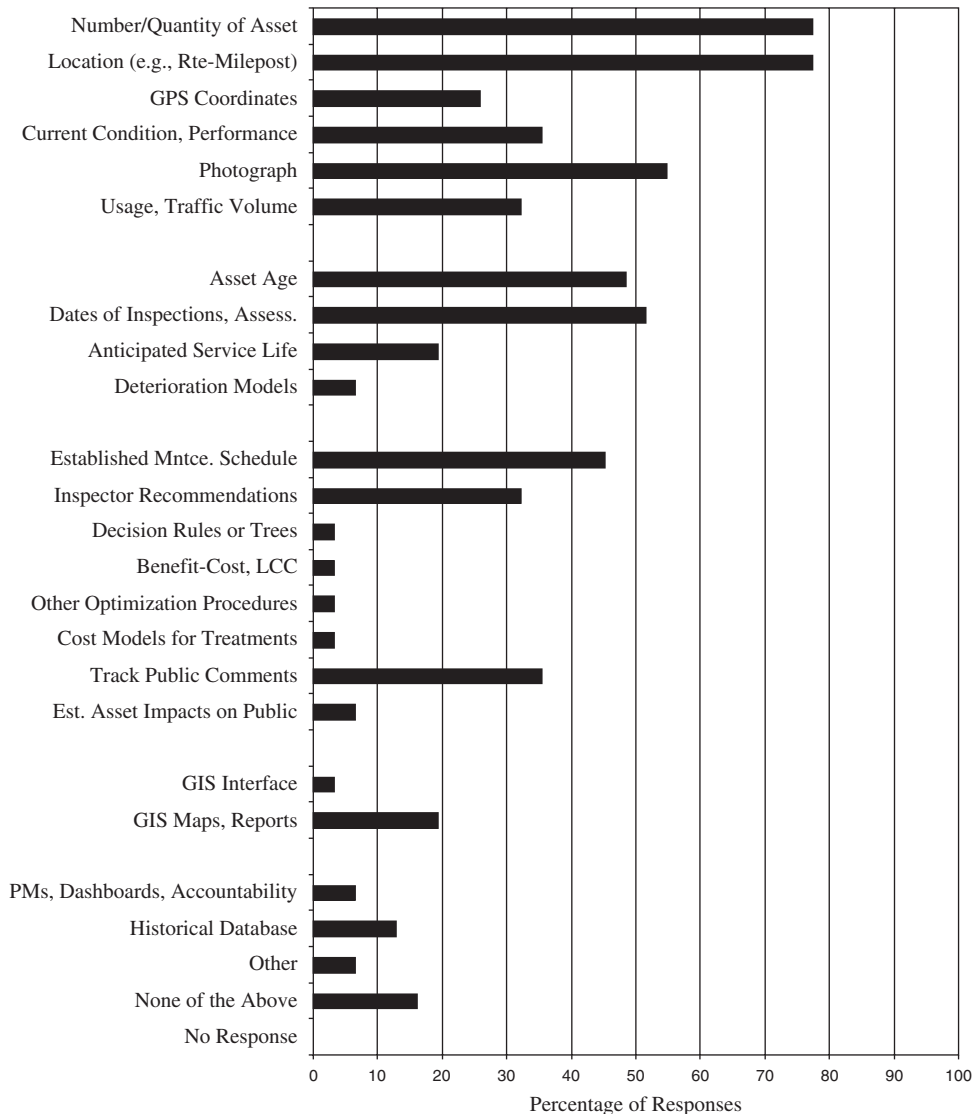


FIGURE 18 IT capabilities to help manage signal systems. GPS = global positioning system; LCC = life-cycle cost; GIS = geographic information system; PMs = performance measures.

- Workbooks or spreadsheets that address traffic signals; and
- Parts of other products or procedures that the agencies were requested to describe briefly.

The responses to this survey item are summarized in Figure 19, showing a relatively uniform distribution of use across the several system categories, with no strong distinctions among different levels of government. Multiple responses by many agencies suggested that different tools were used at different levels within the organization. The agencies that reported using a signal management system or a maintenance management or transportation infrastructure asset management system that includes signals are listed here.

- Signal Management System
 - Michigan DOT
 - Minnesota DOT
 - North Carolina DOT
 - Ohio DOT
 - Oregon DOT
 - Colorado DOT Region 4
 - City of Edmonton, Alberta.
- Maintenance or Asset Management System That Includes Signals
 - Maryland SHA
 - New Mexico DOT
 - Ohio DOT
 - Oregon DOT
 - Virginia DOT
 - Colorado DOT Regions 1 and 5
 - Ministry of Transport of Quebec
 - City of Edmonton, Alberta
 - City of Portland, Oregon.

The “Other Products or Procedures” responses in Figure 19 included mention of a Traffic Signal Information System database (Oregon DOT), the tracking of signals by the Kansas DOT through its Audits of Existing Roadways, and the following comment by PennDOT:

Some of our Regional Engineering District Offices have traffic signal asset databases. We are embarking upon an effort to develop a statewide traffic signal asset management system.
— PennDOT

FHWA State-of-Practice Findings and Signal System Framework

The FHWA survey of state and local agencies for its state-of-practice review of signal system asset management asked participants what software tools they used for signal system management. More than 95% of respondents identified signal timing optimization and simulation as a tool they used to help generate signal timing plans. Other IT capabilities that were identified by more than 50% of respondents included inventory tracking of system components encompassing identification, location, classification, and date acquired or constructed for each item; maintenance and work order management; and budgeting for capital, maintenance, and operations expenditures. Applications to track the available inventory of spare parts, exercise version control of signal hardware and software, and conduct system operational performance monitoring were reported in use by 30% to 40% of respondents (“Signal Systems Asset Management . . .” n.d.).

The FHWA has proposed the architecture of a generic signal system asset management system (SSAMS) that conforms to the principles in the AASHTO *Transportation Asset Management Guide* (Cambridge Systematics, Inc. 2002). This report and associated web document describes the features and decision-support capabilities of a SSAMS, how it could be applied to different signal improvement scenarios, and how a SSAMS compares with other asset management systems. The generic SSAMS is structured of several modules:

- Physical characteristics of the signal system—for example, signal components, detectors, controllers, communications, and central control hardware and software.
- Operational characteristics of the signal system—for example, timing plans, control strategies, coordination, preemption, and design and placement.

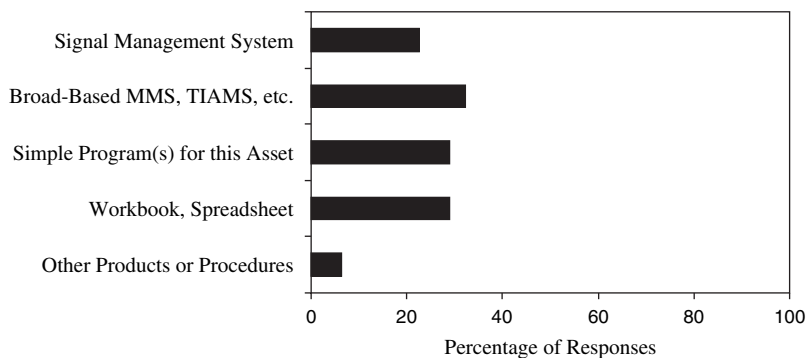


FIGURE 19 Types of analytic tools to support signal system management. MMS = maintenance management system; TIAMS = transportation infrastructure asset management system.

- Operating environment of the signal system—for example, traffic volume, composition, and flow patterns; development affecting traffic growth rate; intersection geometry; pedestrian flows; and variations in these parameters and the degree to which they are predictable.
- Signal system performance—for example, operational reliability and downtime, and impact on traffic as measured, for instance, by throughput, travel time and delay, and effect on safety (e.g., number and severity of crashes).
- Actions and resources to manage the system—for example, the range of actions to correct or improve the system encompassing routine operations and maintenance, system preservation, repairs, upgrades, and replacement; and the labor, equipment, material, and financial resources needed to do identified work.

Although these capabilities appear to resemble those of other transportation asset management systems, the FHWA document notes several differences in a SSAMS; for example, the need to recognize a dynamic operating environment; a shorter service life than assets such as pavements and bridges, and a need to manage potential failure of system components; greater systemwide interdependencies among components; and a redirection in the understanding of what constitutes an “asset” and how one characterizes its behavior, moving from things like materials properties, physical condition, and structural capacity that are typical of pavements and bridges, for example, to concepts of electrical and electronic technology, and operational characteristics and performance. The FHWA document also provides a summary of interviews with the Minnesota DOT (MnDOT) and the Wisconsin DOT on their experiences with signal system management and operations (Harrison et al. 2004).

Analytic Modeling: Group Relamping

As an example of computerized analytic methods applied to signal system asset management, Zwahlen et al. (2004) have applied group relamping concepts to incandescent lamps in traffic signals, using data provided by the Ohio DOT. A relamping model balances the costs of replacing a group of lamps at one time, before they have failed, versus the benefits to the maintenance crew of making one trip to a location rather than multiple trips each time a bulb has failed. The management parameter requiring decision is the relamping interval. If the interval is very much shorter than the expected service life, many bulbs will be replaced while they still have considerable life left, resulting in waste and high cost. As the relamping interval approaches the expected service life, the amount of wasted lamp capacity is much reduced and the efficiencies of one trip versus many trips by maintenance crews take hold, driving costs down. As the replacement interval continues to be lengthened, the number of bulb failures before group replacement increases, requiring a greater number of individual trips by maintenance crews for emergency spot replacement, again increasing costs. There is thus an optimal

relamping interval at which the costs of replacing signal bulbs are minimal.

Zwahlen et al. have created an Excel® spreadsheet to compute the minimum cost solution—that is, the optimal relamping interval—as a function of several maintenance, intersection, and cost variables. Their study used incandescent bulbs rated for 1-year, 7,000 h of service (Ohio DOT considers one year of service as 8,760 h). Actual bulb survival percentages by month were developed over a 24-month study period in Ohio District 4, which were then input to the analysis spreadsheet. The group replacement analysis showed that the optimal relamping interval for this case was 10 months. The sensitivity analysis that can also be done with the spreadsheet showed that the results were not that sensitive to changes in bulb performance, maintenance productivity, or cost variables. It should be noted that the study results are an example only; District 4 has since moved to other lamps that comply better with Ohio DOT performance specifications (Zwahlen et al. 2004).

It should also be noted that the costs considered in this spreadsheet are limited to agency costs: that is, the materials costs of the lamps; the costs of performing relamping in both the group replacement and the emergency spot replacement situations; and the cost of travel by the maintenance crew between the maintenance facility and an intersection, and between intersections during the day.

KNOWLEDGE GAPS AND RESEARCH NEEDS

Synthesis Survey Comments

Agencies at all levels identified a number of knowledge gaps and resulting needs for research. These comments have been organized by topic area and paraphrased here.

Data on Field Performance

A number of agencies identified the need for basic data on signal asset management, particularly service-life and performance data gained from actual field experience, and a way to organize these data in useable form.

[We need to get] accurate field information about the condition of equipment on the street.

— Michigan DOT (MDOT)

[We need] a comprehensive signals inventory maintenance database to track repair and maintenance of the major components of a traffic signal installation.

— North Carolina DOT

[We need to know how] many signals are owned by the agency versus how many are maintained by the agency; where are they located; annual maintenance cost per signal; [and] physical condition of all signals. How many of the agency’s signals have been re-timed within the last 3 years? When was the last time that the timing at Signal X was updated?

Adding additional loading to an existing pole can be difficult because structural information is not tracked. We need to assign a structure number for each pole, installation date for the structure, and the standard drawing with revision that was used to perform the installation.

— Oregon DOT

[What is needed is] the real condition of the structures of traffic signals.

— Quebec Ministry of Transport

[What is needed is the] life estimate of a signal.

— Colorado DOT Region 3

It would be nice to have some information on average service lives of components of traffic signals.

— Kansas DOT

[What is needed is a] definition of service-life level; e.g., when is a steel structure replacement needed as compared to use of longevity-increasing remedial applications.

— Maryland State Highway Administration (SHA)

[What is needed is] knowledge of the functional obsolescence of electronic components rather than the life of the hardware. Various options for detection—e.g., preformed inductive loops, saw-cut loops, video, etc. [—also need study].

— Utah DOT

[What is needed is a] knowledge of quality of materials used.

— City of Tampa, Florida

Nature of Asset

Respondents believe that, to some degree, the lack of knowledge regarding asset management of traffic signals relates to the character of these assets as compared with other transportation infrastructure, and to the need for stronger interactions with component manufacturers.

Asset managers are usually accustomed to large highway maintenance equipment, not small electronic devices associated with signals.

— Ohio DOT

[We need] integration of proprietary traffic-signal-controller-unit manufacturer's data into generic agency databases and programs.

— Maryland SHA

Advances in Materials and Technology

Agencies also referred to advances in the materials and devices that are incorporated within signal systems. However, they had different takes on this issue and its implications for asset management. Several identified a need to understand this issue better.

[What is needed are] service lives for the various elements in a signalized intersection, especially since the materials have changed over time.

— City of Portland, Oregon

There is no method in place for the agency to account for the effect of materials evolution on service life.

— Ohio DOT

How to account for changes in materials quality? We don't.

— Colorado DOT Region 1

Signals are getting installed at an alarming rate. We are trying to keep up with technology and maintenance of these additions to our inventory. Calculating life cycles is not a high priority.

— Colorado DOT Region 4

[What is needed is a] study of the service life and reliability of the newer 2070 controller architecture and fiber optic communications network.

— North Carolina DOT

Other agencies contended that they already account for technological change, often as part of intersection projects, and typically involving the professional judgment of agency staff.

Responses are just estimates of how long the agency expects these components to last without being damaged in some other way. It is known that materials are becoming increasingly durable and reliable, and those characteristics are taken into account.

— Kansas DOT

The agency's estimated longevity of signal structural elements has remained consistent at 30 years by the routine use of steel poles/spans or steel mast arms/poles. Wiring and associated signal heads, with a service life greater than 30 years, would be replaced as part of a structural replacement effort. Further, at-grade, in-pavement loop detection would also be replaced as part of the noted structural replacement effort with current detection strategies (video cameras for presence detection and non-invasive detection for upstream detection).

— Maryland SHA

We rely on our field personnel to identify any issues regarding the service life of any particular piece of equipment.

— MDOT

Improvements in technology are observed and factored in based on actual experience.

— New Mexico DOT

Change in materials quality [is] accounted for by a program replacement based on the life of the materials.

— Quebec Ministry of Transport

Change in materials quality [is] accounted for by professional judgment.

— City of Portland, Oregon

We place the older ones on a priority basis and upgrade those components as part of maintenance and/or system upgrades.

— Colorado DOT Region 4

Organizational and Procedural Aspects

Some agencies focused on needs for organizational or procedural changes to manage their signal systems better.

The major gap [in the existing process] is [the need to assign] someone in the agency to apply asset management principles to the traffic signals that we have on the State Highway System.

— Kansas DOT

[There is a need] to have structures inspected to [a] set idea of condition, especially older units, to help establish [a] time line [of their service life].

— Colorado DOT Region 3

[There is a need] to generate some hard numbers [developed from actual experience]. [For example:] This item will last this long. Maintenance is described as keeping the system operational. If a bulb burns out you replace it. A service call record is kept.

— Colorado DOT Region 4

We do not use service life. Materials are replaced when they fail. We have installations and facilities that are in excess of 40 years old with no plans to replace...

. . . Issue is not one of gaps in knowledge. There is no plan, direction, or system in place here to manage traffic [signal] assets.

— City of Tampa

TRB Millennium Papers

The TRB Millennium Paper on traffic signal systems summarized the history of traffic signal technological development and considered current and future needs within a broad context (Bullock and Urbanik 2000). To some degree the technical challenges and emerging issues and opportunities identified in this paper echoed the findings of the NTOC survey discussed earlier, stressing the need to look at traffic signals at a broad systems level, in addition to understanding performance at the levels of individual signal components and signal clusters.

Technical Research Needs

The Millennium Paper on traffic signals identified several technical areas in which research would add useful knowledge (Bullock and Urbanik 2000).

- System integration—Although current system products perform well when considered in isolation, they do not necessarily make effective components of an integrated, interoperable system comprising products of several vendors.
 - Work is needed to reconcile different adaptive control models within a standard architecture.
 - New sensor technology is needed to estimate queue lengths; detect trains, nonferrous bicycles, and pedestrians; and sense environmental conditions such as weather and air quality.
 - This new sensor technology must also be able to pass new information to the control system; for example, bus number and passenger loading for transit priority algorithms.

- Standards will be needed to integrate new sensors within existing signal systems, and improved reliability and lower cost must be achieved for wider market acceptance.
- The different methodologies and predictive capabilities of macroscopic and microscopic traffic models need to be reconciled to provide consistent guidance and gain the confidence of potential users.
- Improved design practice—An accepted reference model for signal performance must be agreed on to enable practitioners to evaluate alternatives in traffic signal design and controller settings. This advance would greatly improve current design practice, which now often relies on individual technological preferences.
- Coordination of research—Research on signal systems is now conducted by many public and private entities, leading to fragmentation of effort and difficulty in achieving the integrated, interoperable systems described earlier. A new initiative will be needed to coordinate the many research efforts so that increasingly complex signal systems can advance successfully.

Emerging Issues and Opportunities

The TRB Millennium Paper on signal systems also identified broader issues and opportunities that will shape the evolution of more advanced signal systems (Bullock and Urbanik 2000).

- Transportation organizations responsible for signal systems will need to revise their priorities from serving primarily automobile traffic to meeting the broader transportation needs of various categories of users.
- These updated organizational objectives will be complicated by jurisdictional and institutional issues, a process likely more challenging than even the technical advances discussed earlier. Agencies will need to work together, a broader constituency for signal systems will need to be engaged, and a wider, more advanced set of expected services will need to be provided.
- Agencies will need to educate the public on the technical complexities of signal systems, the uncertainties inherent in predicting and responding to future traffic demands, and the resulting importance of long-term investments in transportation management and operations.
- The wider market for signal systems created by improvements in service may also provide the wider customer base needed for funding support, but will require public outreach and education.

Another TRB Millennium Paper on vehicle user characteristics identified the need for human factors research regarding drivers' understanding of, and reactions to, the

different ways in which signal systems operate. Different jurisdictions apply different combinations and phasings of signals for certain traffic movements, particularly protected left-hand turns, which can confuse drivers. Research is needed to identify these problems and recommend solutions (Ranney et al. 2000).

The TRB Pedestrians Committee identified two signals-related topics among its top 16 research problem statements: (1) Optimizing Signal Timing for Pedestrians, and (2) Evaluation of *MUTCD* Signing, Markings, and Traffic Signals for People with Visual Impairments, Children, and Elderly Adults (*Transportation Research Circular E-C084* . . . 2005).

ROADWAY LIGHTING

OVERVIEW

Roadway lighting promotes safer, more efficient, and more comfortable and convenient travel at night for vehicles, pedestrians, and cyclists. By illuminating the surface and adjacent features of the roadway or sidewalk users may better see conditions some distance ahead. This improved visibility contributes to safety (fewer crashes). The FHWA has determined that “installing roadway lighting has the highest benefit–cost ratio of all safety improvements,” and several other countries have reported a reduction of 20% to 30% in nighttime crashes after roadway lighting was installed (Hasson and Lutkevich 2002). Lighting can also play a role in adding beauty and influencing the nighttime visual character of an historic district or urban village, and in helping to reduce crime. Agencies participating in the study survey ranked the transportation objectives that are served by roadway lighting in priority order, as given in Table 8.

Meeting these objectives requires agencies to observe standards, technical recommendations, and guidelines from a variety of sources. Figures 20 and 21 present the agencies’ judgments of those sources of guidance that are the important drivers of engineering and management decisions regarding roadway lighting. These results are shown for two key aspects of asset management: new construction and installation, and maintenance and rehabilitation, respectively.

The importance of national standards, and especially individual agency policies, standards, guidelines, and procedures, is evident in these results. National standards include the AASHTO *Roadway Lighting Design Guide* (2005), lighting needs of pedestrians in walking areas and at intersections and crossings (*A Policy on Geometric Design* . . . 2004), luminaire structural supports (*Standard Specifications for Structural Supports* . . . 2001), and safe provision of lighting support structures in the roadside (*Roadway Design Guide* 2002), as well as guidance issued by the Illuminating Engineering Society of North America (“IESNA Profile . . .” 2006).

As an example of up-to-date agency practice, the Iowa DOT is currently sponsoring development of a practical roadway lighting design guide for different types of roads in rural and urban settings that will address several management needs of state and local agencies (“Developing a Rural and Urban . . .” 2005):

- An application guide (matrix) to recommend priority locations for lighting installation based on considerations of roadway, land use, safety, and traffic conditions.
- An evaluation of the criteria used to determine when lighting is warranted at a location, and when alternatives may be acceptable.
- A manual describing a standard design layout for use by state and local agencies, consulting engineers, and contractors.
- An evaluation of the relative safety benefits of lighting versus those of alternatives such as rumble strips, flashers, better signage, etc.
- Consideration of other factors that affect lighting effectiveness; for example, lighting configuration (destination versus full lighting), amount of luminance, and placement.
- Recommendations on dealing with glare from locations outside the roadway boundary (e.g., lighted parking lots).

Quebec employs five basic guidelines for lighting installation at intersections (Bruneau and Morin 2005):

- All intersections in urban and near-urban areas will have lighting.
- The number of luminaires and lighting levels is based on intersection traffic volumes from all approaches.
- Lighting should be installed if an intersection has had an annual average of three night accidents during the previous three years.
- Lighting may be installed if it is logical to expect that there will be a reduced risk of nighttime accidents in the intersection.
- Roadway lighting must be installed at rural intersections where traffic signals exist or are expected to be installed in the near future.

Quebec has studied the safety performance of rural lighted intersections as compared with unlit locations. It has observed a 39% reduction in the night accident rate for intersections with Quebec’s standard lighting as compared with intersections operating in darkness (Bruneau and Morin 2005).

In addition to considerations of motorist, pedestrian, and bicyclist safety, security, and convenience, as well as aesthetics in urban areas, roadway lighting is also designed

TABLE 8
 PRIORITY OF TRANSPORTATION OBJECTIVES SERVED
 BY ROADWAY LIGHTING

Rank	Factor
1	Public safety; accident and accident risk reduction
2	Comfort and convenience of the traveling public (motorists, pedestrians, cyclists)
3	More efficient travel; maintain intended flow and operating speed; reduce travel time
4	Preservation of the existing road infrastructure; reduced agency life-cycle costs
5	Road aesthetics and appeal
6	Crime prevention

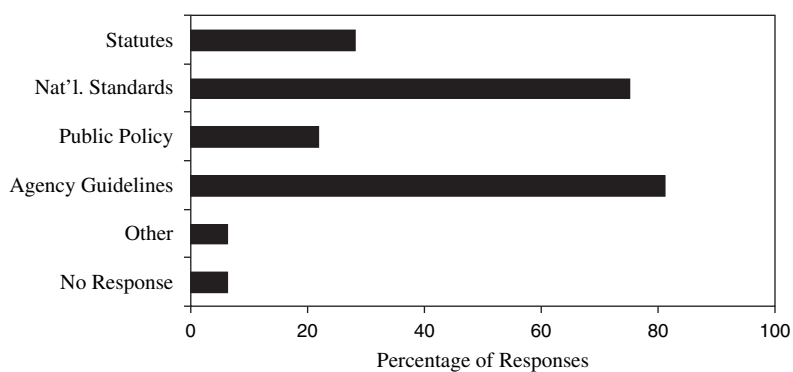


FIGURE 20 Technical management guidance for new installations of roadway lighting.

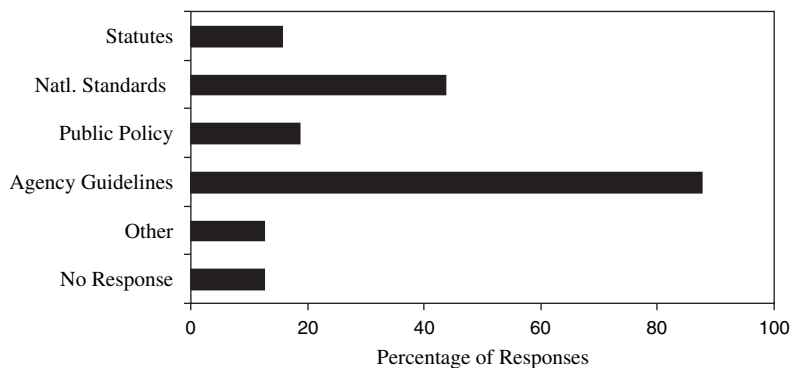


FIGURE 21 Technical management guidance for maintenance and rehabilitation of roadway lighting.

for environmental reasons; for example, reduction in light pollution and protection of wildlife movements. The recent international scan of European road lighting practices, sponsored by AASHTO, FHWA, and NCHRP, has documented several guidelines to reduce sky glow (Wilken et al. 2001), and implementation of embedded roadway lighting systems and bollard-mounted lights on the adjacent bike path has been tested in Florida to protect baby sea turtles in their journey from their beach nests to the sea (Ellis and Washburn 2003). More generally, researchers in the Netherlands are investigating several types of guidance systems including LEDs, pavement markers, LED post delineators, LED pavement marker stripes, fiber-optic “side sights” that are attached full-length to a guardrail, and fiber optic “end lights” (fiber optic cables in the pavement with ends that extend above the pavement surface at fixed intervals, with light emitted from the tips of these ends). These installations are applied where extra guidance is needed in late night. In environmentally sensitive areas, the Dutch use a variety of tailored approaches, including not installing lighting, using lighting that can be dimmed, and investigating lighting as a guidance system as described previously (Wilken et al. 2001).

MANAGEMENT PRACTICES

Synthesis and AASHTO–FHWA Survey Findings

As with traffic signals, maintenance of roadway lighting is often characterized by a sharing of responsibility among public and private organizations. The distribution of work and maintenance management responsibility reported by responding agencies is shown in Figure 22. Although some DOTs, provincial ministries, and local agencies are solely responsible for both overall management as well as conduct of roadway lighting maintenance, many other agencies rely as well on other groups to perform this work. These arrange-

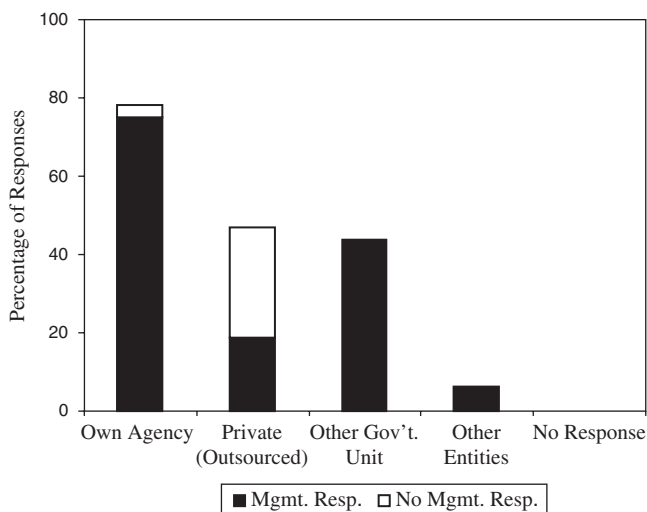


FIGURE 22 Responsibility for maintaining roadway lighting once in service.

ments include outsourcing to private contractors (by all levels of government), and partnerships with other levels of government or, in some cases, with utility companies. In the majority of cases involving outsourcing to private contractors by agencies participating in the survey, these firms do not have management responsibility. This practice contrasts with work performance by other units of government and by the utility companies, in which the performing city, county, or company does exercise management responsibility.

Other aspects of asset management practice are revealed through an agencies’ methods of budgeting for preservation, operation, and maintenance of roadway lighting, and its approaches to preserving and maintaining roadway lighting once in service.

Survey results for the budgeting method are shown in Figure 23. Explanations of the abbreviated budgeting process descriptions in this figure are given in chapter two. Because agencies could select multiple choices, the percentages in Figure 23 do not sum to 100%. Addressing their methods of budgeting, a large number of responding agencies at all levels of government chose the “previous budget plus adjustments” option and the “staff judgments, political priorities, and citizen demands” option as best describing their processes. These two were often selected in combination with each other, and sometimes in conjunction with one or more of the other options shown in Figure 23 as well.

The survey results in Figure 23 show that the number and target performance of assets are used to a degree in budgeting, but are not the primary drivers of budget processes among survey respondents. Approaches based on Target (Asset Performance) Drives Budget and Budget (Asset Performance) Drives Target each were identified in roughly 20% of the responses; Percent of Inventory Budgeted Annually was checked in less than 10% of the responses. By contrast, methods based on Adjustments to the Previous Budget and those that involve Staff Professional Judgment, Political Priorities, and Citizen Demands each garnered at least 40% of the responses (bearing in mind that agencies could select more than one approach). The general thrust of these results is complemented by a January 2000 AASHTO survey of roadway safety hardware that was reported by the FHWA (Hensing and Rowshan 2005). When asked whether asset inventory and asset condition were used as the basis of funding allocation, 7 of 39 states (18%) responded affirmatively for lighting inventory, and 10 of 39 (26%), for lighting condition—again, well less than a majority in each case. The corresponding results for supports of signs, signals, and lighting in this AASHTO survey were 6 of 39 states (15%) responded affirmatively that funding allocation is based on supports inventory, and 11 of 39 (28%), that allocation is based on supports condition.

A related question in the January 2000 AASHTO survey (Hensing and Rowshan 2005) asked whether state DOTs

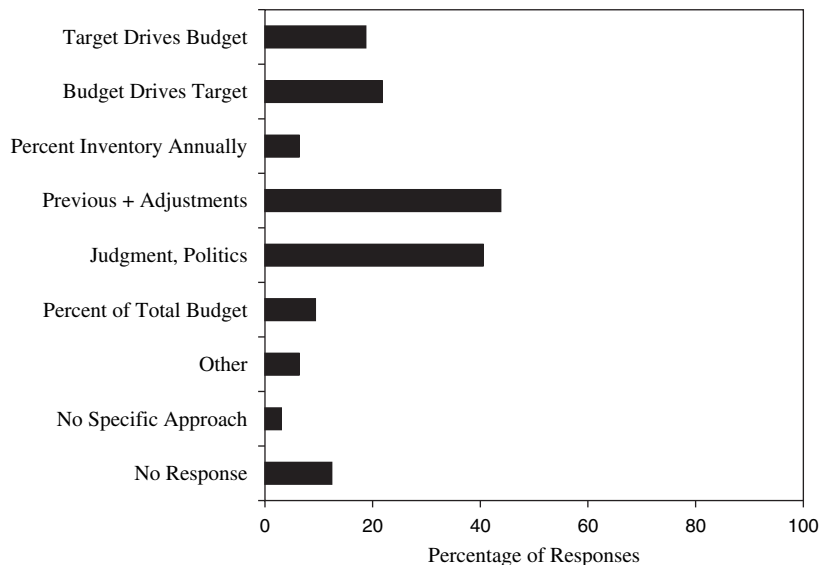


FIGURE 23 Annual budgeting method for preservation and operation of roadway lighting.

have a separate budget line item for *maintenance* of roadway lighting; 17 of 39 agencies (44%) responded affirmatively. The corresponding result for maintenance of sign, signal, and lighting supports was 8 of 39 agencies (21%) responding affirmatively. Although there was no corresponding question for budgeting of *new* lighting installations, the survey did address tracking and updating of asset inventory. These additional responses are reported in a later section of this chapter.

Agencies often described their approaches to preservation and maintenance as well in terms of multiple selections of the items shown in Figure 24. Immediate correction of problems was the most prevalent response, followed by prioritized, worst first, and preventive approaches.

Several agencies explained these multiple approaches by differentiating how and when they are used. For example:

PREVENTIVE: for control cabinets and switch gear;

IMMEDIATE: for cable breaks, knockdowns, and switchgear;

CORRECTIVE: for lamp, ballast, and fixture failures;

WORST FIRST: for underground breaks from deteriorated systems resulting in failures from salt water and freeze-thaw in winter; and

DEFERRED MAINTENANCE: on older, deteriorated systems.
— NYSDOT Region 10

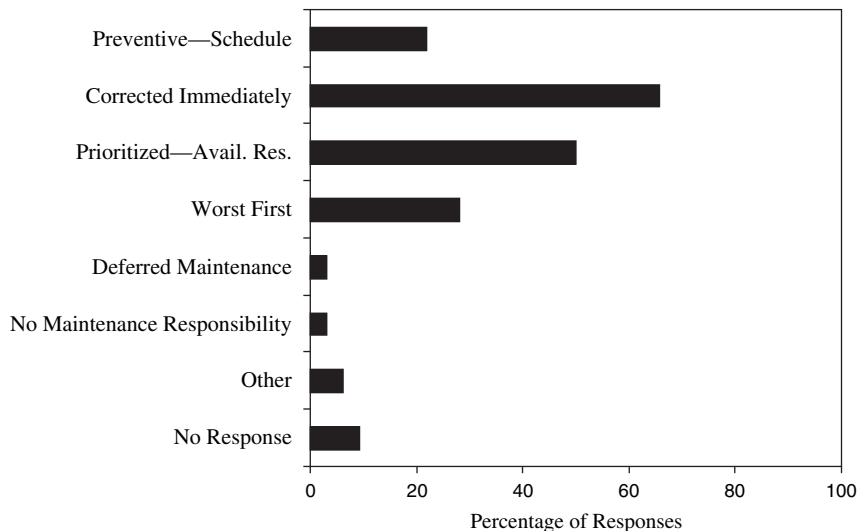


FIGURE 24 Approach to maintaining and preserving roadway lighting.

Highway construction projects call for lighting system replacement/rehabilitation.

— Oregon DOT

Each district has its own method.

— Texas DOT

“Worst first” [is] applied to Critical Pole Replacement.

— City of Edmonton

“Immediate” [is] applied to emergency safety hazard only.

— City of Portland

Leased lighting arrangement with utility focuses on achieving lighting repairs done within 72 hours of request.

City-maintained lights are inspected once every 2 weeks and, if applicable, repairs are made within 1 week of problem identification.

— City of Tampa

International Practice

International scans of practices in roadway lighting and more broadly in transportation asset management have observed that European road agencies give high priority to lighting (Geiger et al. 2005) and European roads are more brightly lit than U.S. roads (Hasson and Lutkevich 2002). Innovative asset management approaches and attitudes that are applied by European agencies in Finland, Switzerland, France, Belgium, and the Netherlands include the following, among other advances identified by the roadway lighting international scan team (Wilken et al. 2001; Hasson and Lutkevich 2002):

- Master lighting plans—Lighting is considered a component of effective city management. Several European cities have developed master lighting plans to support the public image of the city, help create a desired nighttime environment, contribute to urban beautification, improve safety and security, and recognize new developments in lighting technology. The advantage of such plans is that they help coordinate different lighting functions, organize the lighting program across different parts of the city, and schedule needed expenditures.
- Realistic experimentation and progressive attitude toward technology—The scan team found European lighting solutions to be new, practical, creative, and effective. Examples of advanced devices and systems included dynamic (or variable) lighting levels that depend on time of day, weather, and traffic; vertical illumination in crosswalks for more prominent visibility of pedestrians; lighted, in-road traffic guidance systems in lieu of fixed overhead lighting; and energy-absorbing poles in locations where breakaway poles could not be used. The scan team noted a very progressive attitude toward testing and implementing innovative technology, supported by aggressive research programs in several countries (e.g., visibility research using three-

dimensional targets and pavement reflectance research on new paving materials). Experiments are conducted on active roadways, enabling realistic in-service trials and more rapid implementation of new ideas—an approach able to be used owing in part to the lower tendency for litigation as compared with U.S. experience.

- Data on crashes and lighting—Police in Zürich, Switzerland, analyze the causes of accidents and make recommendations with respect to lighting. This finding led the scan team to recommend a uniform accident reporting system among U.S. states that includes more accurate descriptions of the lighting conditions at crash scenes.
- Equipment quality and maintenance—Lighting equipment used by European agencies is of generally higher quality than comparable equipment used in the United States, reducing frequency of outages as well as maintenance requirements. Group relamping is done at 3–5 year intervals. A maintenance issue that affects European agencies as well as U.S. DOTs is the difficulty of maintaining as-designed photometric performance (i.e., overall luminance levels) when replacing luminaires or other system components.

Lighting-related findings of the international scan that relate to signs and pedestrian crosswalks (discussed in chapters four and seven, respectively) were as follows:

- Moving away from lighted signs—Finland is eliminating fixed-sign lighting and moving to high-performance, micro-prismatic sign sheeting. France is likewise eliminating sign lighting, but continuing to use engineering-grade retroreflective sheeting.
- Vertical lighting of pedestrians in crosswalks—Switzerland is now lighting crosswalks from the side to provide greater visibility of pedestrians to drivers. This approach has resulted in a two-thirds reduction in pedestrian-vehicle crashes, although minor vehicle-vehicle crashes have increased as a result of sudden stops before the crosswalk. Although France has confirmed the visibility benefits of the Swiss approach, they caution that pedestrians may believe they are seen by drivers regardless of ambient lighting and weather conditions, even if they are not exactly within the crosswalk.

MEASURING ASSET PERFORMANCE

Synthesis Survey Findings

The information provided by agencies on performance measurement of roadway lighting is summarized in Figure 25, based on categories of performance factors similar to those described in chapter two. Physical measures of non-functioning items (e.g., is the light lit?), asset age, and customer complaints were cited the most often by responding agencies. Many agencies also reported structural condition of supports and corrosion as key items, expressed in

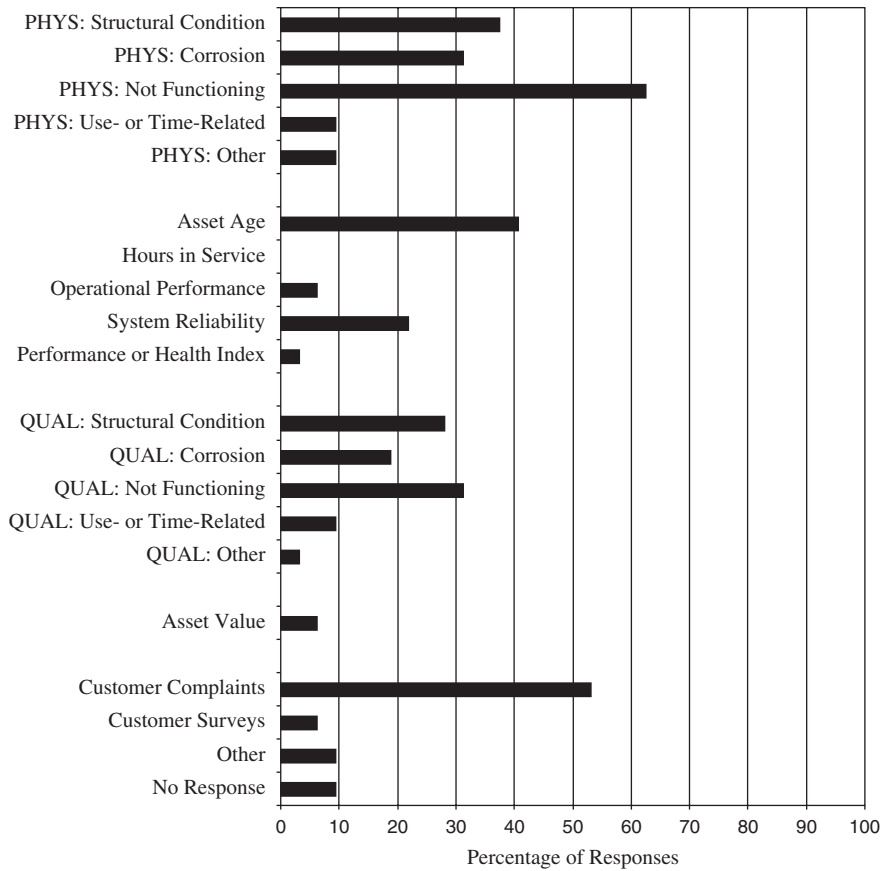


FIGURE 25 Measuring performance of roadway lighting. PHYS = physical; QUAL = qualitative.

physical as well as qualitative terms. The frequencies with which physical measures are addressed are shown in Figure 26. Almost half of the reporting agencies assess lighting condition more than once a year, and almost two-thirds of these agencies at least annually.

The methods used by responding agencies to assess lighting condition and performance are reported in Figure 27.

Visual inspections and customer complaints are by far the most common methods used. Under “Other” methods, Maryland reported use of global positioning systems (GPS) to record the number of lighting units, and the city of Edmonton mentioned ultrasonic nondestructive testing of system components. Edmonton noted its five-year condition assessment program, and Colorado Region 3 included maintenance patrol inspections as a source of condition data.

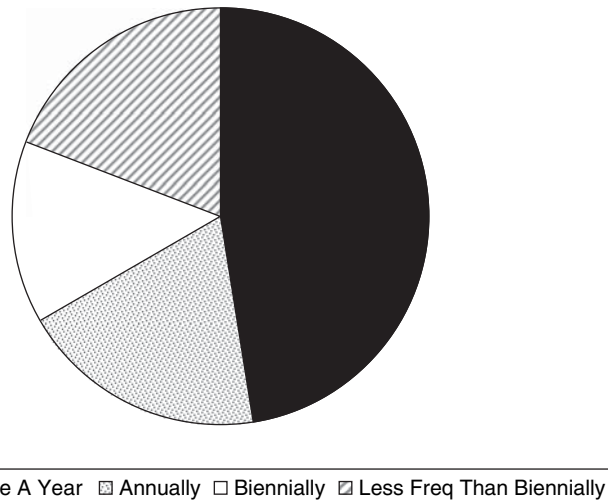


FIGURE 26 Frequency of physical condition assessments of roadway lighting.

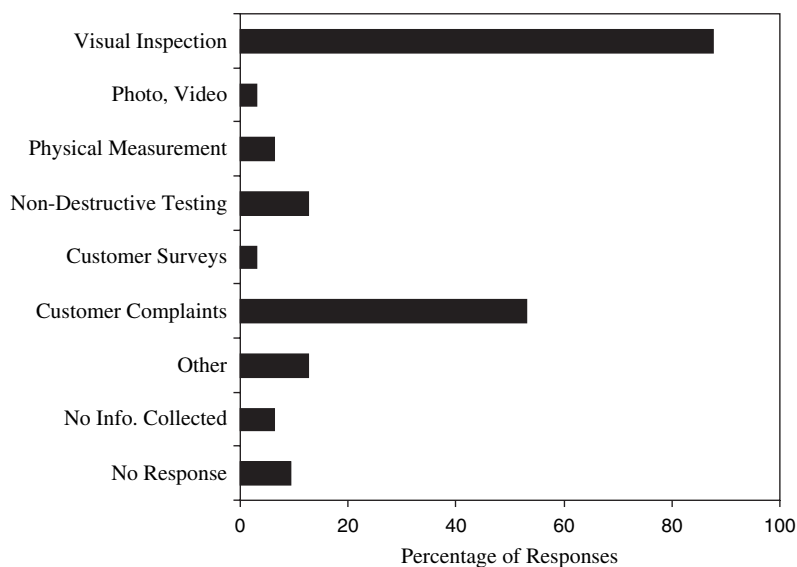


FIGURE 27 Data collection methods for condition and performance of roadway lighting.

Technical and Human Factors Aspects of Performance

The technical aspects of illumination and related measures are discussed in the literature (e.g., Lewin 1999; *Roadway Lighting Design Guide*, Appendix B 2005). Illuminance is the light output striking a given area, measured in lumens per area lit. Its units of measurement are either lux in the metric system (abbreviated lx, in lumens per meter²), or footcandles in U.S. conventional units (abbreviated fc, in lumens per ft²). Illuminance depends on both the light emitted by the lamp and the distance of the light source from the roadway surface (*Roadway Lighting Design Guide* 2005). It is an absolute measure and is therefore independent of the perceptions of drivers. How drivers perceive roadway lighting and related measures such as reaction time to perceived targets depend on other factors in addition to illuminance, including ambient or overall lighting level and the color or wavelengths of the roadway lighting, as well as the vision and ability to react of the driver.

Ambient or overall light conditions are described as follows (Lewin 1999; Bullough and Rea 2004):

- Photopic: high ambient light levels, as in daylight.
- Scotopic: darkness or very low light levels, as in starlight levels at night.
- Mesopic: ambient condition between photopic and scotopic, as in twilight or nighttime under even partial moonlight. Mesopic conditions also exist at typical street or highway lighting levels.

As ambient conditions transition from photopic to scotopic, the vision of the human eye undergoes changes. Its ability to see yellow and red light diminishes, although its sensitivity to blue light increases. Its vision in mesopic con-

ditions lies between its responses in photopic and scotopic light levels. These changes in vision are the result of the eye's two types of photoreceptors: cones, which are most active in photopic light, and rods, which respond to scotopic conditions. Both cones and rods are active when driving at night in mesopic conditions. Because cones are associated primarily with vision directly ahead (foveal vision) and rods with peripheral vision the design of roadway lighting must account for drivers' abilities to see both straight ahead and to the side. The problem goes beyond lumen output and must consider color or wavelength of lighting, configuration of the luminaires (e.g., their location and height, and whether they cast light on the roadway itself or toward the roadside); the type of lamp that best satisfies desired lighting characteristics; and life-cycle characteristics of the lamp, including service life and cost (Lewin 1999; Hasson and Lutkevich 2002; Bullough and Rea 2004).

Road lighting design and management therefore depend on balancing the range of visibility requirements of different drivers, the realistic capabilities of available lighting technology, and their life-cycle feasibility. Visibility and driver reaction time need to be understood in actual (complex) visual situations. Lighting that is specified based on photopic conditions may need to be evaluated using additional criteria for mesopic conditions. Unintended consequences need to be avoided; for example, lighting designed to assist peripheral vision in mesopic conditions may cause distractions to drivers in other conditions, such as fog and falling snow. Lighting solutions have therefore been proposed based on a comprehensive systems approach in which several elements—for example, fixed roadway lighting, vehicle headlamp lighting, pavement markings, signals, and signs—are assembled to provide a total and balanced visual solution (Bullough and Rea 2004).

ASSET SERVICE LIFE

Information on service life was obtained in the study survey for three major components of lighting systems: the structural supports (poles and arms), lamps, and other items (e.g., ballast, photocells, and control panels). Responding agencies were also asked to identify how they would determine service-life values. Responses to this question are shown in Figure 28. Among the 35% of reporting agencies that identified at least one method, their emphasis was on collective agency knowledge, whether represented by their experience with roadway lighting infrastructure (e.g., a database of observed historical service lives) or by the professional judgment of their staffs. Manufacturer’s data were also noted as a source of information, but to a somewhat lesser degree.

A comprehensive statement of all of the items for which estimated service lives were reported is given in Table 9. Examples of histograms showing service-life distributions for those items with the most numerous responses are given in Figures 29 through 34. The labels on the horizontal axis in these figures give the upper values of each range of service-life data. For example, if these labels are 0, 5, 10, 15 . . . , then the column labeled 5 shows the number of responses for estimated service life of zero to 5 years; the column labeled 10, the number of responses for estimated service life of more than 5 to 10 years; the column labeled 15, the number of responses for estimated service life is more than 10 to 15 years; and so forth. It should be noted again that the data in Table 9 and Figures 29 through 34 may be derived in part from the professional judgment of agency personnel.

The structural performance of luminaire supports has also been a topic of recent interest. Research has resulted in updated guidelines and specifications for structural supports

(*Standard Specifications for Structural Supports . . .* 2001, updated in 2003; Fouad et al. 2003).

To apply the service-life concept in asset management, a method is needed to determine where an asset is in its service life—that is, how much life is consumed and how much remains. Agencies were presented with a number of ways to determine the current status of an asset regarding its service life and asked to rank each method by relevance to their agency. The result is shown in Table 10. Note that two instances of tie values occurred in this particular ranking process.

The “other factors” shown in Table 10 included two amplifying comments:

- The city of Portland, Oregon, does group relamping of lamps; and
- The response by the city of Tampa, Florida (to the effect that the agency does not use or monitor service life for this asset), pertains to leased lighting, which is maintained by the utility company.

On the related issue of identifying the extension in service life owing to maintenance, only one of the 32 reporting agencies responded affirmatively. The Oregon DOT reported that this effect was taken into account in its replacement of existing metal halide lamps with new high-pressure sodium luminaires.

INFORMATION TECHNOLOGY SUPPORT

Agencies participating in the study survey identified their key IT capabilities as shown in Figure 35. Many (but not all) agencies have an inventory of roadway lighting assets accompanied by information on location. Recommendations

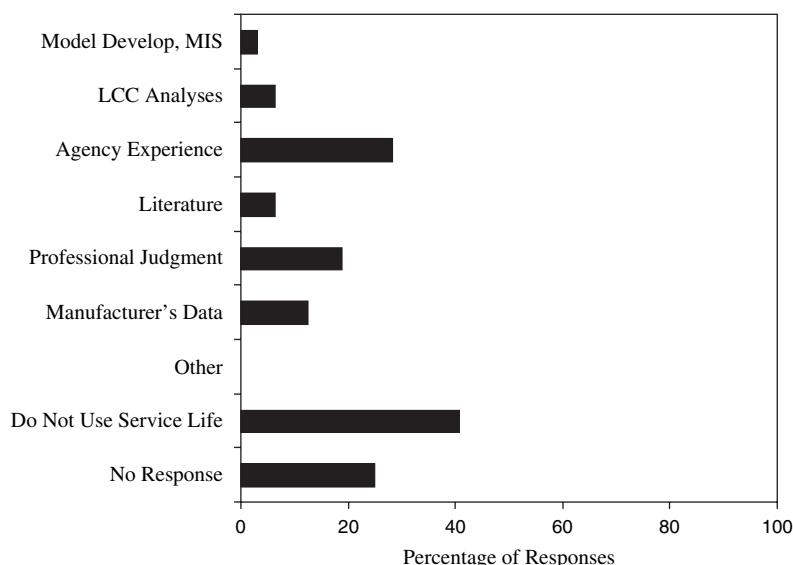


FIGURE 28 Sources for determining service lives of roadway lighting components. MIS = management information systems; LCC = life-cycle cost.

TABLE 9
ESTIMATED SERVICE LIVES OF ROADWAY LIGHTING COMPONENTS

Component and Material	No. of Responses	Minimum (Years)	Maximum (Years)	Mean (Years)	Median (Years)	Mode (Years)
Structural Components						
Tubular steel	12	10	40	25.4	25	25
Tubular aluminum	9	10	40	26.1	25	30
Cast metal	2	15	30	22.5	22.5	—
Wood posts	2	25	40	32.5	32.5	—
High mast or tower	11	10	50	28.6	30	30
Lamps						
Incandescent	3	1	5	2	1	1
Mercury vapor	6	3	5	4	4	4
High-pressure sodium	15	1	6	3.6	4	5
Low-pressure sodium	3	1	5	3	4	4
Metal halide	9	1	5	2.9	3	2
Fluorescent	1	—	—	5	—	—
Other Components						
Ballast	9	2	25	9.7	7.5	10
Photocells	11	1	10	5.2	5	5
Control panels	7	10	25	18.2	20	20
Luminaires	2	5	25	16.25	16.25	—

Notes: —, value is undefined for the particular distribution. When distribution is based on only one data point, its value is shown in the Mean column.

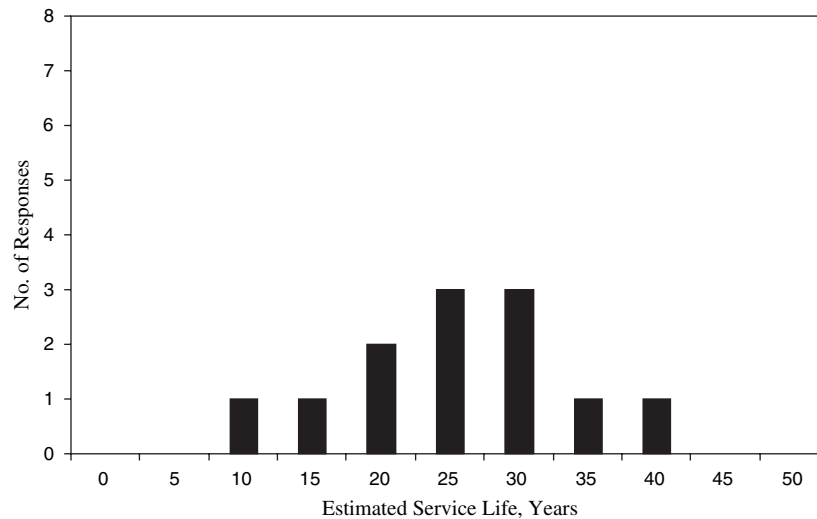


FIGURE 29 Estimated service life of tubular steel mast arm for roadway lighting.

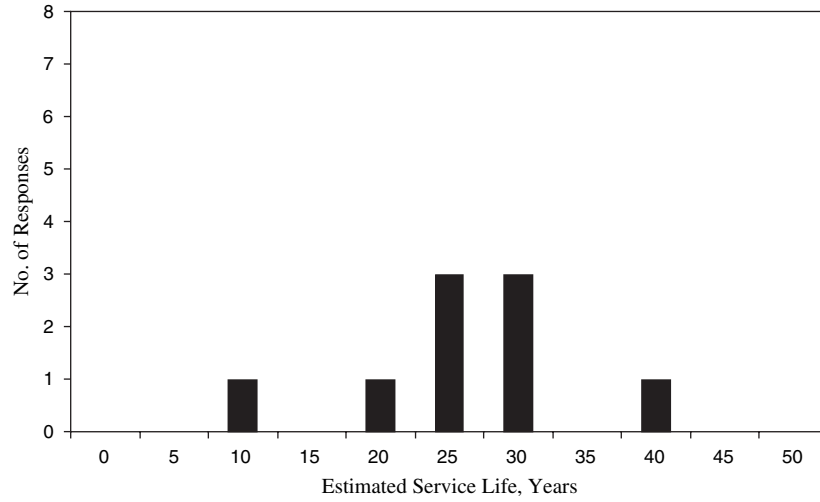


FIGURE 30 Estimated service life of tubular aluminum mast arm for roadway lighting.

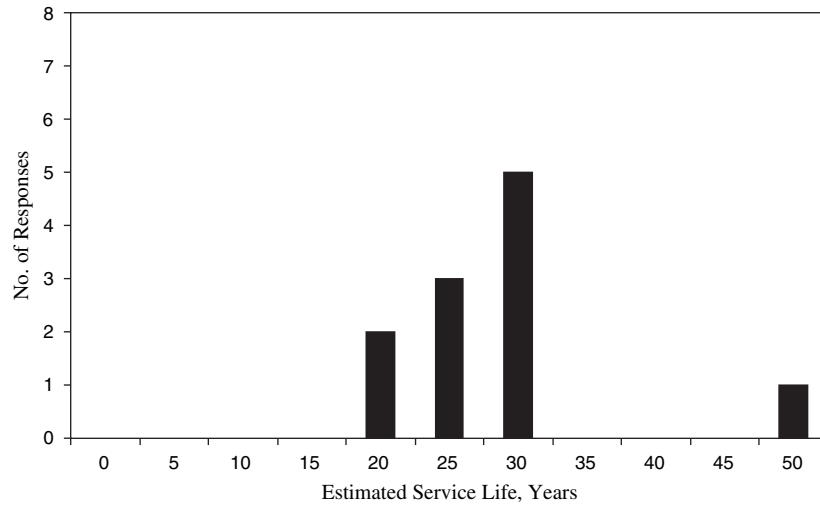


FIGURE 31 Estimated service life of high mast or tower for roadway lighting.

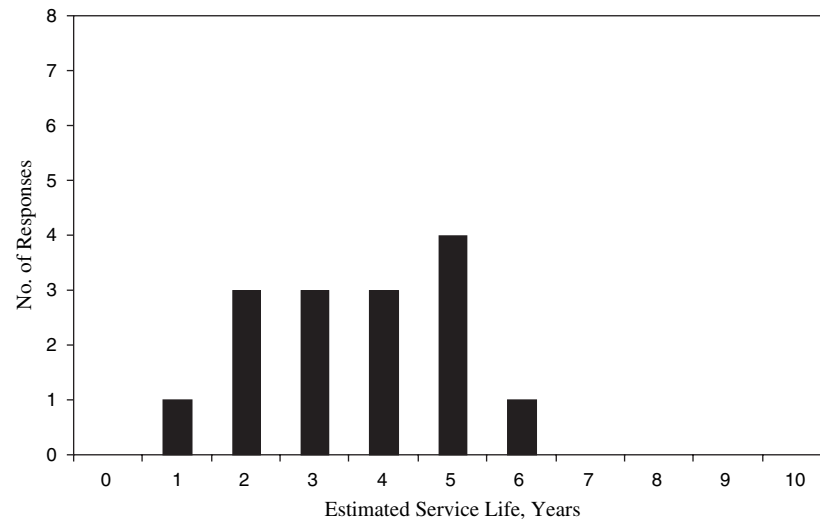


FIGURE 32 Estimated service life of high-pressure sodium vapor lamps for roadway lighting.

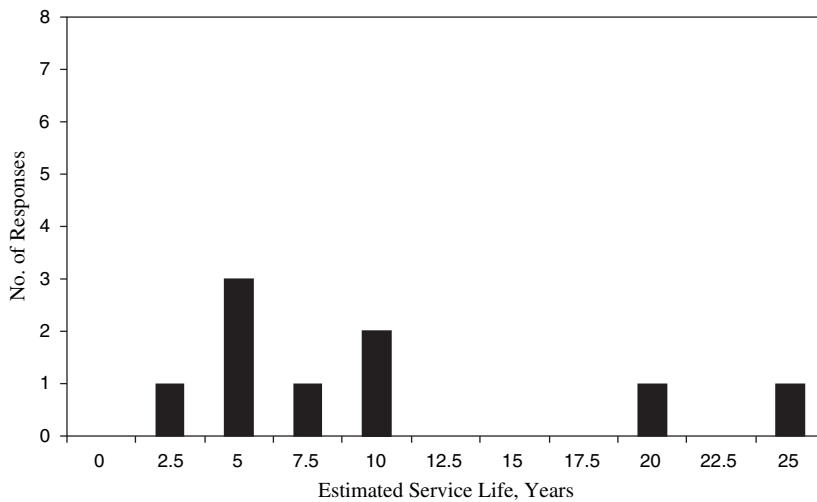


FIGURE 33 Estimated service life of ballast used in roadway lighting.

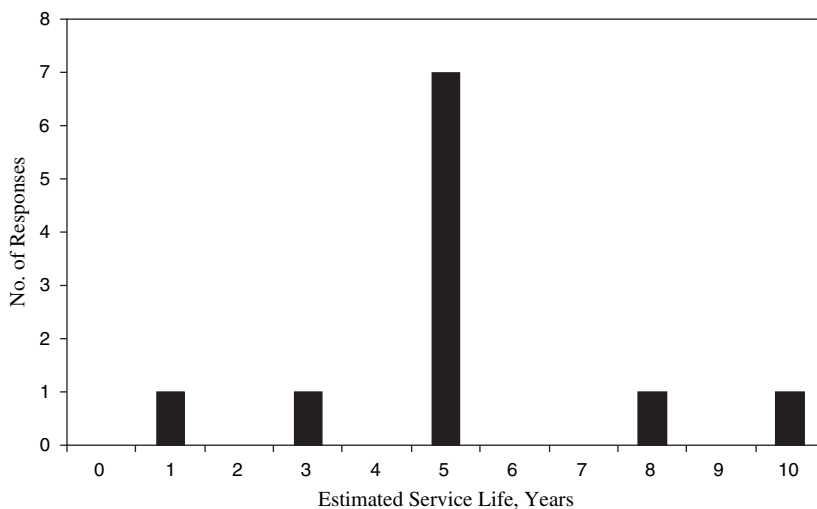


FIGURE 34 Estimated service life of photocells used in roadway lighting.

TABLE 10
RANKING OF METHODS TO DETERMINE WHERE ROADWAY LIGHTING ASSETS
ARE IN THEIR SERVICE LIVES

Rank	Factor
1	Assets are repaired or replaced as soon as they fail without regard to service life
1	The agency does not use/does not monitor service life for this type of asset
3	Monitor condition of the asset occasionally
4	Compare current age of asset with the maximum age that defines service life
5	Service life is often determined more by functional obsolescence than by wear and tear
6	Monitor condition of the asset on a periodic schedule
7	Compare service hours to date with the maximum number of service hours that defines service life
8	Assets are replaced on a preventive maintenance schedule without regard to where they are in their service life
9	Apply deterioration models to estimate where the asset is on “the curve”
9	Other factors

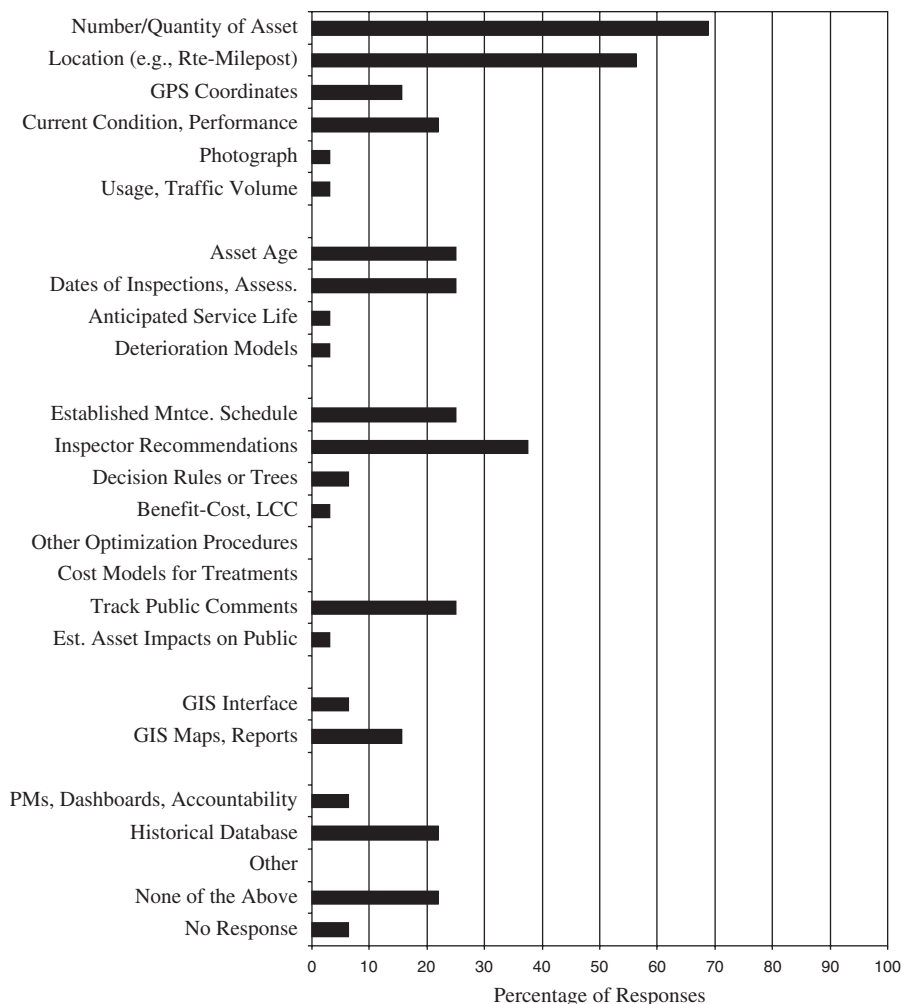


FIGURE 35 IT capabilities to help manage roadway lighting. GPS = global positioning system; LCC = life-cycle cost; GIS = geographic information system; PMs = performance measures.

of inspectors were also reported by a number of agencies. Less than 5% of responding agencies reported that they tracked anticipated service life. No strong distinctions in the findings represented by Figure 35 were observed among different levels of government. By comparison, responses to the January 2000 AASHTO survey (Hensing and Rowshan 2005) indicated that 15 of 39 agencies (38%) had an inventory of roadway lighting, and most of these updated their inventory by manual survey.

Agencies characterized their IT systems for roadway lighting as shown in Figure 36. Most agencies reported using broad-based management systems, such as maintenance management systems, followed by workbooks or spreadsheets and simple programs. The agencies that reported using a roadway lighting management system or a maintenance management or transportation infrastructure asset management system that includes roadway lighting are listed in here.

- Roadway Lighting Management System
 - Colorado DOT Region 4
 - City of Edmonton, Alberta.

- Maintenance or Asset Management System That Includes Roadway Lighting
 - Florida DOT
 - Iowa DOT
 - Minnesota DOT
 - Ohio DOT
 - Oregon DOT
 - Colorado DOT Regions 1, 3, and 5
 - City of Edmonton, Alberta
 - City of Portland, Oregon.

KNOWLEDGE GAPS AND RESEARCH NEEDS

Synthesis Survey Comments

Agencies at all levels identified a number of knowledge gaps and resulting needs for research in their survey responses. These comments have been organized by topic area and compiled and summarized here.

- Basic management capabilities—Although information on roadway lighting design exists, agencies reported

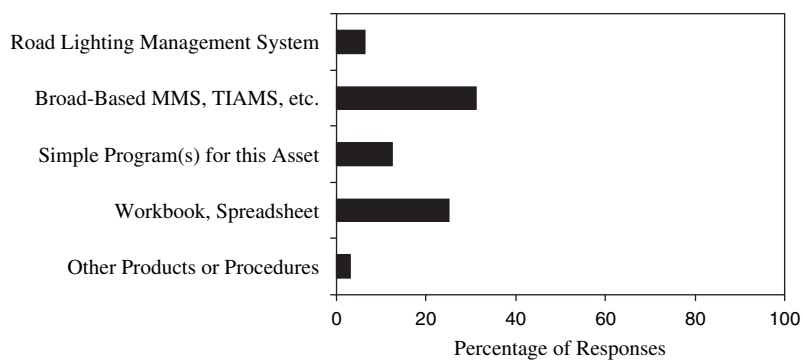


FIGURE 36 Types of analytic tools to support roadway lighting management. MMS = maintenance management system; TIAMS = transportation infrastructure asset management system.

that roadway lighting had not yet been developed within its asset management framework (Saskatchewan), and that legacy systems for maintenance management did not yet have a road inventory needed for asset management (Nevada). Research is also needed to better understand the best approach for maintaining street lighting; for example, whether by group relamping or the “break-repair” method (Tampa).

- Service lives—Several agencies observed that the current data on roadway lighting service life is difficult to use because of inconsistencies, wide variability in values, and the strong influence of local conditions. Research is needed to reduce the wide variation and to develop more useable values for different components of roadway lighting (New Brunswick, Colorado Region 3, and Kansas). There is also a need for more consistent measurement and reporting of product reliability data (Minnesota).
- Nonphysical and physical attributes—Research efforts need to recognize the importance of nonphysical as well as physical measures of condition and performance. Factors such as the energy cost per light, age of the wiring system, and relative benefits of different types of lamps (e.g., high-pressure sodium versus metal halide) need to be understood. For example, how does the color of the light affect driving and security (Maryland and Tampa)? What are the roadway and traffic safety improvements gained by installing illumination (Oregon)?
- New technology—Technological advances could provide more accurate and efficient management of roadway lighting; for example, through the ability to monitor the operational status of lighting systems from a remote location (Minnesota and Utah), and the development of more efficient and economical light sources [e.g., a reliable and cost-effective LED source for roadway lighting (Saskatchewan and Portland, Oregon)]. More complete information on existing technology is also needed; for example, a comparison of one manufacturer’s part compatibility to another’s (Michigan).
- Institutional issues—Management capabilities and information availability need to accommodate different institutional arrangements. For example, in a situation

where the lighting system is leased, the costs associated with design, engineering, construction, customer service, outages, and maintenance are monitored by the electric utility; information on maintenance and operational history of the leased lighting infrastructure is therefore not now available to the transportation agency (Tampa).

- Communicating priority—The urgency of the need to replace deteriorated lighting systems appears not to be well understood within the context of Transportation Improvement Program development in conjunction with the local metropolitan planning organization. Other investment categories are programmed instead (New York Region 10).

FHWA, AASHTO, and NCHRP International Scan

Based on their review of European roadway lighting practice, the international scan team made several recommendations for consideration by U.S. agencies and research sponsors. Of these, the following recommendations bear most directly on asset management practices in roadway lighting (Wilken et al. 2001).

- Develop master lighting plans that help coordinate roadway and urban lighting considering lighting levels, styles, and themes that serve safety, security, and beautification.
- Develop a uniform accident reporting system among states that includes more accurate descriptions of the lighting conditions at crash scenes.
- Investigate dynamic lighting management to be able to dim lights or turn systems off, and consider alternative lighting systems such as embedded-lighting guidance systems.
- Evaluate drivers’ information needs at night—for example, for navigational guidance, stopping distance, object-in-road avoidance, peripheral visibility, and zones of driver attention—considering different lighting levels and traffic volumes.
- Further evaluate European standards, practices, and guidelines to determine potential applicability in the United States.
- Consider vertical illuminance to improve pedestrian safety in crosswalks and other pedestrian areas, benefiting

from positive-contrast illumination of pedestrians. [An initial experiment applying this Swiss technique in the United States is described in Hasson et al. (2002)].

- Develop measurement techniques and standards for off-roadway sources of glare and lighting strategies to mitigate adverse effects of this glare. Also, investigate adverse glare effects on pedestrians and bicyclists, balancing their ability to see and their ability to be seen.
- Train maintenance personnel in correct procedures to maintain the as-designed lighting levels when replacing system components.
- Consider other European practices and research studies in lighting design and component selection such as the following:
 - Consider quality lighting materials as appropriate to improve durability and reduce maintenance requirements.
 - Investigate energy-absorbing poles as an option for selected applications, taking care to account for

the wide range of vehicle mass and speed on U.S. highways.

- Conduct research in pavement reflectance to include newer materials and update values in existing reflectance guidelines (“R-tables”).

Some of these ideas have already been incorporated in the recently updated AASHTO guidance for roadway lighting (*Roadway Lighting Design Guide* 2005). An entire chapter has been devoted to master lighting plans. Lighting curfews are discussed in the context of modern operation and control of the system, taking advantage of opportunities to turn off or dim lighting as local conditions permit. The guide also emphasizes the need to conduct traffic and lighting studies in support of these initiatives. It is not unreasonable to expect that these and the other recommendations listed previously will continue to be the subjects of future research and implementation studies, and to be addressed at conferences, workshops, and other information exchanges.

SIGNS

OVERVIEW

Signs help inform, guide, and regulate traffic, including vehicular traffic, pedestrians, and cyclists. Good signage must communicate its information clearly and with sufficient lead time to transport system users in daytime and nighttime and in variable weather conditions. Signs must be visible to drivers in vehicles of different characteristics regarding head-lights and heights of drivers' eyes above the road surface. Pedestrian and vehicular signs must be legible to different population groups, such as the elderly. The importance of good signage to public safety, particularly in nighttime, is well recognized in the literature. The percentage of total highway fatalities that occurs at night is more than double the percentage of travel during this period, with inadequate or poorly maintained signage often cited as a contributing factor (*How Retroreflectivity . . .* 2005). Additional facts and statistics regarding nighttime versus daytime crash trends, driver visibility, and the role of traffic signage are also provided by the FHWA ("Nighttime Visibility Facts . . ." n.d.; "Driver Night Visibility Needs" n.d.).

Agencies participating in the survey that was conducted for this study were asked to rank in order of importance the transportation objectives that are served by roadway signage. The composite results across all responding agencies are given in Table 11.

Meeting these objectives calls upon agencies to observe standards, technical recommendations, and guidelines from a variety of sources. Figures 37 and 38 present agencies' judgments of those sources of guidance that are the important drivers of engineering and management decisions regarding roadway signs. These results are shown for two key aspects of asset management: new construction and installation, and maintenance and rehabilitation, respectively.

The importance of national standards, and especially individual agency policies, standards, guidelines, and procedures, is evident in these results. The international definition and measurement standard for retroreflection is published by the International Commission on Illumination (Commission Internationale de L'Eclairage) (*Retroreflection . . .* 2001). The U.S. national standard for signs is the *MUTCD*, supplemented by further U.S.DOT/FHWA guidelines on sign retroreflectivity and sign management as discussed here. There are also AASHTO guidelines for pedestrian-related

signs (*A Policy on Geometric Design . . .* 2004), specifications for sign structural supports (*Standard Specifications for Structural Supports . . .* 2001), and guidelines on roadside structures (*Roadside Design Guide* 2002). In addition, many agencies have their own manuals and guidelines for traffic control devices. These supporting or supplementary documents by U.S. agencies must conform substantially to the *MUTCD*, as noted in chapter two.

The literature review has identified several examples of individual agency guidelines for signs from all levels of government:

- State DOTs [e.g., the Delaware DOT *Traffic Control Manual* (2000), Kansas DOT *Special Provision . . .* (1990), Maryland SHA *Standard Sign Book*; MnDOT *Traffic Engineering Qualified Products . . .*; South Dakota DOT *Materials for Highway Signs . . .*; and Texas DOT *Signs and Markings Manual* (2006). Agencies also incorporate signage guidelines in their intersection design guides [e.g., University of Florida for the Florida DOT, *Florida Intersection Design Guide . . .* (2002)].
- Provincial transportation agencies (e.g., Filice 2003; *Specifications for Standard Highway Sign Materials . . .* 2004).
- Local agency and tribal technical assistance (e.g., Montebello and Schroeder 2000; Andrie et al. 2001).
- City government, Lincoln, Nebraska (*Standard Specifications . . .* 2006).

Although these guidelines differ in scope and detail, in general they include information such as the following:

- General discussion of the functions and types of signs.
- Applicable standards, test procedures, and related documents.
- Explanations and characteristics of different grades and colors of sign sheeting, including retroreflective properties.
- Sheeting requirements by sign type, which may include tables of minimum retroreflectivity requirements and color specifications (chromaticity requirements).
- Sign substrate types and requirements.
- Requirements for sign supports (e.g., by size of sign panel), materials selection procedures, and sign mounting and hardware.
- Guidelines for sign installation and maintenance.

TABLE 11
PRIORITY OF TRANSPORTATION OBJECTIVES SERVED BY ROAD SIGNS

Rank	Factor
1	Public safety; accident and accident risk reduction
2	More efficient travel; maintain intended flow and operating speed; reduce travel time
3	Preservation of the existing road infrastructure; reduced agency life-cycle costs
4	Comfort and convenience of the traveling public (motorists, pedestrians, cyclists)
5	Road aesthetics and appeal

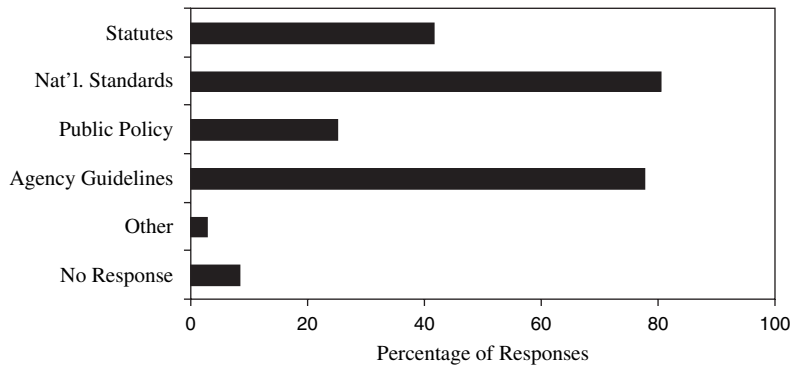


FIGURE 37 Technical management guidance for new installations of signs.

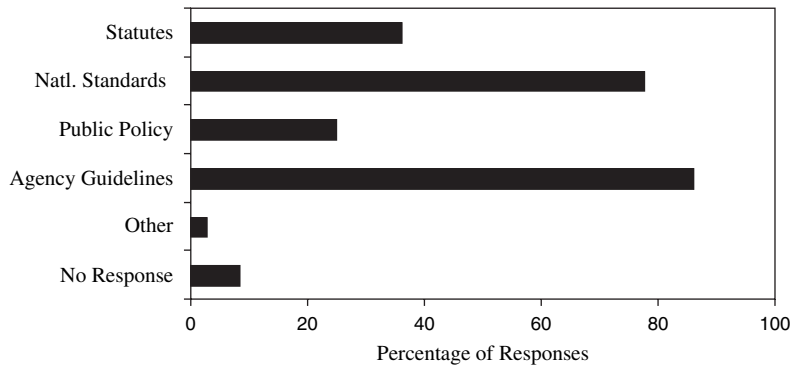


FIGURE 38 Technical management guidance for maintenance and rehabilitation of signs.

- Qualified products lists, sources, or vendors; procurement procedures.
- Warranty requirements.

Agencies may also specify their own sign material testing requirements (e.g., *Florida Method of Test* . . . 2000).

MANAGEMENT PRACTICES

Synthesis and AASHTO–FHWA Survey Findings

In contrast with other selected assets discussed to this point, responsibility for sign maintenance resides much more closely with the owning agency. The distribution of work and

maintenance management responsibility reported by agencies participating in the study survey is shown in Figure 39. Although some DOTs reported contracting with private firms for sign maintenance, seldom did these firms have management responsibility. All of the local governments and Canadian provincial ministries that participated in the study survey maintained their own signs, with no involvement by other public or private organizations. In some cases, cities maintain signs on the state highway system within their municipal boundaries (e.g., in Kansas).

Other aspects of asset management practice are revealed through agencies’ methods of budgeting for preservation, operation, and maintenance of road signs, and their

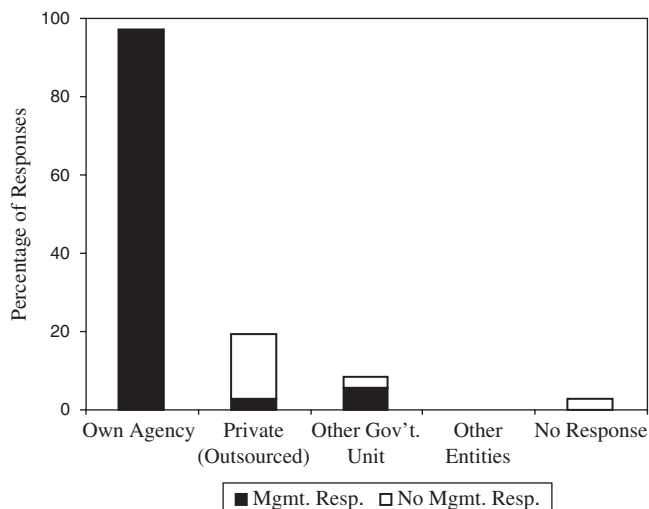


FIGURE 39 Responsibility for maintaining signs once in service.

approaches to preserving and maintaining road signs once in service.

Survey results for the budgeting method are shown in Figure 40. Explanations of the abbreviated budgeting process descriptions in this figure are given in chapter two. Because agencies could select multiple choices, the percentages in Figure 40 do not sum to 100%. Addressing their methods of budgeting, a large number of responding agencies at all levels of government chose the “staff judgments, political priorities, and citizen demands” option and the “previous budget plus adjustments” option as best describing their processes, followed by the two options involving performance targets.

These descriptions were sometimes selected in combination with each other.

The survey results in Figure 40 show that the number and target performance of assets are used to a degree in budgeting; however, they are not the primary drivers of budget processes among survey respondents. Approaches based on Target [Asset Performance] Drives Budget, Budget [Asset Performance] Drives Target, and Percent of Inventory Budgeted Annually were identified in 19%, 31%, and 17% of responses, respectively. By contrast, methods based on Adjustments to the Previous Budget and those that involve Staff Professional Judgment, Political Priorities, and Citizen Demands each garnered almost 40% of the responses (bearing in mind that agencies could select more than one approach). The general thrust of these results is complemented by a January 2000 AASHTO survey of roadway safety hardware that was reported by the FHWA (Hensing and Rowshan 2005). When asked whether asset inventory and asset condition were used as the basis of funding allocation, 10 of 39 states (26%) responded affirmatively for sign inventory, and 12 of 39 (31%) for sign condition—again, less than a majority in each case. The corresponding results for supports for signs, signals, and lighting in this AASHTO survey were 6 of 39 states (15%) responded affirmatively that funding allocation is based on supports inventory, and 11 of 39 (28%) that allocation is based on supports condition.

A related question in the January 2000 AASHTO survey reported by the FHWA (Hensing and Rowshan 2005) asked whether state DOTs have a separate budget line item for *maintenance* of road signs, with 23 of 39 agencies (59%) responding affirmatively. The corresponding result for

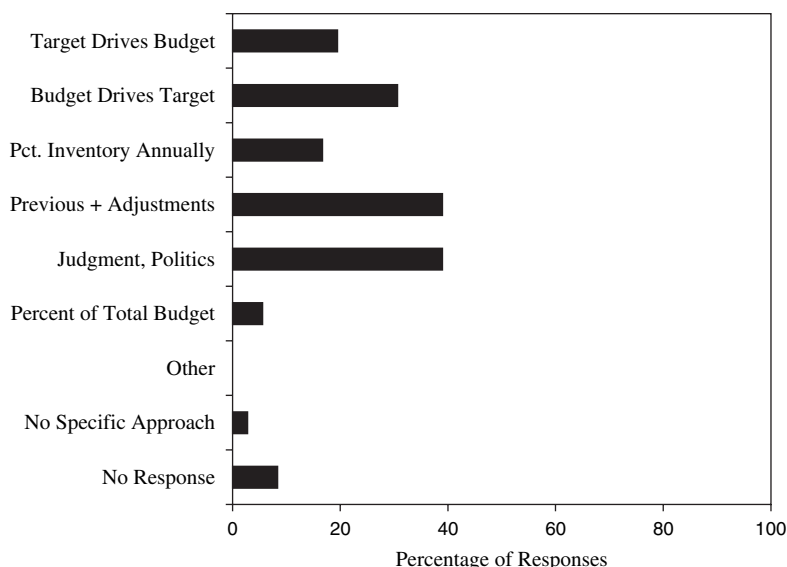


FIGURE 40 Annual budgeting method for sign preservation and maintenance.

maintenance of sign, signal, and lighting supports was 8 of 39 agencies (21%) responding affirmatively. Although there was no corresponding question for the budgeting of *new* sign installations, the survey did address tracking and updating of asset inventory. These additional responses are reported later in this chapter.

Agencies often described their approaches to preservation and maintenance as well in terms of multiple selections of the items shown in Figure 41. The immediate correction of problems was most prevalent response, followed by preventive, prioritized, and worst-first approaches. Many agencies explained these multiple approaches by differentiating how and when they are used. For example:

- An “Immediate” approach was identified for high-priority or critical signs having safety implications (e.g., Stop, Yield, Keep Right, Curve Warning, and Pedestrian Warning) by several agencies, including Pennsylvania, Vermont, Edmonton, and Portland. An immediate response was also noted for certain types of signs (New Brunswick) and sign damage resulting from severe weather (Saskatchewan). Edmonton reported that damaged high-priority signs are addressed within 2 h on a 24/7 basis, and Tampa also reported a policy of repairing sign damage that is phoned into the city’s Action Center within 2 h.
- A “Preventive” policy was associated by responding agencies with programs of periodic inspection and repair by several agencies. The nature of these policies however, and the frequencies of inspections, differ considerably. For example:
 - Kansas inspects signs in its High Performance Signing Projects on a 10-year cycle.
 - Tampa has a 12-year sign replacement cycle.
 - New Mexico cleans and straightens its signs on an annual basis; Portland conducts annual sign maintenance during nonstriping months.

- Pennsylvania conducts its preventive work on a 3- to 5-year cycle.
- Edmonton performs area checks weekly to identify maintenance issues.

Considerations in Improved Sign Management

There are several considerations in managing the physical and operational performance of highway signs.

- One is the choice of sheeting material, which plays a strong role in initial appearance and long-term performance of the sign, and affects its life-cycle costs.
- A second is to be able to track the rate of deterioration in the sign’s visibility and legibility throughout its life. This reduction in the visual quality of the sign directly affects the ability of motorists, cyclists, and pedestrians to read, comprehend, and respond to the sign’s information.
- A third is that because many signs are mounted in the roadside or on sidewalks they are susceptible to being hit by vehicles, potentially damaging the sign supports and the panel itself. As a safety measure, sign supports must be designed to break away or to absorb the energy of the crash to help protect the vehicle’s occupants.
- Fourth, effective maintenance is needed to clean signs, repair damaged posts and panels, and replace signs when they have exhausted their service life.

The FHWA has outlined several aspects of an improved sign management approach on its safety website. Considerations in implementing better management processes are given in the “Implementation” section. A component of this guidance concerns options to improve sign management (“Improving Traffic Sign Management . . .” n.d.), which include:

- Developing a comprehensive sign inventory.
- Developing or purchasing system software.

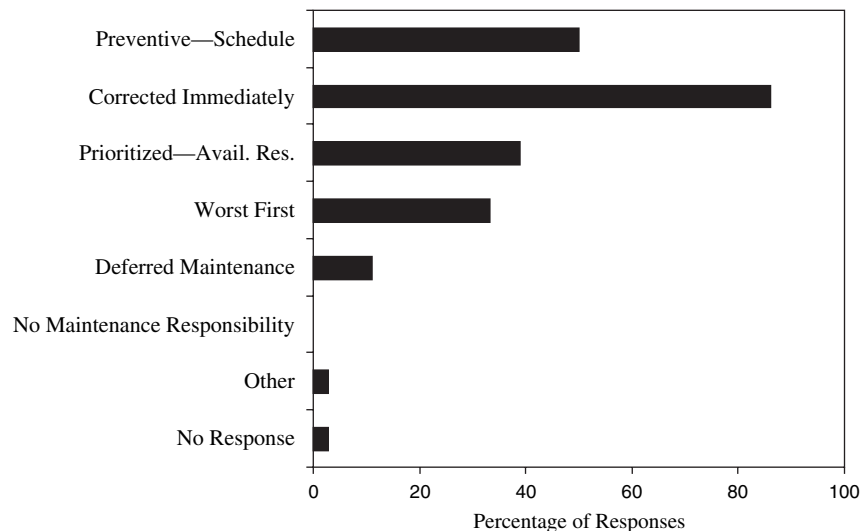


FIGURE 41 Approach to maintaining and preserving road signs.

- Adjusting sign fabrication processes (e.g., to use higher quality materials).
- Adding identifying codes (such as bar codes) to each sign.
- Changing methods of sign procurement.
- Using contract forces for some or all of sign inspection and replacement work.
- Linking sign management to an agency's other asset management practices.

Guidelines prepared through the Minnesota Local Road Research Board (LRRB), with the participation of the MnDOT, are designed to assist cities and counties with traffic sign management. Best management practices in this document include (Montebello and Schroeder 2000):

- Acquiring a sign management system or, at a minimum, a sign inventory system. These tools can help an agency identify, plan, budget, and track needs for sign work.
- Use higher-grade reflective sheeting on more critical types of regulatory and warning signs (e.g., Stop, Yield, Stop Ahead, Yield Ahead, curve warnings) and wide-angle, microprismatic retroreflective sheeting at locations that benefit from these advantages: for example, where signs are at angles to traffic or must be located farther from the roadway.
- Consider increasing the size of signs at locations with a history of safety problems or where the visibility of typical-sized signs would be limited.
- Consider using signs that are larger and brighter than typical configurations in urban areas, where other activities compete for drivers' attention.
- Explore bulk purchases of sign sheeting (e.g., tying into state DOT or other agencies' purchasing contracts) to seek lower prices.

The LRRB guidelines also provide an example of a life-cycle cost analysis of different sign sheeting materials. The results illustrate that higher-grade retroreflective materials result in lower long-term costs because of longer life and therefore longer intervals between sign replacements. Moreover, these results do not include the increased benefits to road users owing to the higher initial and long-term retroreflectivity of superior grades of sign sheeting. The document also refers to a MnDOT life-cycle analysis comparing Type III and Type IX sign sheeting (these grades will be explained in the following section). The results showed that the materials cost accounted for a small percentage of total installation cost and that the higher-grade, higher-initial-cost Type IX sheeting was more cost-effective in the long term (Montebello and Schroeder 2000).

MEASURING ASSET PERFORMANCE

Managing Sign Retroreflectivity

Many things can happen to signs over time to degrade their visibility to transportation users. Causes of deterioration can include color fading, loss of materials durability (e.g., crack-

ing, curling, pitting, edge lifting, or blistering of sheeting), weathering, physical damage (e.g., from vehicle impact), obliteration resulting from dirt or sap accumulation, and vandalism. One important measure of a sign's ability to appear visible and understandable to road users, particularly at night, is its retroreflectivity. Retroreflectivity is the ability of a material to reflect light back toward its source. It is a property of the sheeting material used in the sign's fabrication. In the case of highway signs that are not lit by road or street lighting, the source of light is the vehicle headlamps; the retroreflective sign sheeting redirects light back toward the vehicle, where it is perceived by the driver's eyes. The coefficient of retroreflectivity compares the light returned to the driver's eyes (luminance) with the light from headlamps incoming to the sign's surface (illuminance). The units of measure are candelas per square meter per lux in the metric system, abbreviated $\text{cd}/\text{m}^2/\text{lx}$ (or, equivalently, $\text{cd}/\text{lx}/\text{m}^2$), and in U.S. customary units, candelas per square foot per footcandle, abbreviated $\text{cd}/\text{ft}^2/\text{fc}$ (or, equivalently, $\text{cd}/\text{fc}/\text{ft}^2$). The concept of retroreflectivity as it applies to highway signs is explained in the FHWA's *Roadway Delineation Practices Handbook* (Migletz et al. 1994).

At a series of 2002 FHWA-sponsored workshops on minimum levels of sign retroreflectivity, participants discussed their current practices in managing road signs. These approaches included periodic nighttime visual inspections (and in at least one agency, training of personnel in nighttime sign inspections), formal statewide sign replacement programs (two agencies), sponsored research to measure sign retroreflectivity as a basis for predicting sign service life (two agencies), mobile automated measurement of sign fabrication or installation dates as a basis for age-based management of signs (at least two agencies), and sign inventory systems (at least five agencies) (Hawkins et al. 2003).

Synthesis Survey Findings

The information provided by agencies on performance measurement of road signs is summarized in Figure 42 based on categories of performance factors similar to those described in chapter two. Many agencies reported measures of physical condition and the corresponding qualitative descriptors, asset age, conformance to current standards, and customer complaints. Three municipalities (Edmonton, Portland, and Tampa) reported using asset value as one of the measures of performance. The frequencies with which physical performance measures are addressed are shown in Figure 43.

The methods used by responding agencies to assess sign condition and performance are reported in Figure 44. Visual inspections and customer complaints are by far the most common methods used. Under "Other" methods, the city of Cape Coral, Florida, reported a commercial software package for work history; Oregon reported a roadside inventory on construction projects; and Edmonton mentioned a system condition report based on estimated quantity and age of

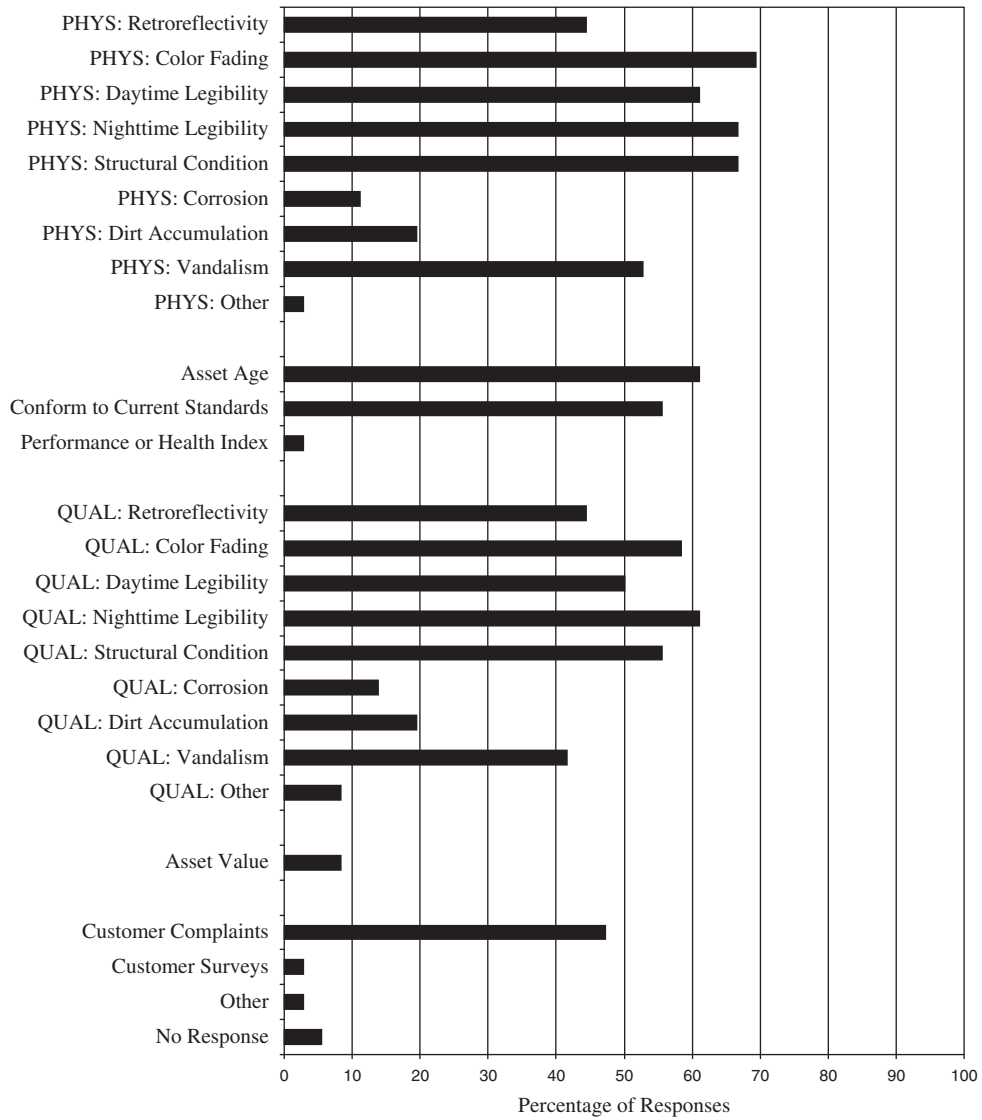


FIGURE 42 Measuring performance of road signs. PHYS = physical; QUAL = qualitative.

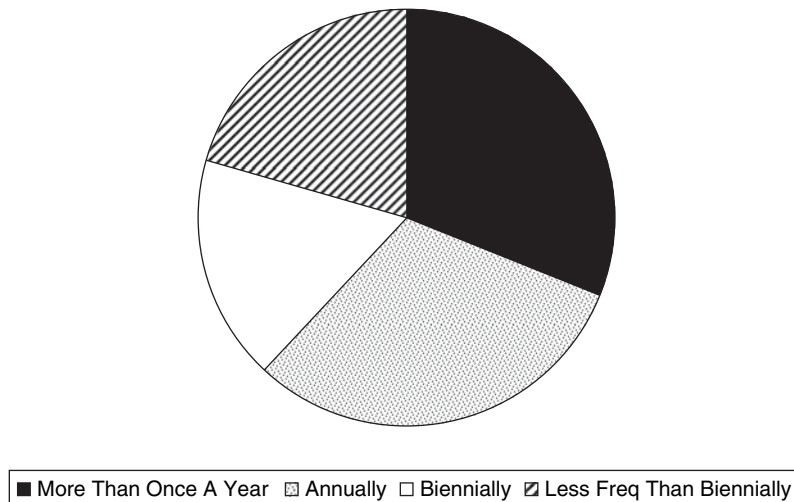


FIGURE 43 Frequency of physical condition assessments of road signs.

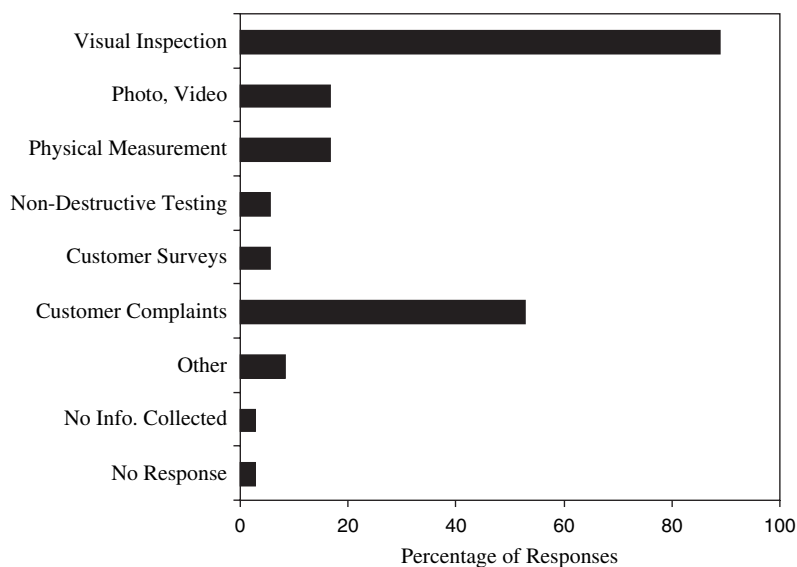


FIGURE 44 Data collection methods for sign condition and performance.

signs. Vermont noted that its use of video is only to complement on-site inspections.

Measuring Sign Retroreflectivity

The FHWA website on sign retroreflectivity includes information on sign retroreflectometers and reflectivity measurement (“Sign Retroreflectivity” n.d.). Because handheld retroreflectometers require multiple individual readings per sign, are time-consuming, expensive, and may require lane closures, MDOT has worked with the FHWA to develop a mobile evaluation of traffic signs system. This van-mounted system takes digitized pictures of a sign illuminated by a flash tube at a specified distance, and automatically computes its retroreflectivity. The van travels at highway speeds, enabling measurement of 300–400 signs daily. The flash tube is bright enough for measurements to be done in daytime. Benefits cited by MDOT include more reliable sign management and its positive implication for improved public safety, more complete data on sign performance over time, and cost-effectiveness as compared with manual retroreflectometer readings (Long 1997).

Other studies describe additional methods and tools used to evaluate and analyze highway sign visibility and retroreflectivity. For example, the luminance of the new types of microprismatic sign sheeting materials (Types VII, VIII, and IX) have been evaluated by computer simulation, using different assumed roadway geometric layouts, vehicle dimensions and headlamp illumination levels, sheeting retroreflectivity values, sign placement, and viewing distances (Bible and Johnson 2002). Researchers at the University of Iowa have used their Traffic Sign Simulator Facility to test the luminance requirements (luminance contrast and background luminance) for symbol signs. These experiments have considered several types of symbols, background luminance and

complexity levels, and luminance contrast values. Given these variables, the researchers have assessed driver recognition of sign meaning at two “comfort” or “confidence” levels (Schnell et al. 2004). Photometric modeling results do not always match the illuminance and luminance values measured in the field. A study of one such group of inconsistencies has revealed the source of the problem to be pavement glare (Carlson and Urbanik 2004).

Ketola (1999) has investigated the potential use of accelerated laboratory testing of retroreflective sign materials in lieu of outdoor testing. Although accelerated lab testing theoretically can yield several benefits, Ketola found that these procedures actually “are unreliable predictors of retroreflective sheeting durability, are more variable than expected, and are relatively expensive.” Outdoor evaluation is much more reliable and ideally should be conducted in a hot, wet climate (e.g., Miami, Florida); a hot, dry climate (e.g., Phoenix, Arizona); and a third climate as agreed on by the seller and purchaser. The data analyzed in this study suggest that a 36-month test period is a minimum requirement; shorter test periods may not give true indications of relative material durability. The author cautions, however, that even data from 36-month outdoor programs only address the question of minimum acceptable performance; they do not reliably predict the ultimate lifetime of sign materials (Ketola 1999).

It has also been recognized that the headlamp illumination data used in modeling sign performance is based on lamps and mountings used in laboratory tests, rather than lamps in natural conditions mounted on a vehicle. Researchers have therefore outlined a method to measure illuminance at different points representing typical sign locations, from headlamps mounted on automobiles, motorcycles, light trucks, vans, and heavy trucks. These measurements will be conducted without aiming or cleaning the headlamps (Chrysler et al. 2002).

Minimum Sign Retroreflectivity Standards

The FHWA has devoted considerable attention to methods, materials, and guidelines to promote more effective performance of traffic signs. A major focus of attention has been the retroreflectivity of highway signs, an issue that has been a high priority for the FHWA since the 1980s. Although this work has been driven, and continues to be strongly motivated, by the FHWA's interest in highway safety, it was given additional impetus by an Act of Congress in 1993. Congress addressed the issue that whereas the *MUTCD* required signs either to be lit at night or to be retroreflective, it did not specify the minimum retroreflectivity required. Congress directed the Secretary of Transportation to revise the *MUTCD* to include a standard for the minimum levels of sign retroreflectivity that must be maintained (Public Law 102-388 1993). (A similar requirement was also included for the minimum retroreflectivity of pavement markings; see chapter five.) Over the past several years, the FHWA, working with highway industry constituents and stakeholders, has devoted considerable effort in meeting this directive. There have been a number of steps and iterations in this process, which have been described in several FHWA web documents and published research sources. Among these are:

- An overview of FHWA efforts in retroreflectivity through the 1990s: "Overview of FHWA Efforts/Response," 2006: http://safety.fhwa.dot.gov/roadway_dept/retro/gen/overview_efforts.htm.
- *Minimum Sign Retroreflective Guidelines: Summary Report*, FHWA RD-97-074, 1997: <http://www.tfhr.gov/humanfac/97074/97074.htm>.
- FHWA Workshops on Nighttime Visibility of Traffic Signs, Summary of Findings, Report FHWA-SA-03-002 (Hawkins et al. 2003): http://safety.fhwa.dot.gov/roadway_dept/retro/sa03002/index.htm.
- General information on sign retroreflectivity, current through 2003, with a description of sign sheeting materials as of 2005: http://safety.fhwa.dot.gov/roadway_dept/retro/sign/sign_retro.htm.
- *Maintaining Traffic Sign Retroreflectivity*, Report FHWA-SA-03-027, 2003; Web version updated in 2005: http://safety.fhwa.dot.gov/roadway_dept/retro/sign/sa03027.htm.
- Examples of supporting research:
 - "Minimum Retroreflectivity for Overhead Guide Signs and Street Name Signs" (Carlson and Hawkins 2002).
 - "Comparison of Observed Retroreflectivity Values with Proposed FHWA Minimums" (Nuber and Bullock 2002).
 - *Updated Minimum Retroreflectivity Levels for Traffic Signs*, Report FHWA-RD-03-081 (Carlson and Hawkins 2003a): <http://www.tfhr.gov/safety/pubs/03081/index.htm>.
 - *Minimum Retroreflectivity Levels for Overhead Guide Signs and Street-Name Signs*, Report FHWA-RD-03-082 (Carlson and Hawkins 2003b): <http://www.tfhr.gov/safety/pubs/03082/index.htm>.
- "Developing Updated Minimum In-Service Retroreflectivity Levels for Traffic Signs" (Carlson et al. 2003).
- "Maintaining Traffic Sign Retroreflectivity," Notice of Proposed Amendments (NPA), *MUTCD, Federal Register*, July 30, 2004.
- "Maintaining Traffic Sign Retroreflectivity," Supplemental Notice of Proposed Amendments (SNPA), *MUTCD, Federal Register*, May 8, 2006.

The *Federal Register* SNPA is the most recent official step in the FHWA's response to the Congressional directive requiring specification of minimum levels of sign retroreflectivity. It responds to the comments received following the 2004 NPA, and has modified the NPA proposals in significant ways. Because the docket was still open as this report was being written, final rulemaking was not yet completed. In the SNPA, the FHWA is proposing an *MUTCD* Standard requiring agencies to use an assessment or management method to manage and maintain sign retroreflectivity at or above the minimums that will be defined in a new Guidance table to be included in the *MUTCD*. The proposed Guidance table bases recommended minimum retroreflectivity levels on the type of sign sheeting, sign color, size, and type of symbol or message. Sign sheeting types or grades are established using ASTM Standard D4956 and are explained in Table 12, based on information presented by the FHWA (Carlson and Hawkins 2003b).

The SNPA proposes five options to maintain sign retroreflectivity at or above the established minimum levels, but allows agencies flexibility to consider and use other effective methods. It also proposes eliminating the use of certain lower grades of sign sheeting for particular types of signs. There are many other details in the SNPA that (1) explain the background and rationale of the proposed *MUTCD* amendments; (2) describe practical steps that agencies can consider to comply with these provisions; and (3) address other matters, including questions and issues raised by stakeholders responding to the docket. Readers interested in these details should consult both the NPA and the SNPA ("Maintaining Traffic Sign Retroreflectivity" 2004; "Traffic Control Devices . . ." 2006).

When minimum levels of sign retroreflectivity are finally established, they will provide a basis for strengthened sign management in several ways:

- They will establish defined reference values for gauging service lives of different sign materials in terms of retroreflectivity, and projected replacement intervals.
- They will strengthen the basis for life-cycle comparisons of sign alternatives on the basis of performance (retroreflectivity) and long-term cost-effectiveness.
- The assessment or management method called for in the SNPA should strengthen an agency's sign-management capabilities, enabling it to track the condition of the sign inventory and anticipate replacement needs.
- Having the legal requirement as well as an assessment or management method in place to maintain minimum

TABLE 12
TYPES OF RETROREFLECTIVE SIGN SHEETING

ASTM Type Designation	Description
I	Medium-high-intensity retroreflective sheeting, sometimes referred to as “engineering grade,” and typically enclosed-lens, glass-bead sheeting. Typical applications for this material are permanent highway signing, construction-zone devices, and delineators.
II	Medium-high-intensity retroreflective sheeting, sometimes referred to as “super engineer grade,” and typically enclosed-lens, glass-bead sheeting. Typical applications for this material are permanent highway signing, construction-zone devices, and delineators.
III	High-intensity retroreflective sheeting that is typically encapsulated glass-bead retroreflective material. Typical applications for this material are permanent highway signing, construction-zone devices, and delineators.
IV	High-intensity retroreflective sheeting. This sheeting is typically an unmetallized, microprismatic, retroreflective-element material. Typical applications for this material are permanent highway signing, construction-zone devices, and delineators.
VII	Super-high-intensity retroreflective sheeting having the highest retroreflectivity characteristics at long and medium road distances as determined by the R_A (coefficient of retroreflection) values at 0.1° and 0.2° observation angles. This sheeting is typically an unmetallized, microprismatic, retroreflective-element material. Typical applications for this material are permanent highway signing, construction-zone devices, and delineators.
VIII	Super-high-intensity retroreflective sheeting having the highest retroreflectivity characteristics at long and medium road distances as determined by the R_A values at 0.1° and 0.2° observation angles. This sheeting is typically an unmetallized, microprismatic, retroreflective-element material. Typical applications for this material are permanent highway signing, construction-zone devices, and delineators.
IX	Very-high-intensity retroreflective sheeting having the highest retroreflectivity characteristics at short road distances as determined by the R_A values at 0.1° observation angle. This sheeting is typically an unmetallized, microprismatic, retroreflective-element material. Typical applications for this material are permanent highway signing, construction-zone devices, and delineators.

Source: Carlson and Hawkins (2003b).

retroreflectivity levels provides a solid incentive and capability for agencies to prioritize sign replacement needs and allocate limited resources effectively.

- The resulting better planning and programming of sign investment needs and the improved basis of resource allocation should contribute to greater safety and mobility of the road system to the benefit of the public.
- The improved visibility of signs expected to result from maintaining signs at or above minimums, coupled with the elimination or restricted use of lower-grade sheeting materials, will help older drivers, the numbers of whom are expected to increase.
- It is understood that continuing research may result in subsequent updates of these minimum-value retroreflectivity guidelines.

ASSET SERVICE LIFE

Synthesis Survey Findings

Information on service life was obtained in the study survey for three major components of sign installations: (1) the sign panels including sheeting, (2) roadside sign posts, and (3) overhead sign bridges. Responding agencies were asked also

to identify how they would determine service-life values. Responses to this question are shown in Figure 45.

Among the 50% of reporting agencies that identified at least one method, their emphasis was on collective agency knowledge, whether represented by their experience with road sign infrastructure (e.g., a database of observed historical service lives) or by the professional judgment of their staffs. Manufacturer’s data were also noted as a source of information, but to a lesser degree. Some agencies also reported the data used in life-cycle comparisons of different sign materials as a source of service-life information.

Comprehensive service-life data reported by agencies in the study survey are given in Table 13. Examples of the distributions of estimated service lives of sign components are shown in Figure 46 for sign sheeting, in Figures 47 and 48 for sign posts, and in Figures 49 and 50 for overhead sign bridges. The labels on the horizontal axis in these figures give the upper values of each range of service-life data. For example, if these labels are 0, 2, 4, 6 . . . , then the column labeled 2 shows the number of responses for estimated service life of zero to 2 years; the column labeled 4, the number of responses for estimated service life of more than 2 to 4 years; the column labeled

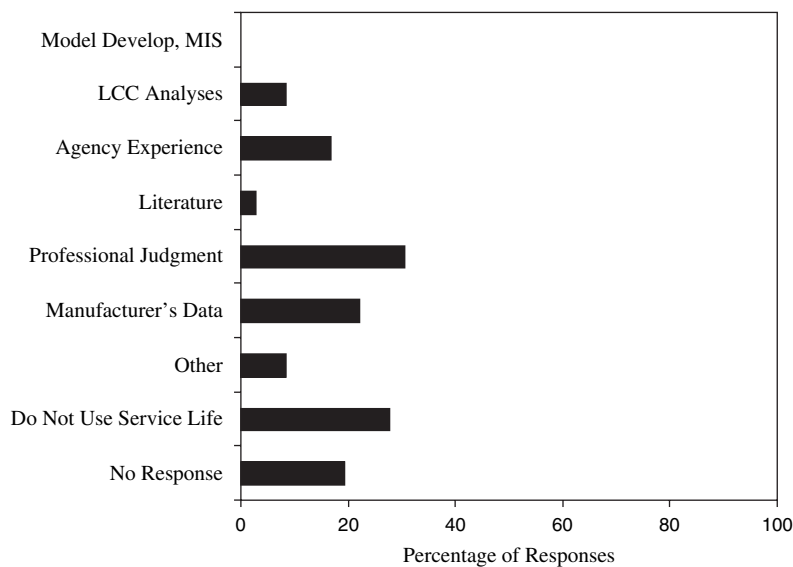


FIGURE 45 Sources for determining service lives of sign components. MIS = management information systems; LCC = life-cycle cost.

TABLE 13
ESTIMATED SERVICE LIVES OF ROAD SIGN COMPONENTS

Component and Material	No. of Responses	Minimum (Years)	Maximum (Years)	Mean (Years)	Median (Years)	Mode (Years)
Sign Sheeting						
All sheeting	17	7	20	11	10	15
Aluminum	3	7	40	19.8	11	—
Vinyl sheeting	2	5	7	6	6	6
Sign Posts						
Steel U-channel	10	10	40	18.0	15	10
Steel square tube	10	10	40	16.3	15	10
Steel round tube	3	15	40	23.3	15	15
Aluminum tube	1	—	—	10	—	—
Wood	3	15	20	16.7	15	15
Structural steel beam supports	2	25	30	27.5	27.5	—
Overhead Sign Bridges and Supports						
Steel sign bridge	12	10	50	30.8	30	30
Aluminum sign bridge	8	10	45	26.9	30	30
Overpass/bridge mounting	1	—	—	50	—	—

Notes: —, value is undefined for the particular distribution. When distribution is based on only one data point, its value is shown in the Mean column.



FIGURE 46 Estimated service life of sign sheeting undifferentiated by reflective performance or color.

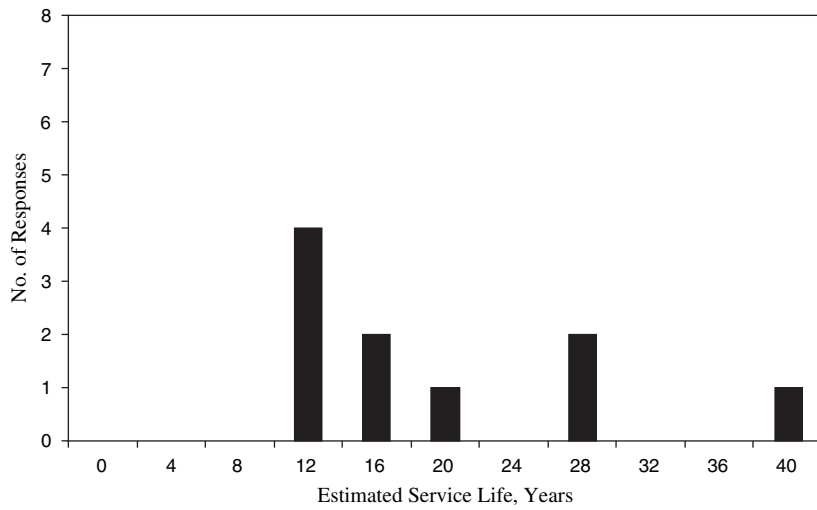


FIGURE 47 Estimated service life of steel U-channel posts.

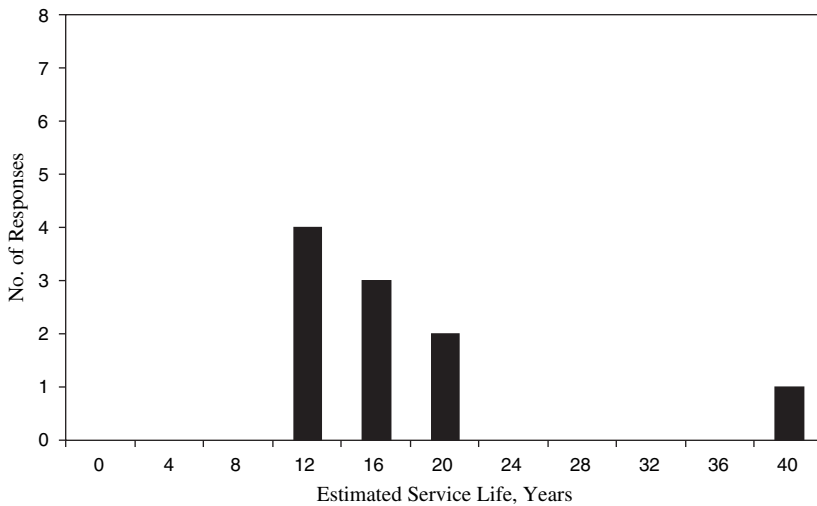


FIGURE 48 Estimated service life of steel square-tube posts.

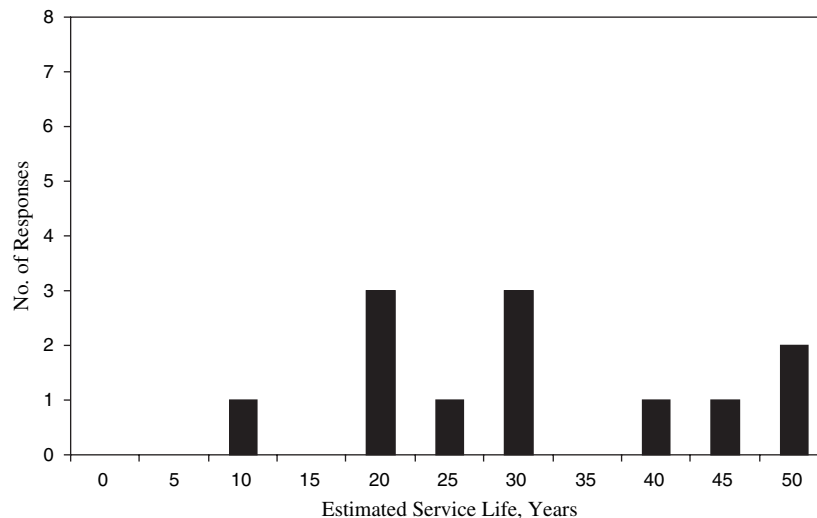


FIGURE 49 Estimated service life of steel overhead sign bridges.

6, the number of responses for estimated service life more than 4 to 6 years; and so forth. It should be noted again that the data in Table 13 and Figures 46 through 50 may be derived in part from the professional judgment of agency personnel.

In addition to the data in Table 13, agencies also provided more specific estimates of service life for different types of sheeting, differentiated by grade of retroreflectivity performance, color, or a combination of these attributes. Performance grade is given in terms of either the type of sheeting as defined by ASTM D4956 (see Table 12), or by product descriptions (e.g., high intensity, diamond grade). The additional service-life data from survey respondents are as follows:

- Maryland
 - Type I 7 years
 - Type III 10 years
 - Type IV 10 years
 - Type IX 10 years

- Pennsylvania
 - Type I 7 years
 - Type III 12 years
- Utah
 - Red 10 years
 - Brown 10 years
 - 40 Yellow 15 years
 - Green 30 years
 - White 15 years
 - Blue 30 years
- Vermont
 - Type I or II (red) 5 years
 - Type I or II (not red) 10 years
 - Type III and above 15 years
- High-performance or high-intensity sheeting
 - Kansas 10 years
 - New Brunswick 18 years
 - Saskatchewan 10 years
 - Tampa 12 years

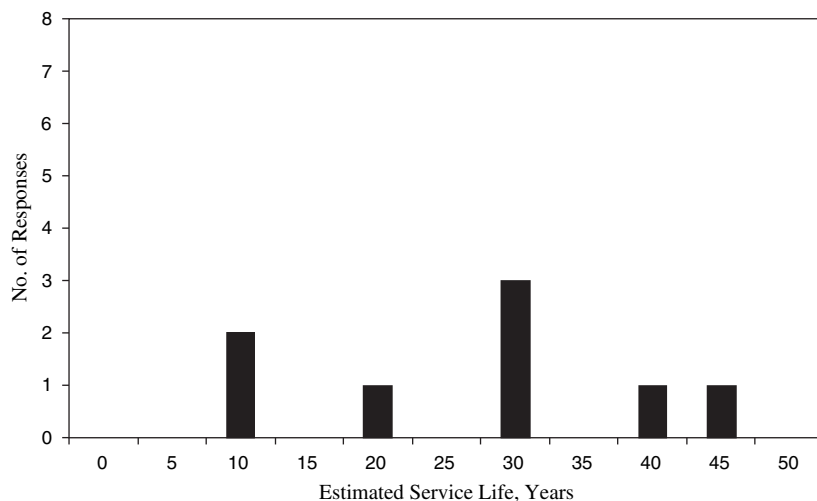


FIGURE 50 Estimated service life of aluminum overhead sign bridges.

- Diamond grade sheeting

Florida	7 years
Saskatchewan	12 years

The structural performance of sign supports has also been a topic of recent interest. Research has resulted in updated guidelines and specifications for structural supports (*Standard Specifications for Structural Supports . . .* 2001, updated in 2003; Fouad et al. 2003).

Other Data on Sign Materials and Service Life

- The FHWA has produced a two-page “Retroreflective Sheeting Identification Guide” (2005) that organizes sheeting by its two basic retroreflective surfaces: glass bead and prisms. Within each of these groups, the guide identifies the ASTM grade, associated manufacturer and brand name and series number, and relevant notes.
- The Minnesota LRRB guidelines include a sign sheeting matrix that identifies, for each type of sheeting, the retroreflective mechanism (e.g., different types of lenses or beads, or microprismatic), estimated cost, anticipated service life, life-cycle costs, initial retroreflectivity, and advantages and disadvantages. The estimated service lives are as follows (Montebello and Schroeder 2000):
 - Type I: 5–7 years
 - Type II: 5–7 years
 - Type III: 14 years
 - Type IV: Not available
 - Type VII: Not available
 - Type VIII: 15–20 years
 - Type IX: 15–20 years
- The *Federal Register* SNPA cites data on typical service life for selected sheeting types based on a 1996 FHWA study (“Traffic Control Devices . . .” 2006):
 - Type I: 7 years
 - Type III: 10–12 years

The SNPA proposes eliminating the use of Type I sheeting for warning signs and for legends on ground-mounted guide signs. Types I, II, and III would be unacceptable for legends on overhead signs. These provisions are intended to help older drivers (Carlson et al. 2003; “Traffic Control Devices . . .” 2006).

- The Kansas DOT lists minimum coefficient of retroreflection values by sheeting color, ranging from 200 cd/m²/lx for white to 9 cd/m²/lx for brown (*Special Provision . . .* 1990). The Delaware DOT also specifies minimum coefficients of retroreflection according to color, as well as observation and entrance angles (functions of the distance between sign and observer and the offset distance to the sign from the travel lane with the sources of headlamp light) (*Traffic Control Manual* n.d.). Other DOT guidelines that were reviewed specify the grade of

sheeting required by sign classification, but do not include a minimum retroreflectivity. The Minnesota LRRB guidelines for local government agencies include minimum retroreflectivity recommendations in a series of tables based on type and color of sign background and legend, type of symbol, size of sign, and traffic speed (Montebello and Schroeder 2000).

- The Minnesota LRRB guidelines include an example of life-cycle cost analysis of sign sheeting materials. The results demonstrate the cost-effectiveness of better grades of sheeting (Montebello and Schroeder 2000). The potentially lower life-cycle cost of using more durable grades of sheeting is also cited as a rationale in support of the FHWA’s SNPA minimum retroreflectivity proposals (“Traffic Control Devices . . .” 2006).
- Materials and dimensions for sign posts are also included in the agency guidelines listed previously. Current practices and state of knowledge for sign supports, particularly posts and structures for larger signs, have been updated in *NCHRP Report 494* (Fouad et al. 2003). Innovation in smaller sign supports is illustrated by Caltrans’ field experiments with a new, reusable sign post foundation that reduces exposure of maintenance crews to traffic when replacing damaged posts (White et al. 2000). A life-cycle cost analysis of alternative materials has been illustrated based on data from the Kansas DOT (Raman et al. 2005).
- The North Carolina DOT has a study underway to model the durability of road sign performance as a basis for predicting sign replacement needs. The agency has collected data on the degradation in sign retroreflectivity, together with sign location (GPS), sign message, type and color of sheeting, sign age, and a photograph of the sign. Threshold levels of retroreflectivity have been developed by type of sheeting and sign color as a basis for determining end-of-service life and need for replacement. From these data, the North Carolina DOT has estimated the rate of deterioration by sheeting type and color. The modeling approach is a simulation of the in-service inventory of signs to predict the number of deficient signs each year. This result can then be translated to a projected cost of sign replacement. The analysis is performed in a spreadsheet (Harris et al. 2005).
- A facility for nationwide calibration of retroreflectometers has recently been established at the National Institute for Standards and Technology. The Center for High Accuracy Retroreflective Measurements will standardize and certify the measurement of retroreflection on reference artifacts that can be distributed to agencies for calibrating their own retroreflectometers (*NCHRP Research Results Digest 297 . . .* 2005). These certified national calibration standards are a necessary step in improving the accuracy in readings among different retroreflectometers; ensuring an accurate and reliable implementation of proposed minimum retroreflectivity

levels for signs; and contributing to the public safety on the nation’s road system.

Determining Current Asset Status

To apply the service-life concept in asset management a method is needed to determine where an asset is in its service life—that is, how much life is consumed, and how much remains. Agencies were presented with a number of ways to determine the current status of an asset regarding its service life, and asked to rank each method by relevance to their agency. The results are shown in Table 14. Note that two instances of tie values occurred in this particular ranking process. The “Other” factors in Table 14 included the following:

- Check sticker dates on the signs (Colorado Region 4);
- Use commercial software to track work history (Cape Coral, Florida); and
- Some districts look at the nighttime legibility of their signs to determine service life (Oregon).

On the related issue of identifying the extension in service life owing to maintenance, none of the reporting agencies responded affirmatively.

INFORMATION TECHNOLOGY SUPPORT

Synthesis Survey

Agencies participating in the study survey identified their key IT capabilities as shown in Figure 51. More than half of the agencies have an inventory of road sign assets accompanied by information on location. Asset age, maintenance and inspection data, and anticipated service-life information were also mentioned by a number of respondents. No strong

distinctions in the findings represented by Figure 51 were observed among different levels of government. By comparison, responses to the January 2000 AASHTO survey reported by the FHWA (Hensing and Rowshan 2005) indicated that 24 of 39 agencies (62%) had an inventory of signs, and most of these updated their inventory by either manual surveys or semi-automated methods.

Agencies characterized their IT systems for road signs as shown in Figure 52. The greatest number of responses pertained to broad-based management systems (such as maintenance management systems) followed by workbooks or spreadsheets, sign management systems, and simple programs. “Other” options mentioned by agencies included a videolog and use of crew-leader log books to record data initially, with subsequent transfer to electronic format. The agencies that reported using a road sign management system or a maintenance management or transportation infrastructure asset management system that includes road signs are listed here.

- Road Sign Management System
 - Arkansas DOT
 - Michigan DOT
 - South Carolina DOT
 - Vermont AOT
 - Colorado DOT Region 2
 - Saskatchewan Highways and Transportation
 - Dakota County, Nebraska
 - City of Tampa, Florida.
- Maintenance or Asset Management System That Includes Road Signs
 - Florida DOT
 - New Mexico DOT
 - North Carolina DOT
 - North Dakota DOT

TABLE 14
RANKING OF METHODS TO DETERMINE WHERE ROAD SIGN ASSETS ARE IN THEIR SERVICE LIVES

Rank	Factor
1	Monitor condition of asset on a periodic schedule
2	Assets are repaired or replaced as soon as they fail without regard to service life
3	Compare current age of asset with maximum age that defines service life
4	Monitor condition of the asset occasionally
5	Service life is often determined more by functional obsolescence than by wear and tear
6	Assets are replaced on a preventive maintenance schedule without regard to where they are in their service life
7	The agency does not use/does not monitor service life for this type of asset
8	Apply deterioration models to estimate where the asset is on “the curve”
8	Other

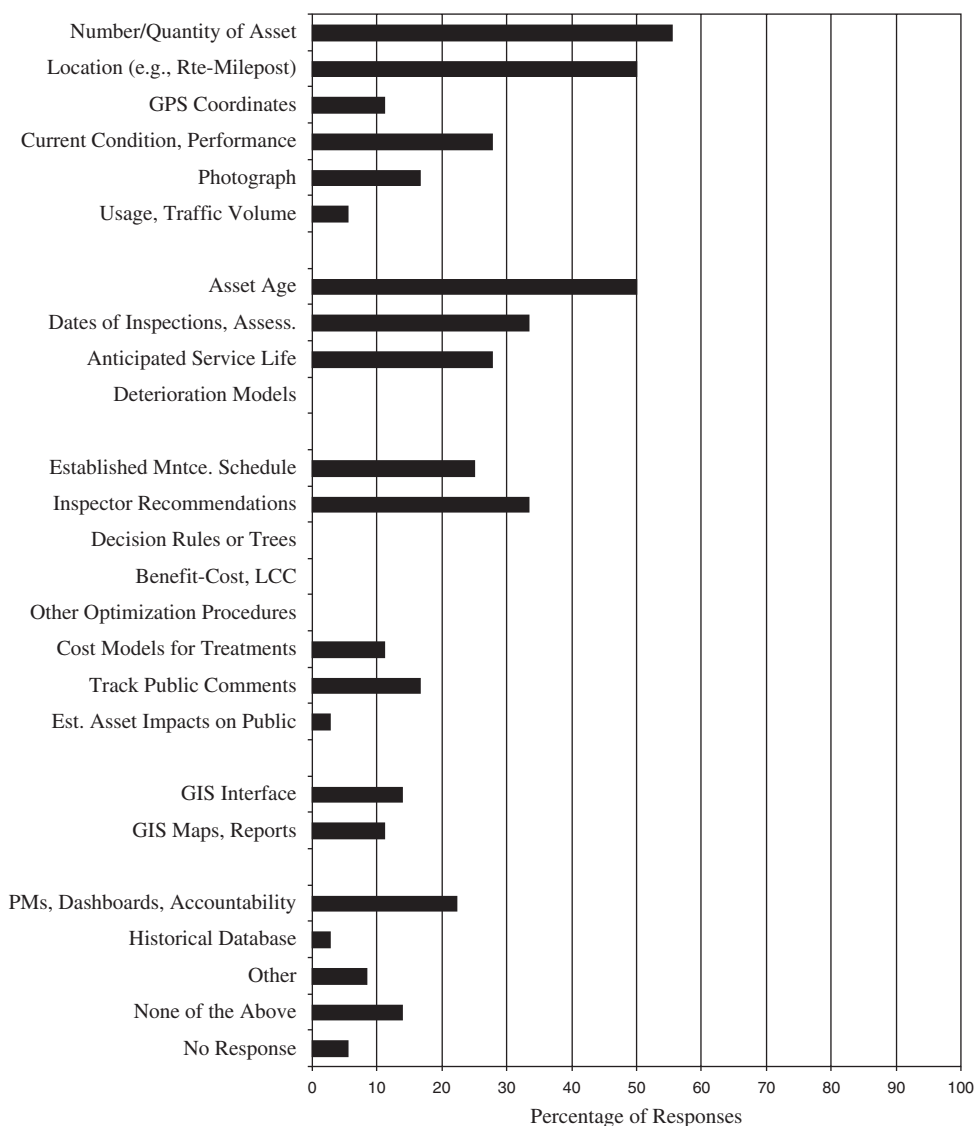


FIGURE 51 IT capabilities to help manage road signs. GPS = global positioning system; LCC = life-cycle cost; GIS = geographic information system; PMs = performance measures.

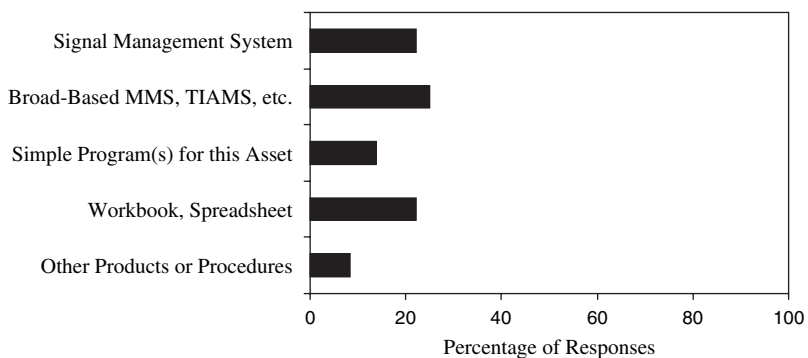


FIGURE 52 Types of analytic tools to support road sign management. MMS = maintenance management system; TIAMS = transportation infrastructure asset management system.

- Utah DOT
- Colorado DOT Region 5
- New Brunswick DOT
- City of Cape Coral, Florida
- City of Portland, Oregon.

Two agencies mentioned partial implementations of sign management programs and databases. In one instance, an agency-developed program was adopted by some, but not all, regions. In the other case, sign management districts with independent responsibility for their respective sign inventories have developed and use their own IT programs and databases.

Other Data on Sign-Related Systems

In 2002, at a series of FHWA-sponsored workshops on minimum levels of sign retroreflectivity, participants discussed their current sign management practices and tools. At least five agencies mentioned sign inventory systems (and three were contemplating such systems), which are typically linked to geographic information systems (GIS) data. One agency automated its data uploading using handheld personal digital assistants (PDAs). Although these systems generally lacked information on sign retroreflectivity, they could be modified to include such information in the future (Hawkins et al. 2003).

NCHRP Project 4-29, Selection of Materials to Optimize Sign Performance, has been completed and an interim report is available at this time.

The objectives of this project are to develop a simple, user-friendly decision-making tool that will aid transportation agencies in the selection of retroreflective materials for traffic signs, based on roadway conditions and other factors that most critically affect sign performance. Appropriate selection must also take into account sign design and placement decisions. The decision-making tool should be appropriate for use by traffic authorities at the local, county, regional, state, and federal levels and by consulting engineers. It should be suitable for an agency's sign installation and management functions and provide procedures for policy development, new sign requests, system upgrade decisions, and safety analyses.

— Source: "Selection of Materials . . ." 2006

The Minnesota LRRB guidelines describe data elements that can be included in a sign inventory system for local governments.

- Basic information—sign location within the highway system, position with respect to the road (e.g., left, right, and overhead), *MUTCD* or other identifying code, current sign condition, and maintenance history with dates.
- Additional technical information—sign size, installation date, type of sheeting, type of substrate or backing, type of post or support, condition of post or support, sign orientation (cardinal direction in which the sign

faces), and speed limit of the roadway on which the sign is located.

- Detailed technical information—sign offset (from the edge of the pavement), height, retroreflectivity data, identification of inspector, sign identification number, photolog or videolog of sign, comments or annotations regarding the sign, its condition, etc., and any other reference numbers needed (e.g., district location, applicable contract numbers, and plan numbers).

If the provisions of the current FHWA SNPA become a Standard within the *MUTCD*, they will require agencies to apply management methods to maintain sign retroreflectivity at or above the specified minimums ("Traffic Control Devices . . ." 2006). These methods may well include some type of IT data or management system support.

KNOWLEDGE GAPS AND RESEARCH NEEDS

Synthesis Survey

The many comments received in the study survey regarding knowledge gaps and research needs in sign management fell into several groups.

- The topic mentioned most often in these comments was the need for a sign management inventory system, and the importance and difficulty of keeping this inventory up to date once the initial database is developed. At least eight agencies referred to this issue; some are now actively developing such systems and databases.
- Two agencies referred to the difficulty of gaining attention for sign management issues. Oregon observed that signing is a relatively low-budget, roadway item; therefore, there is little incentive to develop a management system when districts do a reasonably adequate job of maintaining their signs based on field judgments. Utah noted a lack of a perceived need for sign management, as opposed to "fix what's knocked down."
- A few agencies mentioned shortcomings of retroreflectorometer readings (too variable) to use in determining sheeting life and the desire for a low-cost, efficient method to evaluate sign retroreflectivity.
- Several agencies identified the need for a more comprehensive understanding of the degradation in sign legibility and retroreflectivity over time as a function of several variables, including location, orientation, sunlight exposure, sheeting type, climate (the northern U.S. climate was mentioned specifically by Saskatchewan), aging, and vandalism. A related comment mentioned the need for survival curves that capture these relationships.
- At least two agencies mentioned the desirability of better understanding the actual needs of drivers with respect to sign condition and performance.
- Several gaps in technical knowledge and a desire for related research were noted by agencies:

- To understand the benefit–cost and comparative service lives of different types of sign sheeting, such as high-intensity sheeting versus the new prismatic sheeting.
- A related comment observed that new products emerge continually and it may be difficult to test service life of sheetings that will not have failed before new models become available.
- To understand the effect of a new wood preservative treatment (alkaline copper quaternary, or ACQ) on retroreflective sheeting.
- To understand the effect of deicing materials on retroreflective sheeting.

Research Needs Identified in the Literature

The 2002 FHWA workshops on sign retroreflectivity identified several unanswered questions. Although some have been implicitly addressed in the recent FHWA SNPA, at least in the interim, they will likely remain of interest to the highway community even as research continues. Other questions reflect unmet research needs. The complete list of questions compiled at the workshops is as follows (Hawkins et al. 2003, chapter 3):

What is the impact of ambient lighting on the visibility of signs? Can intersection and street lighting provide sufficient luminance without retroreflectivity?

Should minimum levels represent best case, typical case, or worst case scenarios?

How will agencies develop accurate information on sign sheeting service life as a function of sheeting type, exposure direction, color, and other factors? What is the impact of product lines changes on previous data about sign service life?

What driver characteristics are of greatest concern? How does driver age relate to the types of vehicles driven? How many older drivers actually drive at night?

How can agencies stop the trend of headlamps directing less illumination toward signs? It is worth noting that the participants felt that it is not appropriate for agencies to assume the increased costs of improving the infrastructure that result from changes in automobile manufacturing standards. Headlamp performance changes every few years while signs that agencies install are intended to last at least 7–10 years, often longer. Participants felt that headlamp changes that impact traffic control device performance should be limited or better coordinated with the transportation agencies. A few participants even suggested that automobile manufacturers should provide funding for traffic control device improvements while changes are made.

Workshop participants also expressed a desire for the FHWA to develop performance-based information that would more strongly link nighttime sign visibility to reduced nighttime crashes. Discussions with the FHWA indicate that they are proceeding with such a research project.

The TRB Millennium Paper on signing and marking materials cites materials performance, in both durability and

utility (i.e., to motorists), as a hallmark of future state of the art. Examples of materials that are anticipated to become more widely used in road signs are fluorescent materials, wet-reflective materials, and new materials such as corner-cube sheeting and all-plastic sign panels (Kalchbrenner 2000).

Ongoing testing of signage products is carried out by the National Transportation Project Evaluation Program (NTPEP), sponsored by AASHTO and its member agencies. NTPEP conducts laboratory and field tests on various materials at sites in four climatic zones around the country, and publishes results on performance for participating agencies (Thomas and Schloz 2001). As of 1999, outdoor testing of sign sheeting through NTPEP had been conducted in Arizona, Louisiana, Minnesota, North Carolina, and Virginia (Ketola 1999). NTPEP results are expected to be used increasingly by AASHTO member agencies when selecting signage materials and products.

A second Millennium Paper on vehicle user characteristics addresses human factors issues at both ends of the driver age spectrum, as well as general driver comprehension of, and response to, traffic control devices. With respect to asset management, the key human factors issues are those associated with older drivers. These knowledge gaps and research needs are in the following areas (Ranney et al. 2000):

- Data on the impairments that older drivers may have with driving-related vision, attention, cognition, and physical impairments, and the distribution of these characteristics among the elderly population.
- Epidemiological studies of age-related medical conditions that potentially increase the risk of collision, and research using simulation and instrumented vehicles to establish older-driver performance as affected by these medical conditions.
- Further applications of simulation and instrumented vehicles to determine how older-driver performance is affected by ITS components, and to what degree these innovations are accepted and accommodated by older drivers.
- Related topics that need to go into older-driver education programs.

This Millennium Paper observes that sign specifications and elements such as letter heights in the *MUTCD* have traditionally been based more on road design speed than on driver needs. Moreover, such standards have been calibrated to the performance of young drivers during daylight; when the needs of older drivers in nighttime are considered, recent studies suggest that revisions in current standards may be needed. Moreover, computer models that are now used to predict driver reaction to signs, particularly those signs that require drivers to act before a sign is reached, need to be updated to predict the retroreflectivity required for nighttime visibility and sufficient time to respond across the driver

population, including older drivers (Ranney et al. 2000). (Some of this research has been accomplished in support of the FHWA's SNPA for minimum retroreflectivity levels; but again, ongoing interest in this topic and continuing research are likely in the future.) Research is also needed on driver comprehension and improved design and the use of signs that are not now well understood, such as certain symbol signs that have replaced word signs and intersection schemes combining geometric layout, signage, and delineation that

vary from one another and may cause driver confusion (Ranney et al. 2000).

Among the top 16 research priorities identified by the TRB Pedestrians Committee, one research problem statement addressed signs: "Evaluation of MUTCD Signing, Markings, and Traffic Signals for People with Visual Impairments, Children, and Elderly Adults" (*Transportation Research Circular E-C084* . . . 2005).

PAVEMENT MARKINGS

OVERVIEW

Pavement markings encompass lane striping, raised lane markers, and painted symbols and messages on the road surface that provide information and warnings to road users. Pavement markings help to channel and guide traffic flow in an orderly, safe stream. They play an important role in traffic separation when it is necessary to identify distinct lanes or crossings for particular modes; for example, bus-, taxi-, automobile-, or truck-only lanes; bicycle lanes; and pedestrian crosswalks. They are used, often in conjunction with warning signs and signals, where particular attention is demanded of motorists; for example, at major crosswalks; when advance alert is needed approaching intersections, rail crossings, changes in speed, required stops, and so forth; and for informational guidance in school zones, in areas with elderly, disadvantaged, or handicapped populations; and for turning movements in intersections of multilane roads.

Pavement markings are applied using a variety of materials, including various types of paints, thermoplastics, reflective tapes, and raised markers. Because they are applied on top of the pavement surface, their performance is judged in several ways; for example, by their visibility in daytime, nighttime, under various weather conditions, and against the background color and texture of the pavement itself; by their durability—their ability to withstand damage resulting from traffic, weather, and actions such as snow plowing; and their skid resistance and avoidance of impediment to any form of traffic, including cyclists and pedestrians. Because paints may contain volatile organic compounds (VOCs), there may also be an environmental aspect to their application. Pavement marking materials may be applied by hand-operated machines or mechanized vehicles, and may entail preparatory work. For example, raised markers or reflective tape may require prior grooving or machined insets in the pavement surface to recess the markings, protecting them from snow plows. Thicker thermoplastics can be used to form rumble strips, providing visual as well as aural warnings of vehicles leaving the travel lane.

It is estimated that in the year 2000, state and local transportation agencies in the United States and the 13 Canadian provinces and territories spent more than \$1.5 billion on pavement markings. On a unit dollar-per-mile basis among levels of government, U.S. state DOT expenditures are the highest, given their greater inventory of multilane freeways

and highways. State agencies also use the greatest variety of marking materials, including the more expensive durable markings and pavement markers (Migletz and Graham 2002).

Agencies participating in the survey conducted for this study ranked the transportation objectives that are served by pavement markings in priority order, as given in Table 15. Meeting these objectives calls on agencies to observe standards, technical recommendations, and guidelines from a variety of sources. Figures 53 and 54 present agencies' judgments of those sources of guidance that are the important drivers of engineering and management decisions regarding pavement markings. These results are shown for two key aspects of asset management: new construction and installation, and maintenance and rehabilitation, respectively. The importance of national standards, and especially of individual agency policies, standards, guidelines, and procedures, is evident in these results.

Nationally recognized U.S. policies and standards for pavement markings are found in Part 3 of the *Manual on Uniform Traffic Control Devices* (2003). A summary of the *MUTCD* warrants for the use of longitudinal pavement markings is given in Table 1 of *NCHRP Synthesis of Highway Practice 306* (Migletz and Graham 2002). These standards, guidelines, supporting discussions, and allowable options specify the functions and accepted meanings of recognized markings; requirement for standardized application, materials, colors, widths, patterns, locations, and lengths or dimensions of usage; and illustrations of examples. The *MUTCD* also recognizes other sources, including legal citations (in this case, *MUTCD* Section 1A.11, which cites 23 CFR Part 655, Subpart F, Appendix regarding color specifications for retroreflective sign and pavement marking materials), and supporting documents by the FHWA (discussed here) and AASHTO (*A Policy on Geometric Design* . . . 2004).

One of these referenced sources is the FHWA's *Roadway Delineation Practices Handbook* (Migletz et al. 1994), which supplements the policies and standards of the *MUTCD*. This *Handbook* describes the devices and materials used in pavement markings and other delineators. It presents findings on their installation, performance, maintenance, and removal, drawing on the experience of agencies at different levels of government, field trials, laboratory experiments, and ongoing research. The FHWA *Handbook* includes guidelines for

TABLE 15
PRIORITY OF TRANSPORTATION OBJECTIVES SERVED
BY PAVEMENT MARKINGS

Rank	Factor
1	Public safety; accident and accident risk reduction
2	More efficient travel; maintain intended flow and operating speed; reduce travel time
3	Preservation of the existing road infrastructure; reduced agency life-cycle costs
4	Comfort and convenience of the traveling public (motorists, pedestrians, cyclists)
5	Road aesthetics and appeal

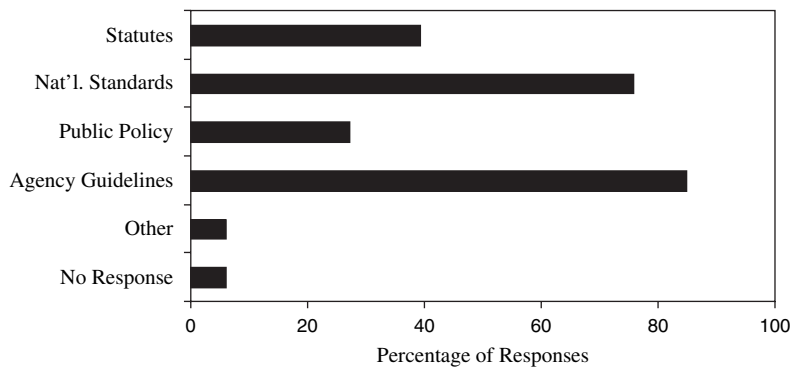


FIGURE 53 Technical management guidance for new installation of pavement markings.

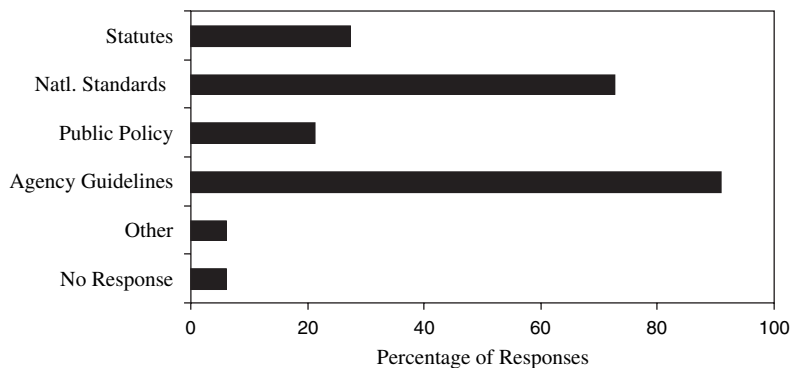


FIGURE 54 Technical management guidance for maintenance of pavement markings.

conducting engineering economic evaluations of competing pavement marking materials. Its information will be cited in several upcoming discussions. The FHWA has also compiled guidelines for the use of raised pavement markers (RPMs) (*Guidelines for the Use of Raised . . .* 1998).

The FHWA is in the process of developing minimum retroreflectivity requirements for pavement markings, in response to a Congressional mandate (Department of Transportation and Related Agencies Appropriations Act 1993). Threshold values that could serve as candidate proposals have been developed through research (e.g., Migletz and Gra-

ham 2002). However, the FHWA has signaled its intention to issue an NPA for minimum levels of pavement marking retroreflectivity only after the corresponding rulemaking process for sign retroreflectivity is completed (“Traffic Control Devices . . .” 2006; refer to discussion in chapter four).

Individual agencies have likewise developed guidance based on their particular needs and experience. This guidance should be viewed as supplementary to the policies and standards of the *MUTCD* and may appear in general highway design manuals, including bikeway design. Some agencies have developed specific pavement marking manuals, Texas

(*Signs and Markings Manual 2006*) and Wyoming (*Pavement Marking Manual 2002*), intersection design guides that include markings (Florida DOT 2000), and separate guidelines for pedestrian crosswalks Utah (Cottrell and Mu 2004) and Vermont (*Guidelines for the Installation . . . 2004*). A manual for pavement markings is under development for cities and counties in Iowa (Andrie et al. 2001). Agencies may also issue unpublished guidelines in the form of internal agency policies and directives. The focus of these guidelines is typically on criteria for the installation of pavement markings and other delineators (e.g., road class, average daily traffic, and pedestrian traffic) and techniques and materials that have been found to work well in the particular jurisdiction. Experience with the service life of materials and maintenance replacement cycles may or may not be included in these agency documents; however, if so, it is typically in general form.

MANAGEMENT PRACTICES

Synthesis and AASHTO–FHWA Survey Findings

Among the agencies responding to the synthesis survey, maintenance of pavement markings is accomplished as shown in Figure 55. A different survey of local governments in Iowa showed a similar pattern among small and large cities, although Iowa’s participating counties reported that they rely on contractors virtually 100% of the time, as indicated in Table 16 (Andrie et al. 2001). Other aspects of asset management practice are revealed through agencies’ methods of budgeting for preservation and maintenance of pavement markings, and their approaches to preserving and maintaining pavement markings once in service.

Survey results obtained in this study for the budgeting methods used by agencies are shown in Figure 56. Explanations of the abbreviated budgeting process descriptions in this figure are given in chapter two. Because agencies could select multiple choices, the percentages in Figure 56 do not sum to 100%. Addressing their methods of budgeting, the largest number of responding agencies at all levels of government chose the “previous budget plus adjustments” option as best describing their processes, although other options were also well represented in the responding agencies’ results. The

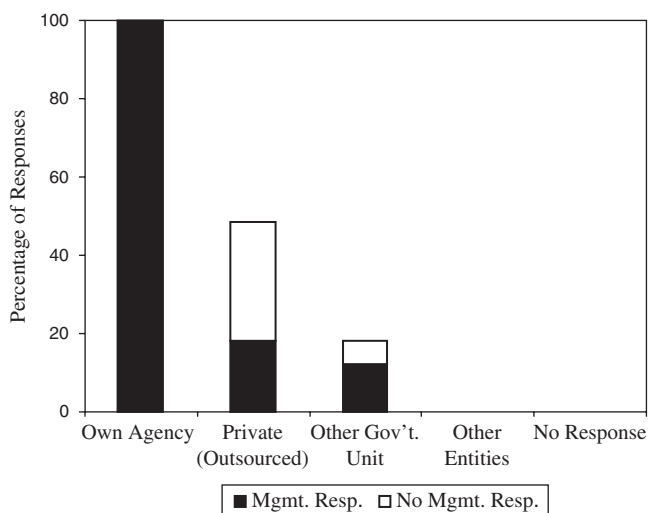


FIGURE 55 Responsibility for maintaining pavement markings once in service.

selections in Figure 56 were often specified in combination with one another.

The survey results in Figure 56 show that the number and target performance of assets are used to a degree in budgeting, but that they are not necessarily the primary drivers of budget processes among survey respondents. Approaches based on Target [Asset Performance] Drives Budget and Budget [Asset Performance] Drives Target each were identified in about one-third of the responses, and those based on Percent of Inventory Budgeted Annually, in less than 20% of responses. By contrast, methods based on Adjustments to the Previous Budget were selected in almost one-half of the responses, whereas those that involve Staff Professional Judgment, Political Priorities, and Citizen Demands, in approximately one-third of responses (bearing in mind that agencies could select more than one approach). The general thrust of these results is complemented by a January 2000 AASHTO survey of roadway safety hardware (Hensing and Rowshan 2005). When asked whether asset inventory and asset condition were used as the basis of funding allocation, 9 of 39 states (23%) responded affirmatively for pavement markings inventory, and 11 of 39 (28%), for pavement markings condition—again, well less than a majority in each case.

TABLE 16
RESPONSIBILITY FOR REPLACING MARKINGS AMONG LOCAL GOVERNMENTS IN IOWA (percent of responses)

Local Jurisdiction	In-House Staff	Contractors	Other Groups	No Response
Small Cities	72	21	2	5
Large Cities	68	24	8	0
Counties	0	95	0	5

Notes: Small cities, those with populations of less than 5,000; large cities, those with populations of greater than 5,000.
Adapted from data in Andrie et al. (2001).

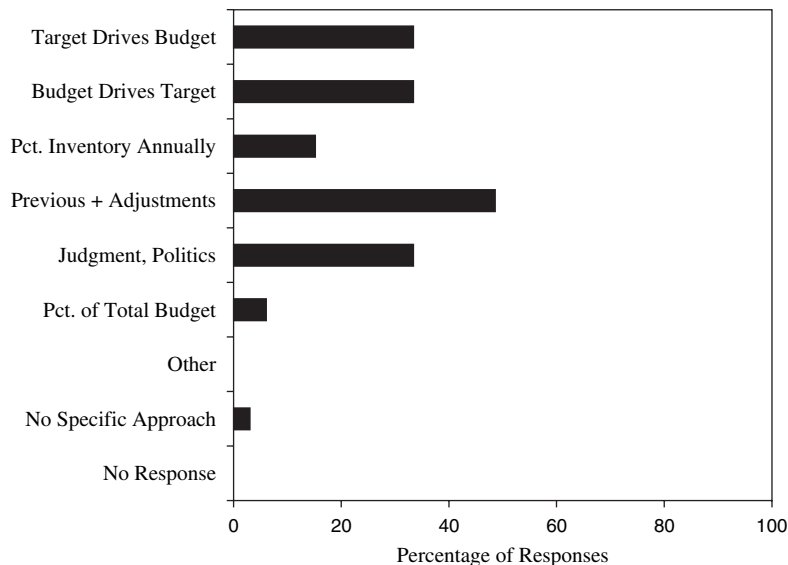


FIGURE 56 Annual budgeting method for maintenance and rehabilitation of pavement markings.

A related question in the AASHTO survey asked whether state DOTs have a separate budget line item for *maintenance* of pavement markings; 28 of 39 agencies (72%) responded affirmatively. Although there was no corresponding question for the budgeting of *new* pavement marking installations, the survey did address tracking and updating of asset inventory. These additional responses are reported in a later section of this chapter.

Agencies often described their approaches to preservation and maintenance as well in terms of multiple selections of the items shown in Figure 57. A review of the survey responses showed that different preservation and maintenance approaches were often associated with different pavement marking materials.

Materials Usage

Agencies use a number of materials for pavement markings. *NCHRP Synthesis 306*, for example, identifies 16 types of materials used by U.S. state DOTs, with subsets of these applied by U.S. cities and counties and Canadian provinces and territories (Migletz and Graham 2002). *NCHRP Report 392* lists the major types of markings with their estimated service lives, advantages, disadvantages, and levels of VOCs (see Andrady 1997, Table 1). Table 17 identifies comparative DOT usage of a number of marking materials based on information in *NCHRP Synthesis 306*, as summarized in *NCHRP Report 484* (Hawkins et al. 2002). Local government practices in the United States show a somewhat narrower range of materials selections, but nevertheless a mix of products.

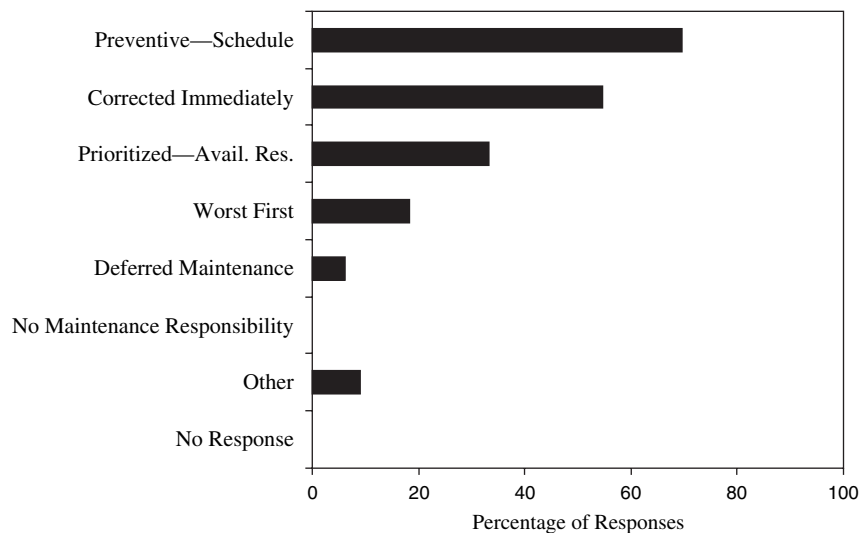


FIGURE 57 Approach to maintaining and preserving pavement markings.

TABLE 17
PAVEMENT MARKING MATERIALS USED BY STATE DOTs

Longitudinal Pavement Marking Material	No. of States ^a	Using Material ^b
Water-Based Paint	33	89%
Thermoplastic	30	81%
Preformed Tape—Profiled	20	54%
Preformed Tape—Flat	19	51%
Epoxy	19	51%
Solvent-Based Paint	13	35%
Methyl Methacrylate	9	24%
Thermoplastic—Profiled	9	24%
Polyester	5	14%
Polyurea	2	5%
Cold-Applied Plastic	1	3%

^aA total of 37 state DOTs responded to the survey.

^bMultiple responses were allowed; totals therefore sum to more than 100%.

Adapted from data in Migletz and Graham (2002), as reported by Hawkins et al. (2002).

For example, local governments responding to the synthesis survey indicated a number of materials used, including non-epoxy and epoxy-based paint, thermoplastic, cold plastic, and raised pavement markers. Findings reported in *NCHRP Synthesis 306* documented a number of paints, durable markings, and pavement markers used by U.S. counties and cities responding to that study’s survey; the results also showed exclusive use of solvent-based paint among the five Canadian provinces reporting (see Migletz and Graham 2002, Table 31). Statistics on the materials most frequently used (i.e., more than 50% of the time) by local governments in Iowa are shown in Table 18 (Andrie et al. 2001).

Based on the findings in *NCHRP Synthesis 306* and other studies, the general trend in the United States across all levels of government is toward wide use of water-based paint and thermoplastic, with significant use of other materials (mostly by states, and to a lesser degree by counties, then by cities), declining use of solvent-based paints, and the continuing

TABLE 18
PAVEMENT MARKING MATERIALS MOST COMMONLY USED BY LOCAL GOVERNMENTS IN IOWA (percent of responses)

Pavement Marking Material	Small Cities (%)	Large Cities (%)	Counties (%)
Water-Based Paint	37	84	91
Alkyd-Based Paint	44	12	5
Tape	0	4	0
Epoxy	2	0	0
Thermoplastic	0	0	0
Other	2	0	2
No Response	14	0	2

Adapted from data in Andrie et al. (2001).

search for better performing, longer-lasting, and environmentally friendly materials. In terms of pavement marking performance, research in the past several years conducted by DOTs in Alaska, Michigan, Ohio, Pennsylvania, and South Dakota, among others, all reinforce a broad understanding that although paint is the least expensive material, it wears the fastest. More durable markings such as thermoplastic and tape have higher retroreflectivity over a longer life, prompting the need to compare the performance and costs of alternate materials on a life-cycle basis. Color also has an effect: white markings are more retroreflective than yellow markings (Thomas and Schloz 2001). More detailed examinations of these general findings are presented in the following sections.

MEASURING ASSET PERFORMANCE

Synthesis Survey Findings

The information provided by agencies on performance measurement of pavement markings is summarized in Figure 58, based on categories of performance factors similar to those described in chapter two. Physical as well as qualitative measures of pavement marking condition, asset age, and customer complaints were cited the most often by responding agencies. The frequencies with which physical measures are addressed are shown in Figure 59. Almost 85% of the reporting agencies assess pavement marking condition at least annually.

The methods used by responding agencies to assess pavement marking condition and performance are reported in Figure 60. All of the responding agencies reported using visual inspections; physical measurements and customer complaints were also identified as common methods used. Physical measurements of pavement markings typically include assessments of reflectivity, color, and durability.

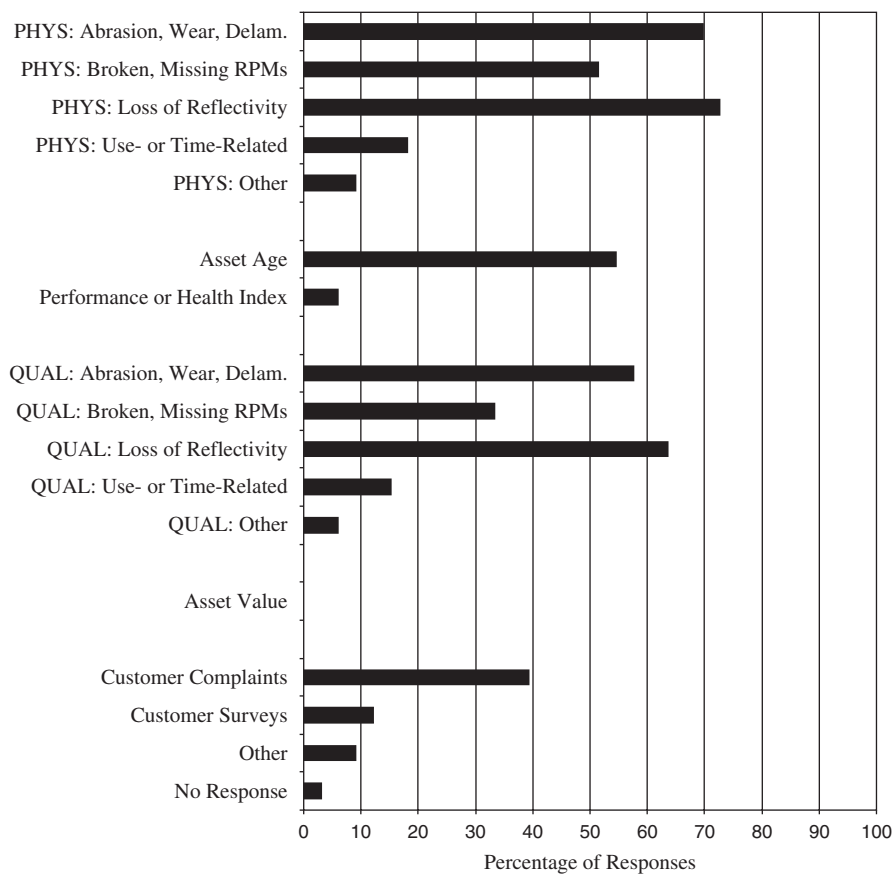


FIGURE 58 Measuring performance of pavement markings. PHYS = physical; QUAL = qualitative; RPMs = raised pavement markers.

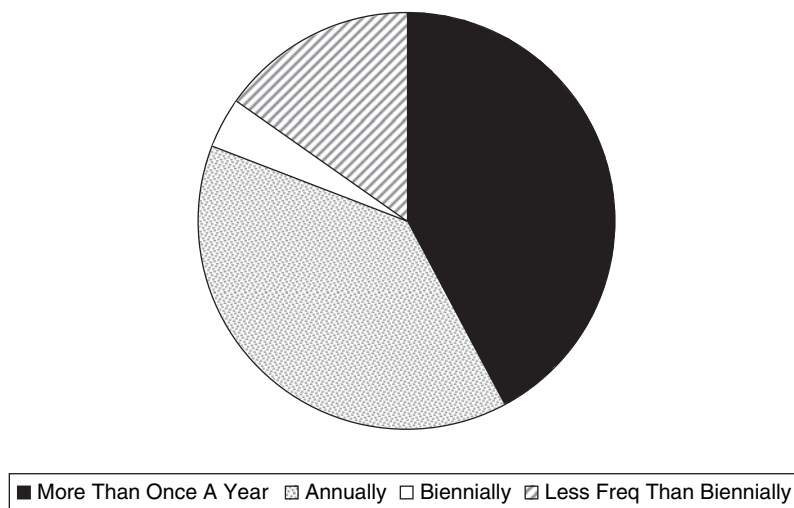


FIGURE 59 Frequency of physical condition assessments of pavement markings.

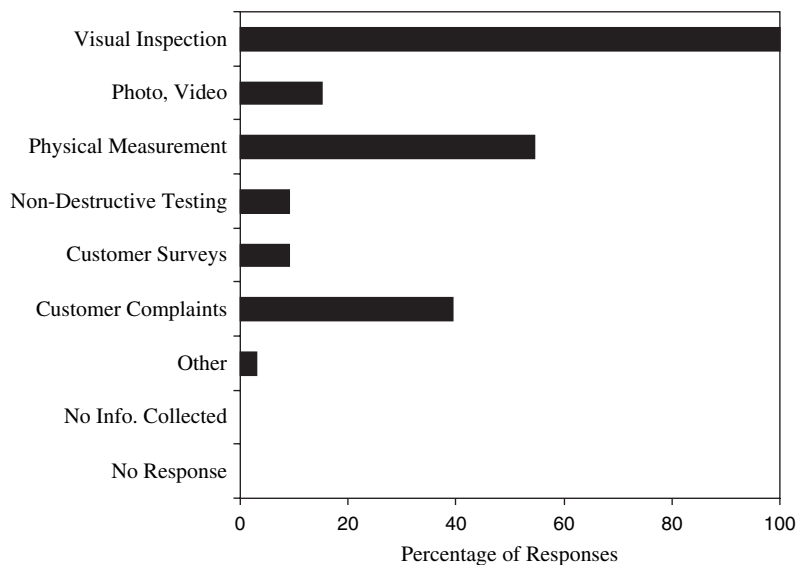


FIGURE 60 Data collection methods for pavement marking condition and performance.

Reflectivity may be measured by handheld or mobile reflectometers. Agencies may use reflectivity readings to verify visual inspections.

Performance Attributes

Several characteristics of pavement marking materials are important to the ease and safety of installation, performance, and cost, and may be considered by agencies in deciding among competing marking materials (Migletz et al. 1994; Andrady 1997; Thomas and Schloz 2001; Hawkins et al. 2002).

- **Visibility, retroreflectivity**—The visibility of pavement markings is critical to the safety and orderly movements and interactions among motor vehicles, bicyclists, and pedestrians. The *MUTCD* requires that retroreflective marking materials be used unless adequate nighttime visibility is otherwise provided by illumination. Given the relatively small percentage of well-illuminated roadways, agencies tend to have all pavement markings retroreflective. Retroreflectivity is the ability of marking materials to reflect light back to its source, the same property explained in chapter four for sign sheeting. Technical discussions of retroreflectivity are contained, for example, in the *FHWA Roadway Delineation Practices Handbook* (Migletz et al. 1994) and the synthesis of pavement markings research performed for the Iowa DOT (Thomas and Schloz 2001). The issue of the minimum level of reflectivity needed for safe and effective traffic movements has been a subject of continuing research, and agencies have adopted different approaches and threshold values. Other aspects of visibility to which drivers are sensitive include the apparent brightness or luminance of markings, the contrast between

pavement markings and the pavement surface, loss of color of the marking material [e.g., owing to exposure to ultraviolet (UV) light or contamination by dirt, grime, exhaust, etc.], conspicuity or detection distance (the ability of a driver to notice a marking at a certain distance), and the ability to see the markings clearly at different times of day and in different weather conditions.

- **Durability**—Durability refers to the lasting power of pavement marking, often interpreted as the time interval between placement and need for replacement; that is, its service life. The durability of a pavement marking depends not only on the marking material, but also on traffic average annual daily traffic (AADT), weather, and resulting activity (e.g., snowplowing and application of abrasives), the type of base under the marking surface and damage as a result of chipping and abrasion, and the type and condition of the pavement surface. An issue in assessing durability is defining when a marking has degraded to the threshold that requires replacement. Agencies have adopted different approaches and threshold values for evaluating durability.
- **Volatile organic compounds**—VOCs are one of the environmental measures of interest for pavement markings. VOCs contribute to ozone and smog formation in urban areas. Solvent-based traffic paint has 25% to 30% VOCs by weight, all of which are released into the atmosphere, contributing a considerable quantity of VOCs nationwide. Solvents used in cleaning pavement marking equipment add to this total. Agencies are subject to EPA regulations limiting the VOCs in their pavement marking applications, and state regulations may also apply. These regulations have caused DOTs to shift from solvent-based paints to water-based paints and durable markings (see Table 18). VOC emissions by pavement marking materials

are covered in greater depth in *NCHRP Report 392* (Andrady 1997).

- Toxicity during marking operations—Paints contain compounds that can be harmful to crews applying pavement markings. One problem concerns VOCs that are also hazardous air pollutants, including toluene, methanol, xylene, methyl ethyl ketone, and aromatics. A second problem is lead chromate pigment that has been used in yellow water-based and alkyd paints; both lead and this form of chromium are toxic. Problems associated with both application of these paints and their removal and disposal when replacing markings (residues must be tested for the potential for leaching of lead, chromium, and other heavy metals) have prompted agencies to look at alternate pigments such as organic dyes (Hawkins et al. 2002).
- Life-cycle cost—Initial costs include the labor, equipment, and materials costs associated with preparation (pretreatment) and placement of the marking material. However, costs should be evaluated on a life-cycle basis and equivalent levels of performance, because different marking materials have different service lives. The FHWA *Roadway Delineation Practices Handbook* provides guidance on the conduct of a benefit–cost analysis that considers agency and road-user cost streams through a material’s service life (Migletz et al. 1994). Other examples are given later in the chapter.

These are the major attributes considered for general marking applications. Other characteristics that may be considered for particular materials, locations, or situations include skid resistance and the potential to interfere with pedestrian, disabled, or bicycle traffic (e.g., owing to the thickness or slipperiness of the marking material); material stability during storage; and ease of application and removal. Proper specifications and quality control during installation are also important to good performance.

ASSET SERVICE LIFE

Retroreflectivity

Retroreflectivity is the ability of a material to reflect light back toward its source. It is a property of the pavement marking material used. In the case of markings that are not lit by road or street lighting, the source of light is the vehicle headlamps. The pavement marking material redirects this light back toward the vehicle, where it is perceived by the driver’s eyes. The coefficient of retroreflected luminance, R_L , compares the light returned to the driver’s eyes (luminance) with the light from headlamps incoming to the marking surface (illuminance). Units of measure are millicandelas per square meter per lux in the metric system (abbreviated $\text{mcd}/\text{m}^2/\text{lx}$, or equivalently $\text{mcd}/\text{lx}/\text{m}^2$) and millicandelas per square foot per foot-candle in U.S. customary units (abbreviated $\text{mcd}/\text{ft}^2/\text{fc}$, or equivalently $\text{mcd}/\text{fc}/\text{ft}^2$). The FHWA *Roadway Delineation Practices Handbook* provides a technical explanation of retroreflectivity and R_L using principles of solid geometry

(Migletz et al. 1994). Additional information is contained in other sources (e.g., King and Graham 1989; Clark and Sanders 1993; Thomas and Schloz 2001).

The literature describes other approaches to measuring driver perceptions of pavement marking visibility that are either now used or proposed for future consideration. For example, the ability of drivers to notice the start or stop (or the number of skip marks) of pavement markings on the road ahead are gauged by their detection distance (or visibility distance) measured in meters or feet. This measure has been used in studies of pavement marking visibility in different day–night and dry–wet conditions (Aktan and Schnell 2004; Gibbons et al. 2004). Furthermore, potentially greater use of wider longitudinal striping in the future has prompted consideration of other ways to understand pavement marking visibility beyond those now applied. For example, drivers in tests have noted that wider stripes are more visible and “look better” (Gates et al. 2002). This perception is not explained by traditional characteristics such as retroreflectivity, color, and contrast, because the same longitudinal marking and pavement surface materials are involved as for conventional width striping. Researchers have therefore proposed alternate measurement concepts; for example, to consider the increased peripheral visibility of wider striping, resulting in increased driver comfort and reduced visual workload, and allowing more attention to other driving tasks. Further work is recommended to develop these concepts quantitatively as part of a broader understanding of pavement marking visibility (Gates et al. 2002).

Although laboratory procedures are often used in research and calibration, it remains that R_L readings of in-service markings are influenced by field conditions, including dirt, grime, moisture, dried salt, and other contaminants on pavement markings, as well as the wear of the marking itself. Retroreflectivity varies with weather; specifically, R_L of wet pavement markings is much lower than that of dry markings (Migletz and Graham 2002; Aktan and Schnell 2004). For consistency in comparing data across a number of sources, all the data on R_L in the remainder of this chapter will refer to dry road surface conditions unless explicitly stated otherwise. Field measurements further depend on the type of retroreflectometer used, which affects how the readings are taken and how adjustments for ambient conditions are made (Thomas and Schloz 2001). Different instruments can give varying readings of the same object (*Research Results Digest 297* . . . 2005) and be affected by ambient conditions at the test site, such as temperature, humidity, and background glare. As a result, evaluating field readings against a minimum retroreflectivity threshold may be difficult to do reliably (Thomas and Schloz 2001; Migletz and Graham 2002; Kopf 2004).

Variability in Retroreflectometer Readings

NCHRP Synthesis 306 reviewed several correlation studies of different models of handheld and mobile retroreflectometers. The results across all these studies were mixed. For example,

a study by the FHWA showed divergences among different instrument models, suggesting either that the different instruments were measuring different phenomena or the same phenomena on different scales. A study by AASHTO reported good correlation for individual retroreflectometers, but a lack of correlation between different types of instruments. A South Carolina DOT study reported comparable results among three retroreflectometer models, a mobile unit and two handheld units. A study by the Texas Transportation Institute's Highway Innovative Technology Evaluation Center evaluated four handheld instruments (MX30, LTL 2000, FRT01, Mirolux Plus MP-30) and two mobile instruments (Laserlux and ECO-DYN). Measurements were conducted at six test sites: three types of longitudinal striping on each of two highways. The results showed good agreement (within 10%) in many cases between the readings of the six instruments and the composite mean R_L at each test site. (The composite mean R_L for each test site was computed as the average of the readings by all six instruments at that site.) In several cases, however, an instrument reading varied by 10% to 15% from the composite mean and, in two cases, by 15% to 25% from the composite mean (Migletz and Graham 2002). Missouri DOT District 7 has found that retroreflectivity readings from three instruments (Mirolux 30, LTL 2000, and Laserlux) "do not directly correlate with each other and should not be compared to each other" (Weinkein et al. 2002).

These findings and assessments predate the recent establishment of the Center for High Accuracy Retroreflective Measurements national retroreflectometer calibration center that was discussed in chapter four (*Research Results Digest 297* . . . 2005). It remains to be seen to what degree the variability in retroreflectometer measurements can be reduced through nationally standardized calibration of retroreflectometers supported by the Center. Lacking a nationally recognized retroreflectivity benchmark, one cannot say that a particular retroreflectometer is "more correct" or "more accurate" than another. One can only compare readings between instruments, or against some value such as the composite mean described above, to see to what degree they produce similar results.

Durability

Durability is judged by the lasting power of the marking material. It is often based on a physical measure such as the percentage of the stripe remaining and may be somewhat subjective. The Quebec Ministry of Transport defines five durability classes, each associated with a percentage range of material remaining, and each also associated with a color for use on maps. A guidebook includes photographs that illustrate examples of how each durability class appears in the field (Tremblay and Eng 2004). Durability measures that are commonly applied to thermoplastic include remaining thickness and the percentage of retained area. However, a 1969 survey of highway agencies reported a wide variation in estimated service life based on this concept (Migletz et al. 1994). Missouri DOT District 7 is trying to determine an acceptable limit

for chipping of pavement markings; although it is considering a maximum in the range of 20% to 40% of sporadic chipping, the matter has not been resolved (Weinkein et al. 2002). *NCHRP Report 392* includes examples of subjective appearance ratings on 1–10 scales that were used in studies by the Northeast Association of State Highway and Transportation Officials (NASHTO) and the Southeastern Association of State Highway and Transportation Officials (SASHTO), as well as ratings of the percentage material retained after 12 months in use to reflect damage, debonding, or physical deterioration (Andrady 1997).

The durability of raised retroreflective pavement markings (RRPMs) depends on several aspects of performance (Migletz and Graham 2002):

- Retroreflectivity, which can be reduced by dirt, abrasion, and weathering;
- Proper marking color, which can be degraded by UV rays, heat, traffic, and road surface grime;
- Proper adhesion to the pavement, which must resist wear resulting from traffic, especially in weaving areas and in streams having significant truck traffic; and
- Proper support of the pavement surface, which can be softened by hot temperatures as in desert climates.

Threshold Retroreflectivity Levels

Threshold values of retroreflectivity are used in two ways with regard to pavement markings:

- As an acceptance criterion for newly installed markings, to ensure that marking materials meet the minimum values established by agency procurement requirements. Satisfying this threshold *does not* indicate any information about the service life that will be delivered by the pavement markings.
- As a minimum acceptable value of in-service pavement markings. For a material with a given initial retroreflectivity when new, and an annual decay rate in retroreflectivity, this minimum level *does affect* the service life of the pavement markings.

Examples of the variability in both types of threshold values are given here.

Minimum Level When Newly Installed

Data gathered by the FHWA regarding the minimum initial values used by state DOTs to evaluate the quality of newly applied pavement markings resulted in a range of 175 to 700 mcd/m²/lx for white markings and 100 to 350 mcd/m²/lx for yellow markings. The variability in these thresholds depended on the particular agency, the type of marking material, and the time frame in which the retroreflectivity was measured (Hawkins et al. 2002).

Minimum Level In-Service

In its research, South Dakota used 120 mcd/m²/lx as the minimum acceptable value of retroreflectivity for white paint and 100 mcd/m²/lx for yellow paint, based on the experiences of the NYSDOT (Thomas and Schloz 2001).

Research on several types of painted pavement markings for the Washington State DOT (WSDOT) used a minimum threshold value of 100 mcd/m²/lx to define the need for repainting (Kopf 2004). Establishment of this value was preceded by a literature review identifying the following minimum threshold values by other researchers (references cited in Kopf 2004):

- New Jersey: Between 80 and 130 mcd/m²/lx for drivers below age 55, and between 120 and 165 mcd/m²/lx for drivers older than 55 (Parker and Meja 2003).
- Study of needs of older drivers: Based on subjective judgments of the adequacy of the visibility of pavement markings, 85% of subjects 60 years or older found a value of 100 mcd/m²/lx to be adequate or more than adequate for nighttime driving (Graham et al. 1996).
- MnDOT: Research indicated a threshold value between 80 and 120 mcd/m²/lx based on drivers' nighttime driving experiences on state and county roads. MnDOT adopted a value of 120 mcd/m²/lx for its pavement marking management program (Loetterle et al. 2000).

In a study of relative cost and service life of paint and thermoplastic, researchers inferred a threshold value of 150 mcd/m²/lx based on prior correlations of retroreflectivity readings and vehicle crash data for Alabama highways (Abboud and Bowman 2002).

Missouri DOT District 7 used preset levels of minimum retroreflectivity as a basis for comparing field readings. The preset levels were 80 mcd/m²/lx for yellow markings, and 100 mcd/m²/lx for white markings. Based on its experience, District 7 regards readings above 250 mcd/m²/lx for new, white, water-based paint markings as “a good stripe”; and above 175, a good value for yellow (Weinkein et al. 2002).

In a study of the service life of durable pavement markings in 19 states sponsored by the FHWA's Turner-Fairbank Highway Research Center, researchers specified a range of threshold retroreflectivity values that would define end of service life. These values were a function of type and color of marking material, lighting situation, class of roadway (freeway, nonfreeway), and nonfreeway road speeds (≤ 40 mph and ≥ 45 mph). For example, the threshold values for white markings ranged from 85 mcd/m²/lx on nonfreeway roads with speeds ≤ 40 mph to 150 mcd/m²/lx on freeways (Migletz et al. 2001).

Effect of Minimum Retroreflectivity Threshold on Service Life

In comparing service-life data for different pavement marking colors, highway classes, AADT and vehicle speed ranges, roadway lighting conditions, presence or absence of RRPMS, and other situations, one must be aware of the minimum threshold retroreflectivity that applies to each case. For example, when comparing white and yellow pavement markings:

- If the threshold R_L is the same in each case—for example, 100 mcd/m²/lx—then the white markings will appear to have a longer service life than the yellow markings, all other factors equal.
- If the threshold R_L values differ—for example, 100 mcd/m²/lx for white markings, 80 mcd/m²/lx for yellow—the yellow markings may appear to have a longer service life because of the lower threshold.

In the case of white and yellow marking color, different thresholds enable agencies to replace all of the longitudinal markings on a highway at the same time, recognizing that for a given installation date and equal period in-service, yellow markings will generally have a lower R_L than white markings. Nonetheless, the basic principle applies to other comparisons of pavement marking service life on different roadways: the threshold R_L value, as well as potential differences in highway geometric, traffic, pavement, and other environmental and operating characteristics need to be factored into the comparison.

Service-Life Estimates

Synthesis Survey Findings

Information on service life was obtained in the study survey for three aspects of pavement markings: lane or edge striping, RPPMs, and other pavement markings (e.g., arrows and messages). Responding agencies were also asked to identify how they would determine service-life values. Responses to this question are shown in Figure 61. The majority of responses emphasized collective organizational knowledge, represented by agencies' experience with pavement markings and the professional judgment of their staffs. The remaining responses were distributed fairly evenly among the other choices.

A comprehensive statement of most of the items for which estimated service lives were reported is given in Table 19. Examples of histograms showing service-life distributions for those items with the most numerous responses are given in Figures 62 through 67. The labels on the horizontal axis in these figures give the upper values of each range of service-life data. For example, if these labels are 0, 1, 2, 3 . . . , then the column labeled 1 shows the number of responses for estimated service life of zero to 1 year; the column labeled 2, the number of responses for estimated service life of more

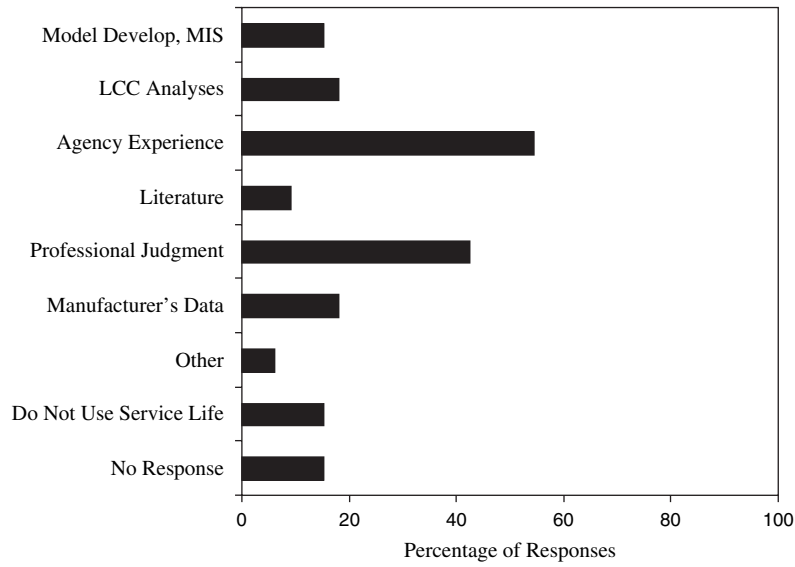


FIGURE 61 Sources for determining service lives of pavement marking materials. MIS = management information systems; LCC = life-cycle cost.

TABLE 19
ESTIMATED SERVICE LIVES OF PAVEMENT MARKING COMPONENTS

Component and Material	No. of Responses	Minimum (Years)	Maximum (Years)	Mean (Years)	Median (Years)	Mode (Years)
Lane and Edge Striping						
Non-epoxy paint	22	0.5	2	1.1	1	1
Epoxy paint	13	1	5	3.3	4	4
Thermoplastic	16	2	10	4.2	4	5
Cold plastic	8	1	10	4.9	5	6
Polyester	2	2	3	2.3	2.3	—
Tape	5	5	10	6.3	6	5
Thin thermoplastic	1	—	—	1–2	—	—
Preformed thermoplastic	1	—	—	3	—	—
Pavement Markers						
Ceramic pavement markers	2	3	3	3	3	3
Raised pavement markers	10	1	5	3.2	3	3
Recessed pavement markers	6	1	5	3.2	2.5	2
Raised snowplowable markers	1	—	—	4	—	—

Notes: —, value is undefined for the particular distribution. When distribution is based on only one data point, its value is shown in the Mean column.

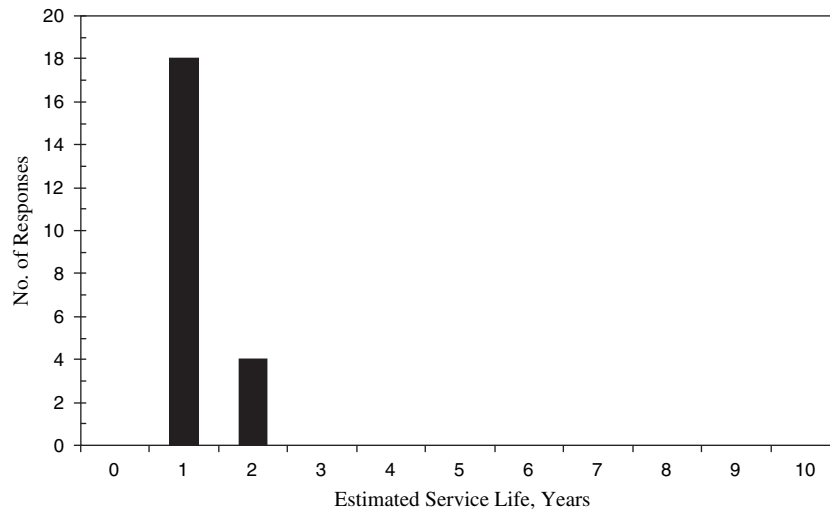


FIGURE 62 Estimated service life of non-epoxy paint in centerlines and edge lines.

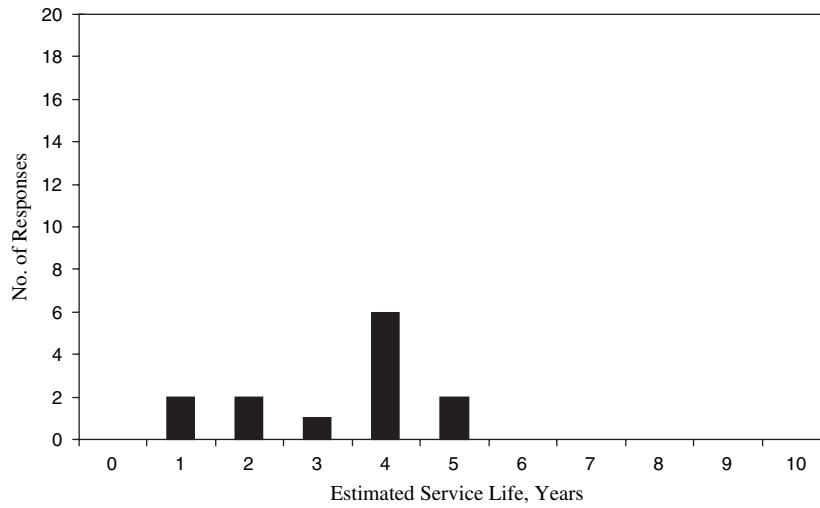


FIGURE 63 Estimated service life of epoxy paint in centerlines and edge lines.

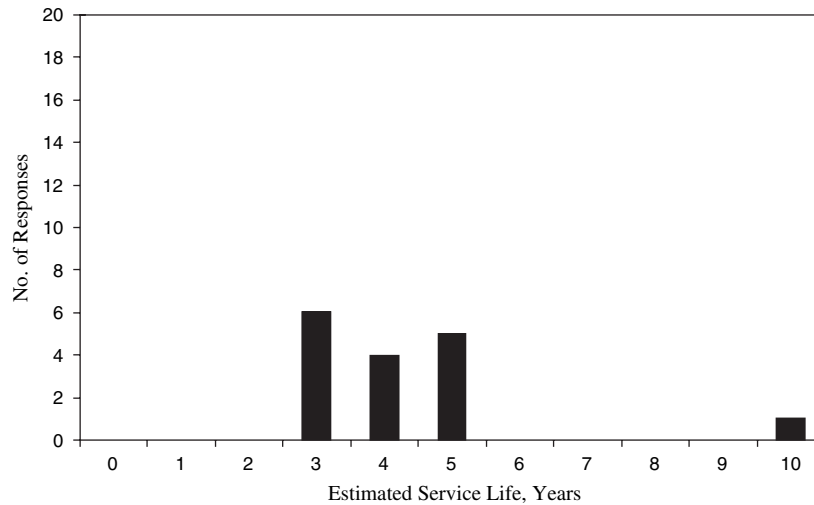


FIGURE 64 Estimated service life of thermoplastic in centerlines and edge lines.

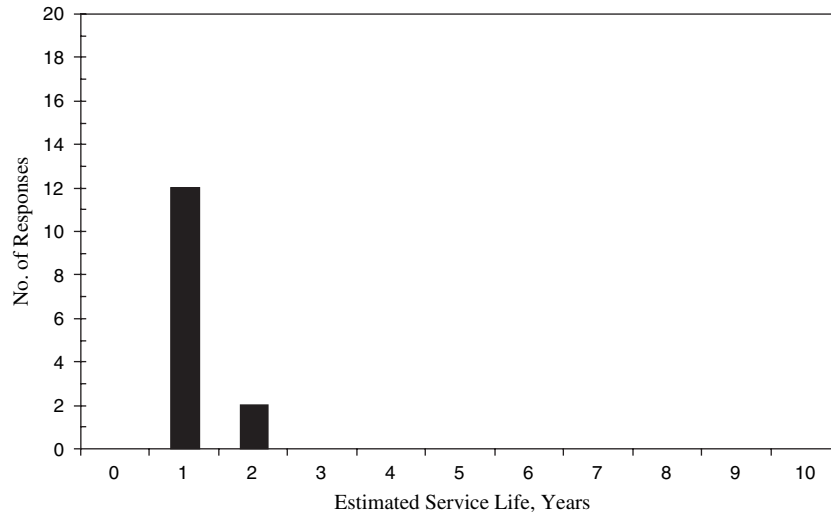


FIGURE 65 Estimated service life of non-epoxy paint in pavement messages.

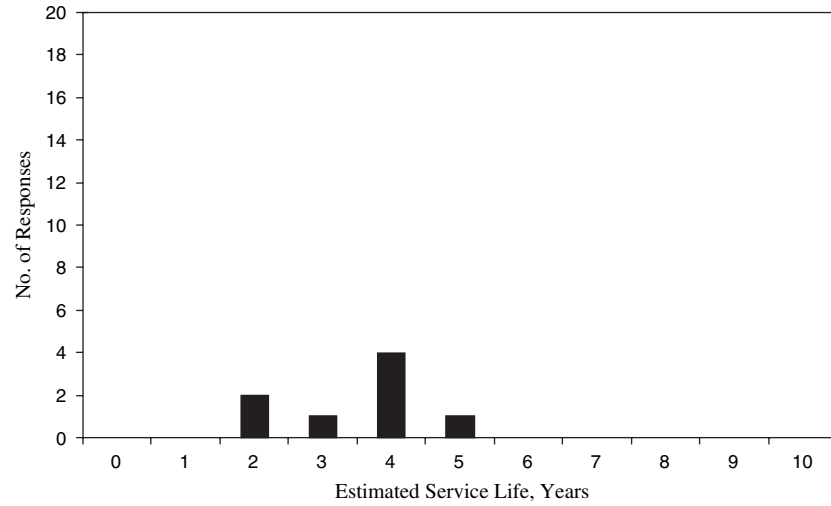


FIGURE 66 Estimated service life of epoxy paint in pavement messages.

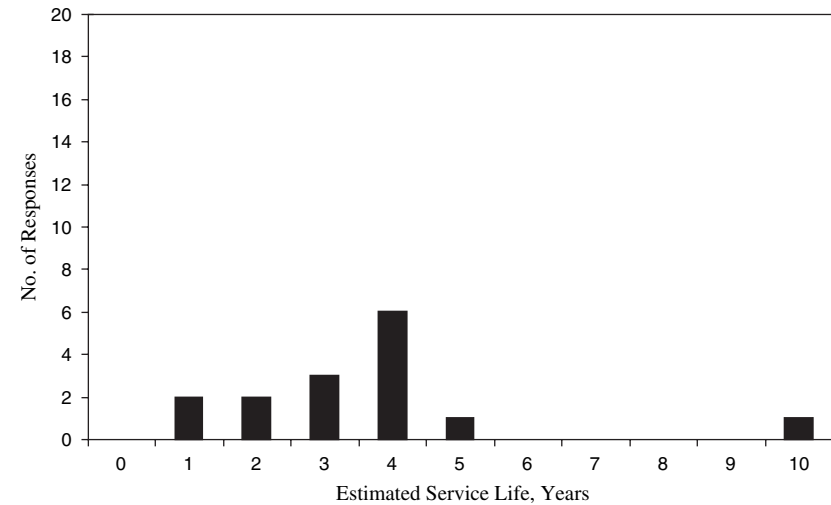


FIGURE 67 Estimated service life of thermoplastic in pavement messages.

than 1 to 2 years; the column labeled 3, the number of responses for estimated service life more than 2 to 3 years; and so forth. It should be noted again that the data in Table 19 and Figures 62 through 67 may be derived in part from the professional judgment of agency personnel.

Agencies also provided service-life information on other specific materials, as follows:

- Urethane 4 years (Oregon)
- Polyurea 4 years (North Carolina)
- Acrylic-based paint 2 years (West Virginia)
- Durable waterborne paint 3 years (Iowa).

Service-Life Estimates in the Literature

- The FHWA *Roadway Delineation Practices Handbook* includes the following estimates of service life (Migletz et al. 1994):
 - Paint—6–12 months. Service life is affected by traffic passages (AADT), traffic composition, and roadway geometry.
 - Thermoplastic—estimates are variable, but all show a long durability. Models show a hypothetical maximum life of 10–12 years; however, this maximum value should be reduced owing to effects of annual snowfall (a surrogate for wear resulting from snowplows), traffic volume, abrasion resulting from studded tires, and pavement type.
- Based on a minimum threshold of 100 mcd/m²/lx, MDOT found that water-based paints had a service life of 445 days, or approximately 15 months. However, the variability in this result was large (Lee et al. 1999, as reported by Kopf 2004).
- Using data for rural highways in Alabama, researchers determined that paint had a useful service life of 4.5 to 22 months for high-to-low traffic volumes [$>5,000$ vehicle per day (vpd) to $<2,500$ vpd], whereas thermoplastic had a service life of 10.5 to 53 months for the same traffic intervals. These results were expressed in both tabular form for three ranges of AADT and as functions relating service life in months to AADT for two-lane highways. The threshold R_L used in this study was 150 mcd/m²/lx (Abboud and Bowman 2002).
- The study documented in *NCHRP Report 392* uses the symbol T_{100} to express service life related to retroreflectivity. T_{100} was defined as the time during which a pavement marking retains its retroreflectivity above the minimum threshold value of 100 mcd/lx/m². An empirical function to estimate T_{100} was proposed and calibrated using two sets of data: one from NASHTO, the second from SASHTO. The values of T_{100} for different materials according to the two sets of data are summarized in Table 20 (Andrady 1997).
- In a study of durable pavement markings in 19 states for the FHWA's Turner-Fairbank Highway Research Center, researchers applying threshold retroreflectivity values

based on road class and speed (among other factors) found that the service life for white paint on freeways, for example, averaged 10.4 months, but varied from 4 to 18 months. Other materials likewise showed considerable variability in service life, whether measured in months or by cumulative number of vehicle passes. An example of these results is shown in Table 21 for white lines on freeways. Additional information for other road classes and for yellow lines is given by Migletz et al. 2001.

- Research findings from several state DOT studies of RRPMS that were reported in *NCHRP Synthesis 306* indicated the following (Migletz and Graham 2002, who also cite Ullman 1994 and Hofmann and Dunning 1995):
 - The Georgia DOT uses RRPMS to supplement pavement markings on all classes of its state highways. Its policy is to replace RRPMS every two years throughout most of the state, except in the northern counties where replacement is annual owing to snow plowing.
 - The Oregon DOT found that retroreflectivity of RRPMS could decline by as much as 70% in one year.
 - The Texas DOT studied the durability of 17 types of RRPMS on San Antonio freeways during a two-year period. One-directional traffic volumes during the two-year test period ranged from 3,300 to 4,500 vpd at the low-volume site, to 58,900 to 63,200 vpd at the high-volume site. Regression analyses demonstrated that cumulative vehicle exposure most strongly affects the decay in retroreflectivity. Many RRPMS on high-volume freeways failed to provide adequate retroreflectivity after only 6 months. More durable and expensive RRPMS become cost-effective when AADT reaches 10,000 vpd per lane.
 - The Texas DOT has issued guidelines on when to maintain RRPMS (i.e., replace selected missing markers) based on visibility during nighttime inspections and frequencies of RRPMS replacement based on highway AADT. For example, suggested replacement intervals range from 3 to 4 years for highways with AADT $<10,000$ to annual replacement for highways with AADT $>50,000$.

Deterioration Modeling

Researchers have attempted to incorporate the deterioration of pavement marking materials within models that would enable practitioners to forecast decay rates and the need for markings replacement.

One attempt was based on the data reported in Table 21. However, the variability in the results in the table translated into inconsistent decay models when mean retroreflectivity was compared with the cumulative number of vehicle passes. Even when considering a single type of material (e.g., white thermoplastic), a single application (e.g., edge line), and a single road class (e.g., freeway), the shapes or the slopes and

TABLE 20
MEASURES OF T_{100} ESTIMATED FOR MARKING MATERIALS BASED
ON NASHTO AND SASHTO DATA

Pavement Marking Material	T_{100} Based on NASHTO Data	T_{100} Based on SASHTO Data
	Months (years)	Months (years)
Water-Based Paint—White	27.7 (2.3)	38.0 (3.2)
Water-Based Paint—Yellow	26.1 (2.2)	17.5 (1.5)
Solvent-Based Paint—White	12.2 (1.0)	9.1 (0.8)
Solvent-Based Paint—Yellow	3.1 (0.3)	7.2 (0.6)
Polyester Paint—White	39.7 (3.3)	165.9 (13.8)
Polyester Paint—Yellow	4.0 (0.3)	47.2 (3.9)
Methacrylate Paint	10.8 (0.9)	18.3 (1.5)
Epoxy Paint	18.8 (1.6)	—
Thermoplastic—White Hydrocarbon type Alkyd type	13.9 (1.2)	13.0 (1.1)
		40.6 (3.4)
Thermoplastic—Yellow Hydrocarbon type Alkyd type	7.8 (0.7)	8.0 (0.7)
		18.5 (1.5)
Preformed Thermoplastic	12.6 (1.1)	3.8 (0.3)
Tape—White	14.1 (1.2)	31.2 (2.6)
Tape—Yellow	12.4 (1.0)	30.4 (2.5)

Adapted from data in Andradý (1997).
—, denotes no data available.

TABLE 21
ESTIMATED SERVICE LIFE FOR WHITE LINES ON FREEWAYS

Pavement Marking Material	No. of Pavement	Average Service Life	Range of Service Life,
	Marking Lines	Months (Years)	Months (Years)
Thermoplastic	14	22.6 (1.9)	7.4–49.7 (0.6–4.1)
Polyester	2	20.8 (1.7)	14.7–27.0 (1.2–2.3)
Profiled Tape	5	19.6 (1.6)	11.7–27.3 (1.0–2.3)
Profiled Thermoplastic	7	18.4 (1.5)	4.7–35.6 (0.4–3.0)
Profiled Poly (methyl methacrylate)	6	14.0 (1.2)	7.8–33.5 (0.7–2.8)
Epoxy	11	12.8 (1.1)	3.4–34.0 (0.3–2.8)
Poly (methyl methacrylate)	6	11.9 (1.0)	6.8–17.5 (0.6–1.5)
Water-Based Paint	3	10.4 (0.9)	4.1–18.4 (0.3–1.5)

Adapted from data in Migletz et al. (2001).

intercepts of the curves that were derived from data on different highways varied considerably (Migletz et al. 2001).

The University of Washington's Washington State Transportation Center (TRAC) conducted another study to develop retroreflectivity degradation models for the WSDOT. The study was beset by considerable variability in data, both within individual highway test sections as well as among highways with similar AADT. Scatter and incongruous trends in the data complicated model development. For example, in one test section for which data were collected by a mobile retroreflectometer 11 times during a 3-month period, average retroreflectivity varied from 76 to 97 mcd/m²/lx. The standard deviation of this average was 42 mcd/m²/lx: relatively large and thus significant, particularly because a durable striping material with a 15-year service life would be expected to exhibit little variability within a 3-month test interval. (The author noted that although this example was an extreme case, it is indicative of the inconsistency that can occur in retroreflectivity measurements.) Detailed analyses of all of the measurement runs on this test section showed little pattern similarity among them, and even yielded counterintuitive trends such as an increase in retroreflectivity by as much as a factor of three between one run and a later run (i.e., with increasing age of pavement marking) (Kopf 2004). Subsequently, the WSDOT determined that the mobile retroreflectometer used in this study was substandard and did not pursue the modeling effort further. The department switched to handheld devices and has since obtained more reliable data, performance trends, and evaluations of different marking materials under winter conditions (Lagergren et al. 2006; WSDOT n.d.). WSDOT has developed specific guidelines for conducting retroreflectivity readings on pavement markings, organized personnel training, and related five ranges of retroreflectivity to the levels of service (A, B, C, D, F) used in its Maintenance Accountability Process (Lagergren and Baroga 2006).

Studies have also looked at the performance of materials constituents as a basis for retroreflectivity trends—in this case, glass beads. The decline in the retroreflectivity performance of two sizes of glass beads in epoxy pavement marking is given in a graphic in the FHWA *Roadway Delineation Practices Handbook* (Migletz et al. 1994, Figure 11). The curves show a decrease to roughly half the value of R_L in a period of 22 months. MDOT researched methods to determine the glass bead content of pavement marking paint and developed two such procedures. It also documented two relationships: (1) between the percentage of glass beads on the paint surface and glass weight in the marking material, and (2) between glass weight and retroreflectivity (Rich et al. 2002).

Impacts of Pavement Marking Performance

The FHWA *Roadway Delineation Practices Handbook* cites several early studies (prior to 1980) of the benefits of pavement markings. One showed reductions in accidents when

pavement markings were added at particular locations in highway geometry where they had not existed before; for example, tangent sections, horizontal curves, no-passing zones, pavement-width transitions, and other geometric situations. Other before-and-after studies of edge line applications showed improvement in driver performance with markings; for example, improved lateral placement of vehicles away from the edge, reduced centerline straddling, and reduced speed on curves. However, it was noted that some agencies do not allow edge striping on very narrow roadways because of driver tendency then to avoid the edge, and the resulting greater possibility of head-on collision. Yet other studies, however, showed little change in accident rates, with only minor changes in the way markings appear, and some were inconclusive, confounded by differences among sites in other factors such as lane width and presence or absence of shoulders. The *Handbook* includes a method for conducting a life-cycle cost analysis of alternate pavement marking materials, including road-user benefits related to reduction in accident costs (Migletz et al. 1994).

More recent studies illustrate several ways in which pavement marking options are compared on the basis of initial cost, cost-effectiveness, or minimum life-cycle-cost criteria.

- The most basic criterion is initial cost, typically presented for material costs only on a dollar-per-foot basis (e.g., Thomas and Schloz 2001, Table 1; Hawkins et al. 2002, Table 11; Migletz and Graham 2002, Table 39).
- The performance of marking materials is factored into comparisons by combining expected service life (e.g., in days) with initial cost (e.g., cents per foot) to derive the cost per stripe length per unit time (e.g., cents per foot per day) of the material. It is a simple, basic cost-effectiveness criterion. The calculation may exclude discounting (e.g., the South Dakota example in Thomas and Schloz 2001) or a discount rate may be used (e.g., the Oregon example in Migletz and Graham 2002, Tables 46 and 47). Initial cost and service life may also be considered together with other performance measures such as durability and initial reflectivity without combining them into a single number (e.g., the Michigan example in Thomas and Schloz 2001).
- A further refinement is to include the cost of traffic delay during the installation of pavement markings, plus the cost of subsequent measurement of retroreflectivity. The sum of these agency costs is divided by the expected service life to produce a cost per stripe length per unit time (e.g., dollars per mile per year) (Migletz and Graham 2002, Table 45).
- A comprehensive economic approach considers life-cycle costs to both the transportation agency and road users. Road-user costs are based on estimates of striping-related crashes for each pavement marking material. Although a discounted approach is recommended in the FHWA *Handbook*, the example in the literature comparing paint and thermoplastic for longitudinal

striping applies cost-per-stripe-length-per-unit-time calculations similar to the earlier examples, with no discounting (Abboud and Bowman 2002).

- *NCHRP Report 392* applies a multi-attribute utility analysis to evaluate competing pavement marking materials across dimensions of cost, several aspects of performance, and environmental and safety impact (Andrady 1997).

Although the previous studies and methods are largely for longitudinal striping, corresponding work has also been done for pavement markers. The FHWA has compiled guidelines for the use of RPMs (*Guidelines . . .* 1998). A comprehensive review and economic analysis of the impacts of permanent RPMs (PRPMs) is provided in *NCHRP Report 518*. This study was prompted by safety concerns regarding PRPMs in New York, Pennsylvania, and Texas. A review of PRPM experience on different classes of highways was accompanied by a survey of current DOT practices, a review of human factor issues, aggregate and disaggregate safety analyses, and recommendation of guidelines for PRPM implementation. Although positive impacts of PRPMs in reduced numbers of crashes were observed in some of the reviewed cases, other cases resulted in negative impacts in terms of inappropriate driver response to PRPMs—for example, increases in speed on curves after installation—and resulting higher crash frequency. Factors involving road standard and geometry, AADT, weather, PRPM spacing and visibility, and human perception and response, all intersect in complicated ways. Implications of these combinations are discussed in detail in *NCHRP Report 518*, which concludes with recommended guidelines for PRPM installation and a detailed analytic procedure for analyzing PRPM benefit–cost on a discounted, life-cycle basis (Bahar et al. 2004; Persaud et al. 2004).

The ability of pavement markings to serve the needs of older drivers has also been considered. The threshold contrast value—the minimum difference between the luminance of a target and the luminance of the background that is needed for detection—increases rapidly above age 65 (Adrian 1989, as cited in Migletz and Graham 2002). An FHWA study conducted laboratory simulations and field tests of several pavement marking treatments with three age groups of drivers. The field tests investigated the recognition distance of each treatment by the oldest and the youngest groups of drivers. As a general rule, treatments that were recognized more quickly (i.e., at greater recognition distances) by older drivers were also recognized more quickly by younger drivers. However, on average, the recognition distances of older drivers were 14% less than those of younger drivers, and the reduction in recognition distance may actually be greater among the elderly in the general population (Pietrucha et al. 1995, as cited in Bahar et al. 2004).

The impacts of pavement markings have also been studied with respect to pedestrian traffic. Case studies in four U.S. cities

reviewed the effect marked crosswalks had at unsignalized intersections, with the finding that such markings are a desirable practice and induced no undesirable behavior on the part of vehicle drivers or pedestrians (Knoblauch et al. 2001). Another study, looking at 5 years of experience in 30 cities, found that improvements such as raised medians, adding traffic signals, and applying speed-reduction measures, were more beneficial than marked crosswalks at uncontrolled locations (i.e., no signals or Stop signs) on multilane roads. If marked crosswalks were to be installed, companion safety improvements were also recommended. On two-lane roads, there was no difference in the pedestrian crash rate between marked and unmarked crosswalks. The study also documented that older pedestrians had a crash rate that was high in relation to their relative exposure (Zegeer et al. 2001). A third study found that advance warnings before crosswalks at uncontrolled approaches on multilane roads were likewise beneficial (Van Houten et al. 2001).

Several jurisdictions in Australia use a thermoplastic audio tactile line marking for edge markings to help counter the effect of driver fatigue. Even though it is initially more expensive than a competing tactile marking product, its life-cycle costs are lower. Experience has shown it to be effective in reducing single-vehicle, run-off-road crashes (Woolley and McLean 2006).

Determining Current Service-Life Status

To apply the service-life concept in asset management, a method is needed to determine where an asset is in its service life—that is, how much life is consumed and how much remains. Agencies were presented with a number of ways to determine the current status of an asset regarding its service life, and asked to rank each method by relevance to their agency. The result is shown in Table 22.

On the related issue of identifying the extension in service life as a result of maintenance, 3 of the 33 reporting agencies responded affirmatively. Quebec presents this information in a pavement markings guide it has prepared. Iowa noted that measuring retroreflectivity provides them with a more objective basis for determining whether existing stripes are still above the restriping threshold, potentially extending their projected service life. Portland described its economic analysis of using thermoplastic for longitudinal striping. The pay-back analysis considered material service life, striping inventory, and estimated productivity of thermoplastic application, including purchase of a thermoplastic long-line striping vehicle. For assumed conditions, it was estimated that an efficient, high-capacity thermoplastic application could reduce life-cycle costs of pavement markings by approximately 28%. Different operational scenarios were also tested, all showing a positive payback within 8 to 10 years. Results of these analyses led Portland to develop a transition plan from paint to thermoplastic (*Portland Transportation . . .* 2004).

TABLE 22
RANKING OF METHODS TO DETERMINE WHERE PAVEMENT MARKINGS ARE IN THEIR SERVICE LIVES

Rank	Factor
1	Monitor condition of the asset on a periodic schedule
2	Assets are repaired or replaced as soon as they fail without regard to service life
2	Assets are replaced on a preventive maintenance schedule without regard to where they are in their service life
4	Compare current age of asset with the maximum age that defines service life
5	Monitor condition of the asset occasionally
6	The agency does not use/does not monitor service life for this type of asset
7	Apply deterioration models to estimate where the asset is on “the curve”

INFORMATION TECHNOLOGY SUPPORT

Agencies participating in the study survey identified their key IT capabilities as shown in Figure 68. A number of elements were ranked highly by responding agencies, including information on inventory, location, condition, and usage; asset age and anticipated service life; information on inspections and maintenance work done; and customer complaints. No strong distinctions in the findings represented by Figure 68 were observed among different levels of government. By comparison, responses to the January 2000 AASHTO survey indicated that 21 of 39 agencies (54%) had an inventory of pavement markings, and most of these updated their inventory by either manual surveys or semi-automated methods (Hensing and Rowshan 2005).

Agencies characterized their IT systems for pavement markings as shown in Figure 69. Most agencies reported using broad-based management systems (such as maintenance management systems) and simple programs, followed by management systems for pavement markings and workbooks or spreadsheets. The agencies that reported using a pavement marking management system or a maintenance management or transportation infrastructure asset management system that includes pavement markings are listed here.

- Pavement Markings Management System
 - Iowa DOT
 - Kansas DOT
 - Minnesota DOT
 - Ohio DOT
 - Colorado DOT Region 4
 - Ministry of Transport of Quebec
 - Saskatchewan Highways and Transportation
 - City of Tampa, Florida.
- Maintenance or Asset Management System That Includes Pavement Markings
 - Florida DOT
 - Maryland SHA

- New Mexico DOT
- North Carolina DOT
- Ohio DOT
- Texas DOT
- Utah DOT
- Colorado DOT Regions 2 and 5
- Dakota County, Nebraska
- City of Portland, Oregon.

The need for IT support of pavement marking management has been recognized in the literature. A pavement marking inventory management system has been developed by the MnDOT to track several aspects of pavement markings (*Pavement Marking . . .* 1999; Migletz and Graham 2002). *NCHRP Synthesis 306* discusses key elements of the MnDOT system: a description of each installation in terms of its location, the date of application, the type of line, and the type and quantity of material used; tracking of inventory on a daily basis, entering changes as soon as they are installed; tracking of retroreflectivity measurements; records of specific actions taken (e.g., reviews of situations and remedial activities in the field), as well as pertinent communications such as complaints and responses thereto; costs of activities in terms of labor, equipment, and materials; and tracking of suppliers and even material batch numbers for quality control (Migletz and Graham 2002). Missouri DOT District 7 has also been using computerized programs to track pavement marking inventory for several years, particularly after responsibility for this task devolved from the DOT General Headquarters to the districts (Weinkein et al. 2002). Local governments also have used inventory systems to serve similar objectives: current and accurate information for management, performance accountability, quality control of materials and installation, and reduction of potential liability (Andrie et al. 2001).

Agencies are also investigating other IT capabilities beyond inventory management to better support their pavement marking programs.

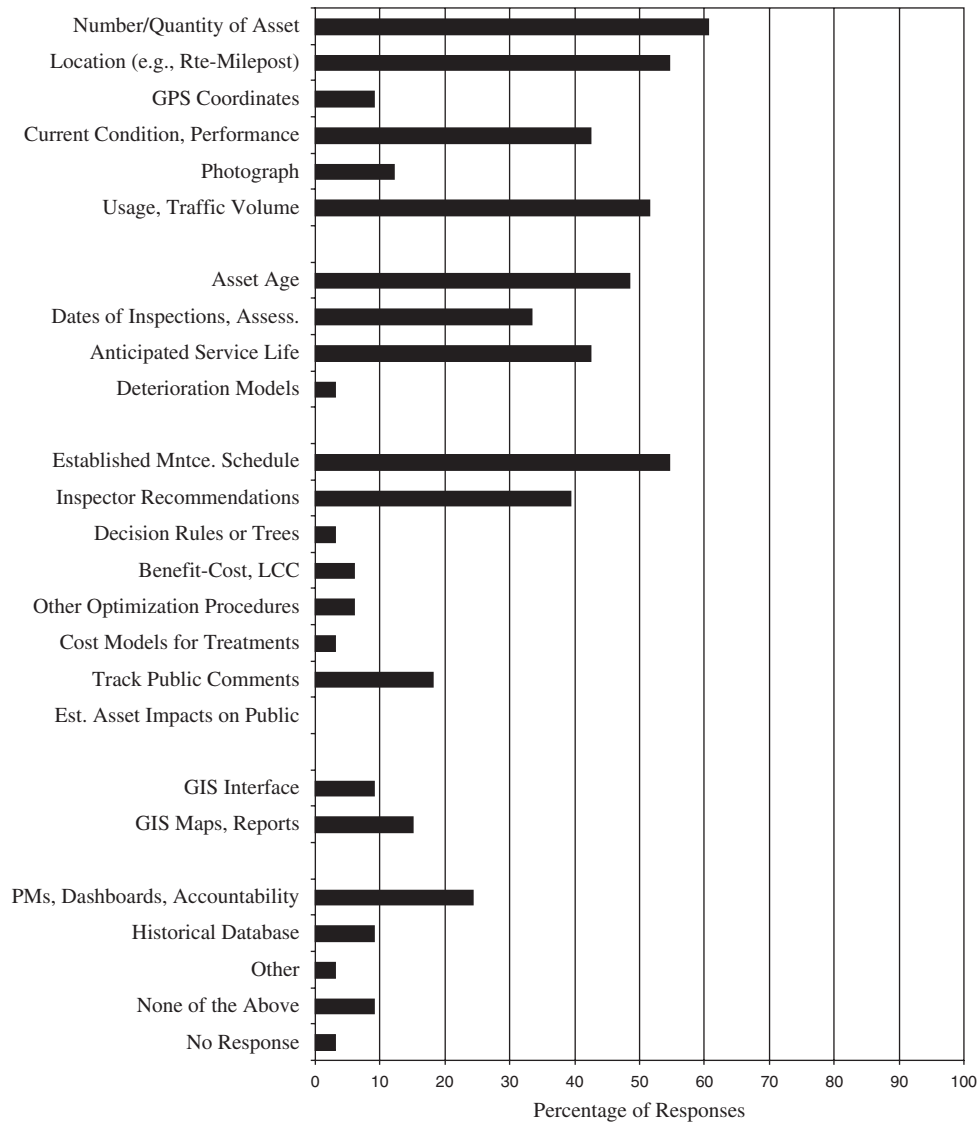


FIGURE 68 IT capabilities to help manage pavement markings. GPS = global positioning system; LCC = life-cycle cost; GIS = geographic information system; PMs = performance measures.

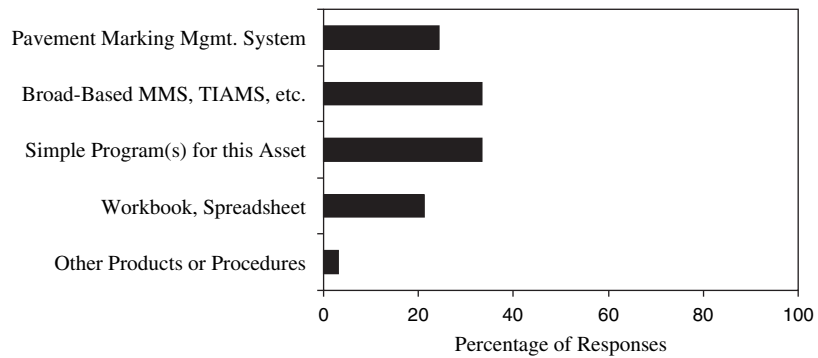


FIGURE 69 Types of analytic tools to support pavement marking management. MMS = maintenance management system; TIAMS = transportation infrastructure asset management system.

- The Utah DOT is pursuing a Crash Avoidance Performance History effort by which managers can evaluate the safety-related impacts of relevant programs, pavement markings among them. Safety-related performance measures under the Crash Avoidance Performance History will be supported by rapidly accessible crash data in the Utah DOT's Crash Data Delivery System (Anderson et al. n.d.).
- South Carolina DOT researchers have used their GIS to help develop models for predicting retroreflectivity of different materials, and displaying retroreflectivity levels in color-coded map displays. The scale of display can be adjusted to show overall results for long lengths of routes or to zoom in to see details (such as segments with low retroreflectivity) along short highway lengths. Another display also aids comparison of test results between mobile and handheld instruments (Migletz and Graham 2002).
- A computer program, the Pavement Marking Assessment System, has been developed to implement the methodology developed in *NCHRP Report 392*. This methodology includes engineering performance (visibility, durability, convenience, and cost) as well as the environmental performance (VOC emissions and health and safety considerations) of pavement marking materials (Andrady and Crowther 1998).

KNOWLEDGE GAPS AND RESEARCH NEEDS

Agencies at all levels identified a number of knowledge gaps and resulting needs for research. These comments have been organized by topic area and compiled and summarized here.

- Basic information on performance—There is a need for basic information on the performance of pavement markings under the many different environments in which they operate. Several agencies addressed this point and identified several variables that need to be accounted for in understanding actual versus predicted service life, the relationship between the cost of striping and roadway traffic volume, and the life-cycle costs of different marking materials. Among the many variables listed by agencies were rural or urban location, traffic volume, weather, altitude and climate (Colorado reports shortened life at high altitudes), degree of snowplowing and type of winter maintenance, type of pavement, roadway classification, and pavement preparation.
- Winter conditions—Special emphasis was given by several agencies to winter weather, with suggestions for research into cold weather pavement markings in addition to the considerations of winter maintenance noted earlier. Quebec reported that it is beginning to investigate this subject.
- Urban conditions—Portland noted that a better understanding of physical wear and tear and loss of retroreflectivity in urban areas would streamline decisions on

pavement marking needs. Variables that should be included in such a study include lane width, traffic volume, traffic mix, and roadway-use description (e.g., arterial/commercial district versus collector/residential, arterial/freight district). Results could be compiled within a matrix for ease of use in applying to different locations.

- Technical—Agencies recommended investigating a number of technical aspects as well; for example, long-life materials for use on bridge decks and the moisture-proofing and adhesion qualities of glass bead coatings in waterborne and epoxy paints.
- Standards—Edmonton noted that a standard definition and measurement of material failure is needed; that is, a minimum value for reflectivity and a threshold value for the number of markers that are missing. Minnesota suggested an objective determination of drivers' needs for pavement markings in various environments.

The TRAC study conducted for WSDOT (Kopf 2004) identified a number of potential sources of variability in retroreflectivity readings: environmental conditions, calibration problems, variability in methods of marking application, varying depth of glass beads in paint, orientation of the laser reflection from the beads, contamination of the pavement marking surface, differences in contrast with the pavement surface, and inherent variability in the retroreflectometer itself. Both the TRAC study and *NCHRP Report 392* also noted that unless retroreflectivity data are collected throughout the life of pavement markings, agencies must extrapolate the trend line of existing, shorter-term data to estimate service life (Andrady 1997; Kopf 2004). This extrapolation can introduce another source of error if the mathematical form and parameter values of the predictive model are not accurate over the long term.

Ongoing testing of pavement marking products is carried out by the NTPEP, sponsored by AASHTO and its member agencies. NTPEP conducts laboratory and field tests on various pavement marking materials at sites in four climatic zones around the country, and publishes results on performance for participating agencies (Thomas and Schloz 2001). However, survey results reported in *NCHRP Synthesis 306* present a mixed picture of current industry perceptions of, and reliance on, NTPEP for product testing data. Based on these findings, recommendations were developed to clarify NTPEP's purpose and criteria for success, strengthen its base nationally, improve clarity and timeliness of its product test results, and instill greater flexibility to respond to new products (Migletz and Graham 2002).

The need for more reliable and standardized retroreflectivity measurements has been discussed many times throughout this chapter. There is a need for better information in several areas; for example, the approval of a national calibration standard for retroreflectometers; a better understanding of how to achieve more repeatable, reproducible, and consistent readings; a better understood correlation

among different instruments; and protocols to measure retroreflectivity reliably and consistently under different conditions, particularly involving wet weather. More broadly, retroreflectivity needs to be understood in a performance context: how retroreflectivity affects driver performance in different highway situations (highway class, number of lanes, horizontal geometry, location of stripe, pavement marking material used, presence of lighting and RPMs, etc.); what are the visibility needs of elderly drivers; how retroreflectivity can be economically improved where needed to meet minimum thresholds, including for elderly drivers; role of pavement markings in reducing highway crashes (including pedestrian crashes); and better understanding of situations where pavement markings have a negative rather than positive impact on safety.

Among the top 16 research priorities identified by the TRB Pedestrians Committee, one research problem statement addressed pavement markings: Evaluation of *MUTCD*

Signing, Markings, and Traffic Signals for People with Visual Impairments, Children, and Elderly Adults (*Transportation Research Circular E-C084*. . . 2005).

Other topics of interest in current or proposed research on pavement markings include:

- Use of driving simulators to investigate driver performance and behavior when presented with different highway and pavement marking situations (Opiela et al. 2002).
- Tests of different embedded roadway lighting systems and configurations, driver and pedestrian responses thereto, impacts on safety, and formulation of guidelines for future usage (Ellis and Washburn 2003; Arnold 2004; Illuminated, Active, In-Pavement . . . in prep.).
- Structured or textured pavement markings to improve wet night visibility (“Making Roads Much Safer by Night” Mar. 2005; “The Right Level of Safety” Mar. 2006).

DRAINAGE CULVERTS

OVERVIEW

Pipe culverts and box culverts (referred to collectively as culverts in this chapter) allow for drainage under and around highways, streets, and sidewalks, providing stability to the road structure and preventing flooding of surrounding areas. Culverts are also increasingly being used for animal passages under highway embankments. Agencies participating in the synthesis survey ranked the transportation objectives that are served by good drainage in priority order, as given in Table 23. Agencies added prevention and reduction of flooding to the objectives listed in the table.

Meeting these objectives calls on agencies to observe standards, technical recommendations, and guidelines from a variety of sources. Figures 70 and 71 present agencies' judgments of those sources of guidance that are the important drivers of engineering and management decisions regarding culverts. These results are shown for two key aspects of asset management: new construction and installation, and maintenance and rehabilitation, respectively. The importance of individual agency policies, standards, guidelines, and procedures, together with national standards for design and statutory requirements, is evident for design of new systems or major expansion of existing systems. National standards and guidelines have been published by the FHWA and AASHTO in several relevant topics, including culvert design (e.g., *Highway Drainage Guidelines* 1987; Brown et al. 2001; Normann et al. 2001); culvert inspection (Arnoult 1986); other areas of hydraulic performance, highway drainage, and scour, as well as guidelines on the safety of roadside features such as drainage headwalls (*Roadside Design Guide* 2002). Statutory guidelines encompass, among other topics, state requirements for fish passages, which are served by culverts. Although national guidelines exist for maintenance and rehabilitation (e.g., Ballinger and Drake 1995; *Maintenance Manual* . . . 1999), guidance issued by individual agencies is the primary technical source, as indicated in Figure 71.

MANAGEMENT PRACTICES

Agencies in general maintain their own drainage systems, as indicated in Figure 72. Among agencies participating in the survey, the use of contractors or other government agencies is limited to DOTs; cities and counties reported no outside entities to conduct or manage drainage work. New Brunswick noted that forestry companies maintain some

culverts and these companies do exercise management responsibility. Ohio voiced a concern that current policies need to better account for the life expectancy of pipe materials, and to consider paying a premium up-front for longer-lasting pipe. Under current procedures, a range of pipe materials and coatings is allowable, and contractors decide which to install based on price. Current procedures need to account better for the actual service life to be expected. The Ohio DOT has developed a workbook to evaluate pipe durability during design.

Other aspects of asset management practice are revealed through an agencies' methods of budgeting for preservation, operation, and maintenance of culverts, and their approaches to preserving and maintaining culverts once in service.

Survey results for the budgeting method are shown in Figure 73. Explanations of the abbreviated budgeting process descriptions in this figure are given in chapter two. Because agencies could select multiple choices, the percentages in Figure 73 do not sum to 100%. Addressing their methods of budgeting, responding agencies at all levels of government chose a variety of options to best describe their process. The role of professional judgment continued to be important, as it has been for other assets to this point. Many agencies selected multiple options. Texas described a formula that allocates drainage funding among Texas DOT districts based on the proportion of vehicle-miles traveled within each district as compared with the statewide total, and a rainfall factor based on annual rainfall within the district compared with average annual rainfall statewide.

Agencies often described their approaches to preservation and maintenance as well in terms of multiple selections of the items shown in Figure 74. Immediate correction of problems was the most prevalent response, followed by the worst-first, prioritized, and preventive approaches. Many agencies explained the multiple approaches that they employ by differentiating how and when they are used. For example, "immediate work" would be applied to sudden failures; "corrective work" to the biennial inspections of large culverts (similar to those for bridges) or to work managed by the agency's maintenance management or maintenance quality assurance approach, and "worst-first" to aged culverts beyond their design lives that need to be rehabilitated or replaced. In a survey reported in *NCHRP Synthesis 303*,

TABLE 23
PRIORITY OF TRANSPORTATION OBJECTIVES SERVED BY DRAINAGE
CULVERTS

Rank	Factor
1	Public safety; accident and accident risk reduction
2	Preservation of the existing road infrastructure; reduced agency life-cycle costs
3	More efficient travel; maintain intended flow and operating speed; reduce travel time
4	Comfort and convenience of the traveling public (motorists, pedestrians, cyclists)
5	Road aesthetics and appeal

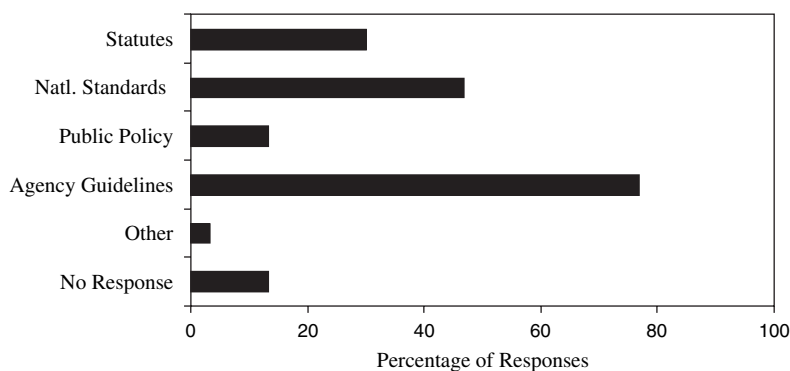


FIGURE 70 Technical management guidance for new construction and installation of culverts.

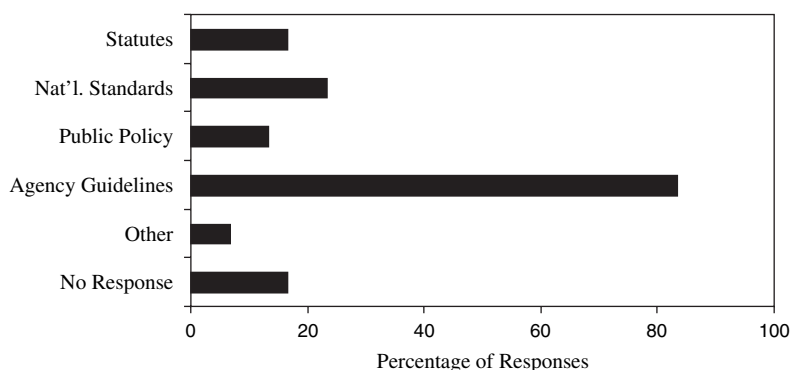


FIGURE 71 Technical management guidance for maintenance and rehabilitation of culverts.

27% of responding state and local agencies reported having a preventive maintenance program, as compared with the 20% reported in Figure 74.

MEASURING ASSET PERFORMANCE

The information provided by agencies on performance measurement of culverts is summarized in Figure 75, based on categories of performance factors similar to those described in chapter two. Many agencies reported measures of physical condition and the corresponding qualitative descriptors, and

customer complaints as their main indicators of performance. Individual agencies included other physical measures; for example, blockage, geotechnical/embankment risk, pavement or embankment settlement, standing water, and so forth. One agency mentioned basing performance on service of the culvert as a fish passage for environmental objectives. The frequencies with which state, provincial, and local agencies reported conducting their physical performance measures are shown in Figure 76. Another survey conducted by the Ohio Research Institute for Transportation and the Environment (ORITE) on behalf of the Ohio DOT indicated that 48% of DOT respondents inspected their culverts on a frequency of

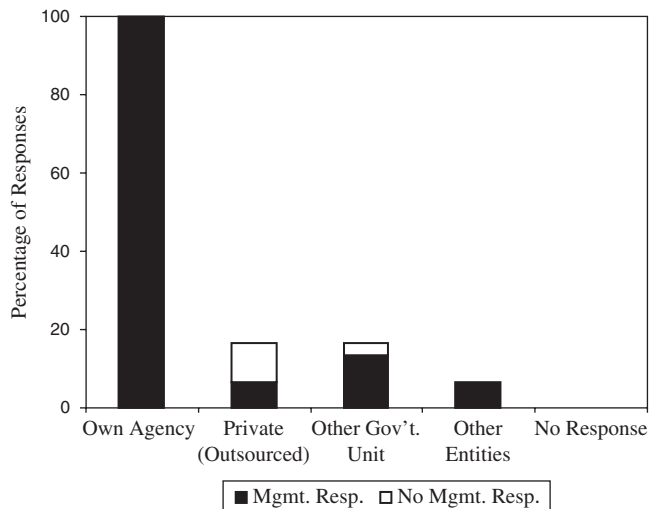


FIGURE 72 Responsibility for maintaining culverts once in service.

1–2 years, whereas 16% reported a range of frequency of 3–5 years, with some states having dual frequencies (e.g., inspecting culverts with larger than a 10-ft diameter at 1–2 year intervals and smaller culverts at 5-year intervals). The remaining 36% reported other ranges of inspection intervals; for example, 1–4 years (Mitchell et al. 2005). These results collectively show that there is no standardized inspection frequency among transportation agencies.

Although the survey in this synthesis study did not go into detail on the specific physical measurements that agencies use in assessing culvert condition, *NCHRP Synthesis of Highway Practice 303: Assessment and Rehabilitation of Existing Culverts* (Wyant 2002) reported that the pipe assessment factors cited most frequently by state, federal, and local agencies included joint failures, corrosion, deflection, and cracking. Several agencies also cited hydraulic capacity,

soil conditions, and pipe wall thickness. A few noted silt accumulation, debris, clogging, settlement, and scour. Only 15 of 59 state, federal, and local respondents (25%) to the *NCHRP Synthesis 303* survey reported having formal guidelines to assess pipe condition; among state DOTs alone, 10 of 27 (37%) had such guidelines (Wyant 2002). The survey by ORITE indicated that 60% of responding DOTs have some type of inspection policy for highway culverts, but only 12% have developed their own culvert inspection manual (Mitchell et al. 2005). ORITE identified Arizona, California, Connecticut, Indiana, Kansas, and Ohio as having such manuals; *NCHRP Synthesis 303* included Maine, New York, and Pennsylvania. Other agencies may have their own manuals, but might not have been included in survey results or mentioned in the cited reports. Also, several agencies apply the FHWA Culvert Inspection Guidelines, as discussed here.

Culverts of more than 20 ft in span, or a series of adjacent culverts that add up to a crossing greater than 20 ft in length, are included in the National Bridge Inventory. They are inspected in the United States as bridges and are therefore subject to FHWA’s National Bridge Inspection Standards (NBIS) requirements and an agency’s bridge inspection guidelines, data collection and processing procedures, and related management tools and decision criteria. Below a 20-ft-span width there are no NBIS-required inspection intervals, and agency practices differ on what defines a culvert. Approximately two-thirds of state DOTs responding to the ORITE survey reported that they apply the AASHTO definition (span less than or equal to 20 ft). Others have adopted different limiting span widths (e.g., less than 6, 10, or 15 ft) or other definitions based on a “drainage” concept, or have no definition yet in place (Mitchell et al. 2005).

NCHRP Synthesis 303 (Wyant 2002) also indicated a wide range of practice in the rating methodology of culvert

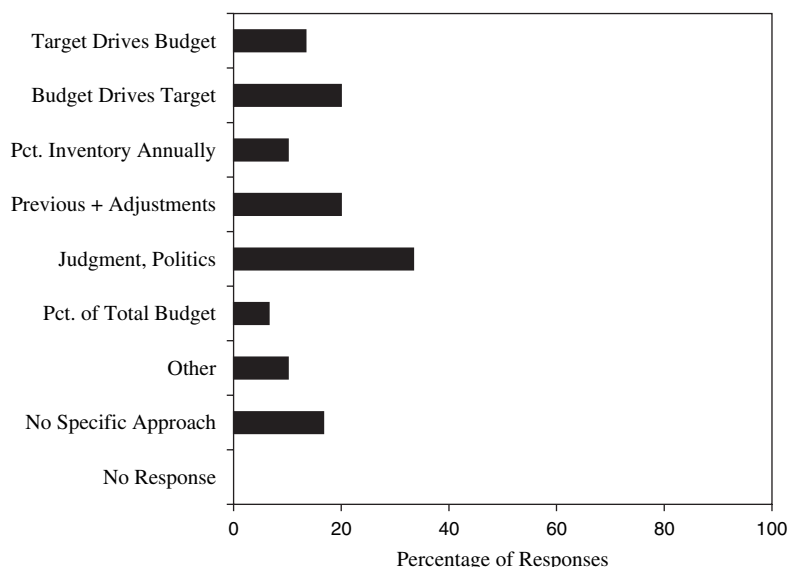


FIGURE 73 Annual budgeting method for culvert preservation and maintenance.

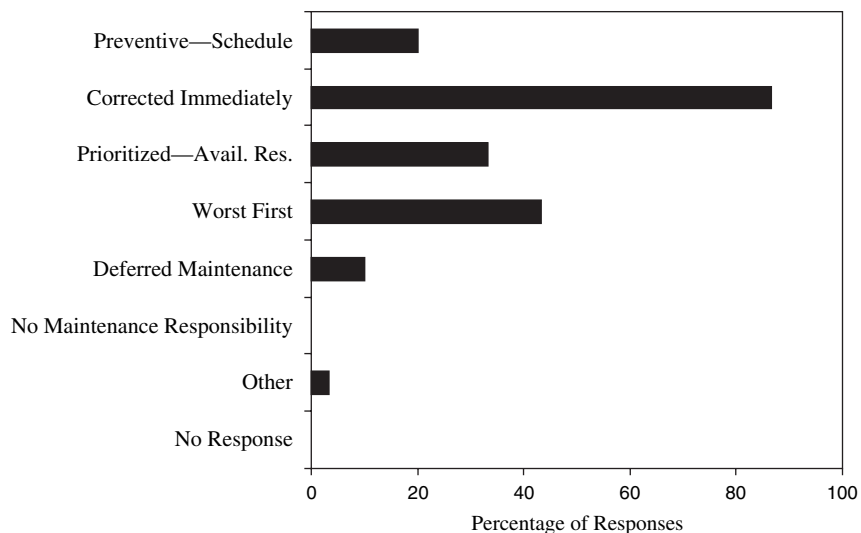


FIGURE 74 Approach to preserving and maintaining culverts.

inspections and assessments. The Utah DOT, Vermont Agency of Transportation (AOT), and many local agencies use the method in FHWA’s *Culvert Inspection Manual* (Arnoult 1986). These culvert inspection guidelines have been incorporated in the NBIS in items 61 and 62 for channels and culverts, respectively (*Recording and Coding Guide . . . 1995*). The NBIS standards continue to refer practitioners to the 1986 *Culvert Inspection Manual* for additional

details on culvert inspection, including specific rating guidelines for individual pipe materials and photographs illustrating rating levels. The specified rating scheme in the 1986 and 1995 FHWA manuals is a 0–9 scale, analogous to that used for bridge items in NBIS, where 9 denotes a new condition and 0 signals a totally failed culvert requiring replacement. Because the 1986 FHWA guidelines apply only to concrete pipes and corrugated steel pipes (CSP), however, additional

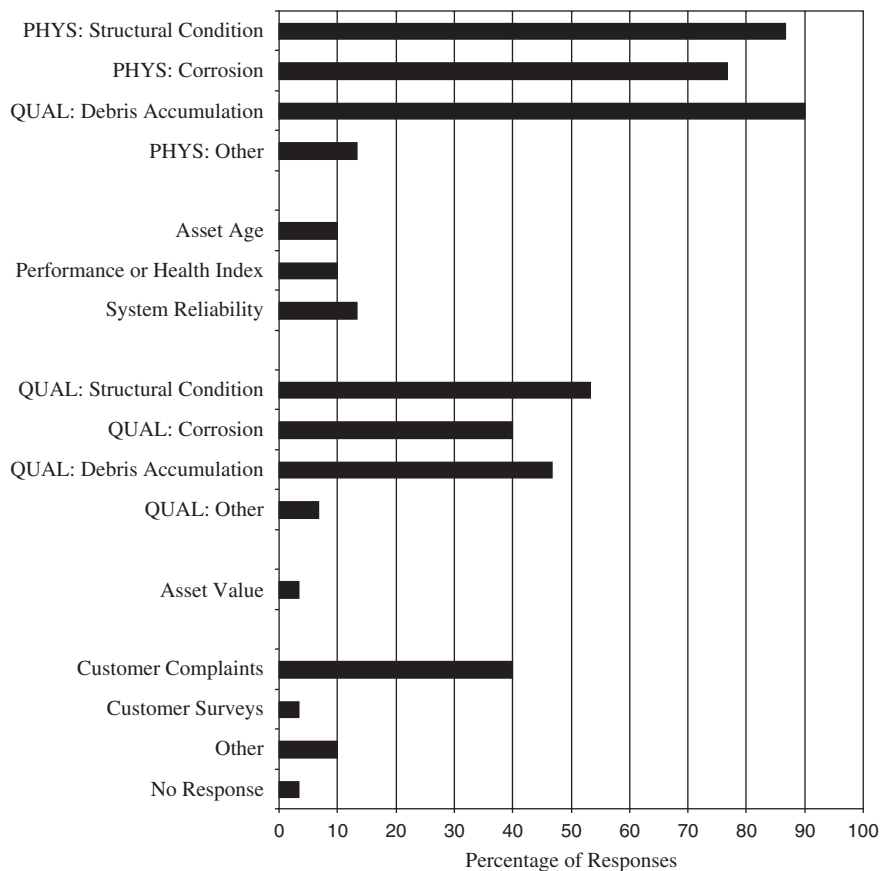


FIGURE 75 Measuring performance of culverts. PHYS = physical; QUAL = qualitative.

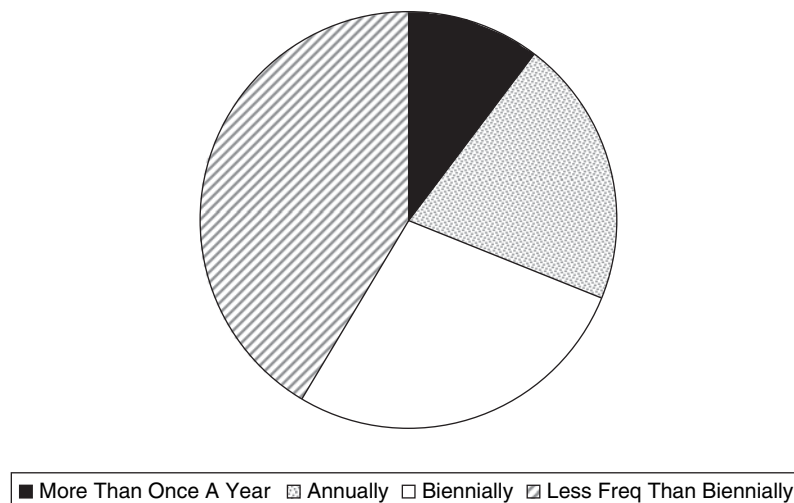


FIGURE 76 Frequency of physical condition assessments of culverts.

guidelines would be needed for other materials such as plastic pipe (Wyant 2002).

Other agencies use different inspection processes that they have developed themselves or adapted from another agency. The California DOT (Caltrans) has instituted a Pilot Culvert Inspection program that is based on a 0–4 scale, with 0 indicating no deficiencies found and 4 signaling a critical condition. Guidelines and photographs (the set not yet complete) describe and illustrate these different severity levels for several conditions (e.g., waterway adequacy, pipe alignment and shape, and condition of joints, seams, and pipe wall material) for concrete, steel, aluminum, and plastic pipe barrels. The Caltrans guidelines also address drainage appurtenances such as concrete headwalls, flared-end sections of metal pipe, drainage inlets, scour at pipe ends, embankment and roadway condition, and metal riser pipe (*Caltrans Supplement . . .* 2003).

In 2001, the Montana DOT developed a rating system for culverts that is based on 33 individual culvert attributes encompassing general information (location, site characteristics, installation date, etc.); culvert shape, dimensions, and height of cover; and indicators of existing damage mechanisms (e.g., age, corrosion, worn invert, side slope failure, piping, perched outlet, etc.) (Cahoon et al. 2002; Baker et al. 2006a,b). For purposes of field testing and calibration, an overall culvert rating was also requested of field inspectors on a 1–5 scale, with 5 indicating excellent condition and 1 denoting poor condition. The 33 inspection items were believed to be all relevant and of potential value in a comprehensive culvert database. Of the 16 indicators of existing damage, however, only a subset of 9 of these was found to be statistically significant in indicating overall culvert condition and need for remedial work. These nine culvert attributes included culvert age, scour at the outlet, evidence of major failure, degree of corrosion, worn culvert invert, sedimentation of cross section, physical blockage, joint separation, and presence of physical damage (Cahoon et al. 2002).

NCHRP Synthesis 303 provides further examples of rating forms, guidelines, and summary reports from different agencies. Current agency experience emphasizes the value of clear guidance, photographs, and inspector training in ensuring a consistent and accurate inspection result, regardless of the guidelines and rating schemes used. Nonetheless, although 37 of 57 respondents (65%) to the *NCHRP Synthesis 303* survey reported having an inspection program, only 27 of these agencies retained these condition records, a step that would otherwise be helpful to a preventive maintenance program (Wyant 2002).

The methods used by responding agencies to assess culvert condition and performance are reported in Figure 77. Visual inspections are the most common method used, followed by physical measurements, photologging or videologging, and fielding customer complaints. Ohio recently instituted a formalized culvert inspection program. The Ohio DOT inspects any culvert with a 10 ft or more combined span length every year (the Ohio DOT also inspects all of its bridges annually, as required by state statute). Culverts with a span length of less than 10 ft are inspected every 5 years. Under “Other” methods, Minnesota noted inspections of the deflection of steel plate arch pipes. Texas monitors culverts during floods to identify culvert obstructions, damage, adequacy of size, or any failures. Portland conducts dye testing and investigations with closed-circuit television.

Survey results regarding the use of video equipment in Figure 77 are consistent with findings of the ORITE survey, which indicated that 30% of the respondents use special equipment for inspection of small culverts. This equipment typically consisted of a video camera, including robotic video systems and tractor-mounted video cameras. Some DOTs responding to the ORITE questionnaire noted that they do not inspect culverts smaller than a certain diameter; for example, 4 ft (Tennessee), 5 ft (New Jersey), or 6 ft (Vermont) (Mitchell et al. 2005).

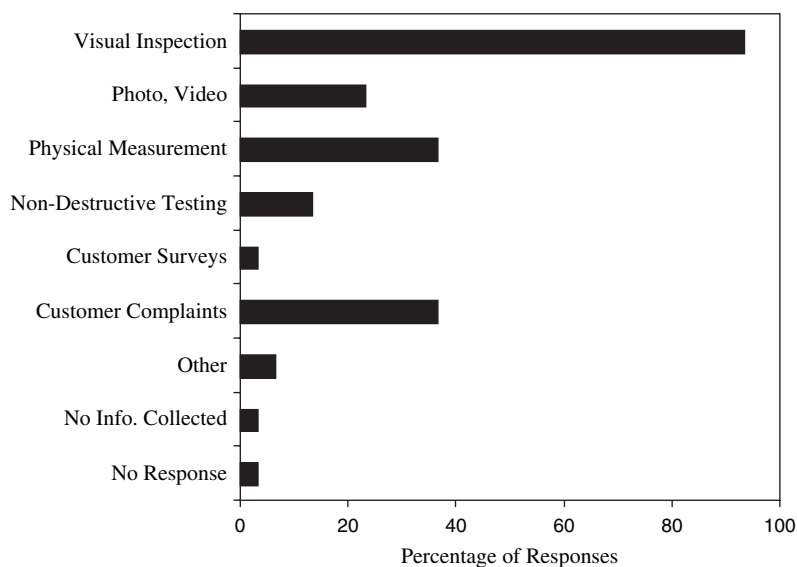


FIGURE 77 Data collection methods for culvert condition and performance.

ASSET SERVICE LIFE

Factors Affecting Service Life

The service life of a culvert pipe is influenced by factors related to the pipe and its placement, the drainage water it carries, and the soil that surrounds it. Studies have shown that no single factor alone is an adequate determinant of service life. Nonetheless, design professionals and asset managers need a practical way to evaluate alternate pipe materials at each location to identify technically and economically feasible options; evaluate life-cycle costs (including prediction of service life); develop construction specifications; and project maintenance, rehabilitation, and replacement requirements. Agencies must therefore balance needed simplicity and practicality against comprehensive, detailed estimation of behavior. The inherent complexity in dealing with pipe durability is indicated by the number of mechanisms that can degrade culvert service life (*Precast Concrete Pipe Durability* 1991; Gabriel and Moran 1998; Cahoon et al. 2002; *Corrugated Steel Pipe Handbook* 2005; *ODOT Hydraulics Manual* 2005).

- **Physical damage**—Physical damage to the pipe can result from crashes by vehicles leaving the road, improperly performed maintenance, fire, distortion of the pipe caused by applied loads that exceed the pipe’s structural capacity, and settlement. All of these mishaps can lead to reduced hydraulic efficiency and potential damage to the roadway foundation and surface. Settlement, which can be the result of improper backfilling, moisture in the roadbed, and exfiltration from leaking pipe joints, can contribute to roadway and side slope damage. Freeze–thaw cycles acting on moisture in concrete pipe walls can cause spalling and lead to further damage as a result of chemical attacks, although the likelihood of this mechanism is reduced in pipe that is completely buried. Structural collapse of the pipe barrel is a failure both hydraulically and structurally, and can have serious consequences for the roadway pavement and foundation.
- **Abrasion**—Abrasion of pipe material is caused by sands and aggregates (bed materials or “bed loads”) carried by water through the pipe. It is affected by the volume and velocity of the flow and the amount, size, and abrasiveness of material transported. If the pipe invert is completely abraded and worn away, the pipe can fail structurally. When abrasion exposes bare metal subject to corrosion, as in corrugated metal pipe (CMP), corrosion also often becomes a problem. Abrasion in concrete pipe can be aggravated by chemical attack (e.g., from acids or sulfates), with the resulting combined damage greater than the sum of the individual effects of these mechanisms. Abrasion of aluminum pipe can be a determinant of service life, because the metal is comparatively soft as compared with the abrasives. Abrasion-resistant pipe materials and proper manufacturing methods, pipe coatings, and paving of the invert are used to resist the effects of abrasion.
- **Corrosion or chemical attack**—Corrosion or chemical attack can occur from within or outside the pipe, and the literature differentiates between water-side and soil-side analyses of these mechanisms. Materials incorporated within the highway foundation design (e.g., lime-treated base) can affect corrosion, as can the chemical composition of the native soil. With concrete culverts, the possibility of chemical attack is increased when a low pH and soluble salts, particularly sulfates and chlorides, are present in soil or in drainage water, although sulfates and chlorides may be a problem more for cast-in-place concrete structures rather than for buried precast concrete pipe (*Precast Concrete Pipe Durability* 1991). Corrosion effects on the concrete

cement and aggregates, as well as reinforcing steel, need to be considered. Acid, caused by acidic soil or aggressively acidic water runoff, can also degrade concrete. If the drainage water is abrasive, chemical degradation of the concrete will accelerate erosion of the pipe wall surface and lead to a destructive cycle of corrosion and abrasion. For steel pipe, “most states have found culvert durability correlates with [soil-side and water-side] pH and resistivity; other states have been unable to confirm this” (Gabriel and Moran 1998, p. 17). Notwithstanding the importance of these variables, however, “predictions of useful service life based solely on pH and resistivity are inconclusive” (Gabriel and Moran 1998, p. 18). The presence of soluble salts, soil moisture content, and oxygen also effect corrosion of CSP in soil. The potential for corrosion may be increased on the soil side by soil moisture, soluble salts, and oxygen, and on the water side by abrasion of the steel or its coating, and the presence of soluble salts and dissolved oxygen or carbon dioxide in the effluent. Aluminum pipe is subject to pitting owing to soluble salts, stress corrosion cracking, and electrochemical corrosion. Although plastic pipe is generally resistant to pH and to chemical and electrochemical corrosion, it can be damaged by serious (albeit unlikely) highway spillage accidents involving concentrated acids and bases or prolonged exposure to high concentrations of certain organic chemicals such as crude oil or its derivatives. Corrosion and other chemical problems are inhibited by using nonreactive, corrosion-resistant pipe materials, coatings, and linings; providing cathodic protection; or installing an oversize pipe, anticipating future relining after corrosion has occurred. The Oregon DOT noted that water containing salt or chemicals can be very corrosive, and site-specific countermeasures are often required (*ODOT Hydraulics Manual 2005*, pp. 5–20).

- Piping—Piping is water flowing through the fill surrounding the culvert barrel. It can result from poorly compacted fill around the pipe or improper or deficient end treatments that allow water infiltration outside the pipe barrel. Because piping can displace the fill that surrounds the pipe, it can lead to deformation of the culvert barrel as well as to settlement and damage of the roadway foundation and surface.
- Other damage or failure mechanisms—Other failure mechanisms such as buoyancy, overtopping, and erosion or failure of side slopes can occur as the result of inadequate culvert design or sizing, inadequate protection or armoring of slopes, and blockage of flow at the inlet or within the culvert barrel. Regarding sun-related effects on plastic pipe: although it can be considered prudent to protect the exposed ends of plastic pipe from sunlight, constituents are often added to the pipe material during its manufacture that can protect it from harmful UV rays. Other mechanisms mentioned in the literature include localized corrosion such as pitting, crevice corrosion, stress corrosion and cracking, and microbiologic corrosion (Gabriel and Moran 1998).
- Sedimentation—Sedimentation and debris collection reduce the culvert cross-sectional area and impede flow. Debris can collect at damaged ends of culverts or be deposited inside the barrel; vegetation at either end may reduce the flow speed, act as a collector, and contribute to debris accumulation. Sedimentation can result from a culvert being installed too low, resulting in a backwater pool at the downstream end. As the speed and flow of water is reduced, additional sedimentation can occur. Culvert sedimentation and debris are usually addressed as a maintenance item; only if ponded water resulting from continued inattention leads to more severe problems will culvert repair or rehabilitation need to be considered.

Therefore, determination of culvert service life has many aspects to consider. The previous descriptions, however, greatly simplify the technical, often site-specific, variables, and potential damage mechanisms that need to be evaluated. As one complicating factor, damage mechanisms can interact with one another, as illustrated by several earlier examples. Further complexity is caused by the role of the local ambient environment. For example, the corrosive effect of chemicals in the soil may depend on the degree of soil aridity; the acidity of drainage water reflects not only local soil, rock, and rainfall conditions, but also surrounding activities such as mining; the decomposition of vegetation in steel pipes serving in a warm, wet climate can create organic acids that can lead to corrosion; and the effect of freeze–thaw cycles and thermal stresses on concrete pipe depend on the degree to which the pipe is buried, which reduces atmospheric exposure. The physical and chemical details of possible reactions need to be recognized with sufficient understanding and sophistication, and translated to effective design and analysis procedures. Because the relationships among pipe material, water chemistry, and soil chemistry are complicated, agencies often find it prudent to specify allowable ranges of factors in terms of both upper and lower bounds, with annotations of critical situations and interactions. As a final point, although each potential damage mechanism can be mitigated by good practice in culvert design, pipe manufacturing, pipe material selection and specification, construction, and maintenance, culvert performance and service life also benefit from a policy of regular, thorough inspection to identify and remedy problems in their early stages.

Synthesis and Other Survey Findings

Information on current practice regarding service life was obtained in the study survey for two major components of drainage networks: pipes and box culverts. Responding agencies were first asked to identify how they would determine service-life values. Responses to this question are shown in Figure 78. Among the 30% of reporting agencies

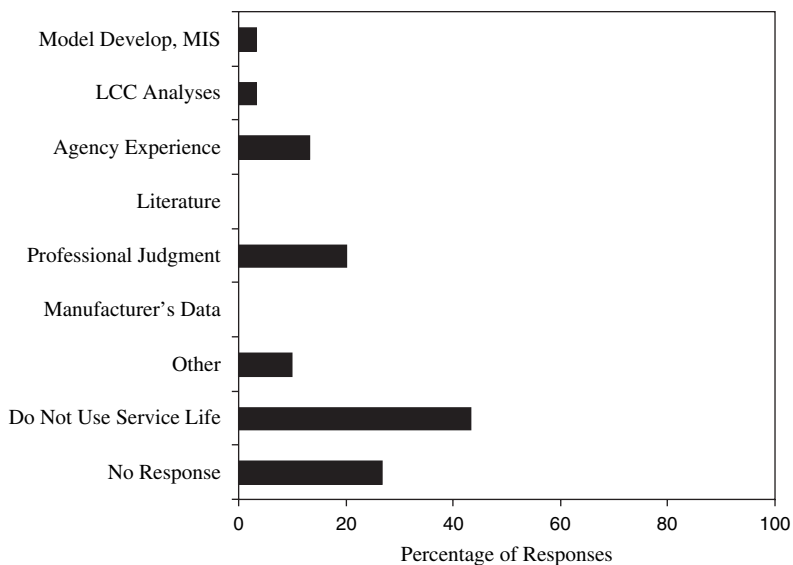


FIGURE 78 Sources for determining service lives of culverts. MIS = management information systems; LCC = life-cycle cost.

that identified at least one method, their selections focused on agency experience, professional judgment, and manuals or guidelines that individual agencies have prepared, which inform the estimation of service life.

Within this context, agencies explained their evaluation of the suitability of different culvert materials for new installation design (none addressed the use of service life for rehabilitation and replacement). For example:

- Kansas—In road design for nonfreeway, cross-culvert applications on lower volume roads, the service life of CSP is estimated in selected counties based on soil pH and resistivity. The calculation determines the suitability of CSP in these locations and applications. In situations unsuitable for CSP, concrete pipe is used. The service life of CSP is thus variable, and the service life of concrete is greater than that of CSP.
- Oregon—The Oregon DOT has developed design service-life data for several types of drainage installations (e.g., cross culverts, other locations of culverts, storm drains, subsurface drains, and slotted drains), type of facility (e.g., freeway), and locations (e.g., within travel way, shoulders, and between curbs). Design lives are specified for each realistic combination of these factors; values range from 25 to 75 years. The Oregon DOT also lists the candidate materials that would be suitable for each combination of factors; these are analyzed in the design process (*ODOT Hydraulics Manual* 2005).

Comprehensive service-life data reported by agencies in the study survey are given in Table 24. Examples of the distributions of estimated service lives for pipes and box culverts are shown in Figures 79 through 82. The labels on the horizontal axis in these figures give the upper values of each range of service-life data. For example, if these labels are 0,

10, 20, 30 . . . , then the column labeled 10 shows the number of responses for estimated service life of zero to 10 years; the column labeled 20, the number of responses for estimated service life of more than 10 to 20 years; the column labeled 30, the number of responses for estimated service life of more than 20 to 30 years; and so forth. It should be noted again that the data in Table 24 and Figures 79 through 82 may be derived in part from the professional judgment of agency personnel.

These results may be compared with results of another survey of U.S. and Canadian provincial transportation departments that was conducted as part of an investigation of life-cycle cost analysis (LCCA) techniques applicable to culverts. The LCCA survey yielded a range of service-life assumptions across 25 responding agencies for the following pipe materials (Perrin and Jhaveri 2004):

- Reinforced and nonreinforced concrete pipe: 50 to more than 100 years.
- CMP: 35 to 50 years.
- High-density polyethylene (HDPE): 30 to 100 years.
- Polyvinyl chloride (PVC): 50 years.
- Vitrified clay: no responses.

Agency Practices

Agency practices regarding culvert service-life data and assumptions are described in more detail in the literature. Data in the Oregon DOT culvert manual regarding values of design life to be used were discussed earlier. *NCHRP Synthesis 303* provides data from several other agencies, noting that most that use service-life base their estimates on soil and water pH and soil resistivity (a measure of the relative quantity of soluble salts, which influences corrosion resistance)

TABLE 24
ESTIMATED SERVICE LIVES OF DRAINAGE CULVERTS

Component and Material	No. of Responses	Minimum (Years)	Maximum (Years)	Mean (Years)	Median (Years)	Mode (Years)
Pipes						
Concrete	13	30	100	60.4	50	50
Corrugated metal	16	10	60	37.3	35	50
Asphalt coated corrugated metal	5	10	75	43	50	50
Small diameter plastic	7	10	75	50	50	50
High-density polyethylene	1	—	—	50	—	—
Box Culverts						
Reinforced concrete	15	30	100	63.3	50	50
Timber	3	10	50	30	30	—
Precast reinforced concrete	1	—	—	50	—	—
Polyvinyl chloride	1	—	—	30	—	—
Aluminum alloy	1	—	—	50	—	—

Notes: —, value is undefined for the particular distribution. When distribution is based on only one data point, its value is shown in the Mean column.

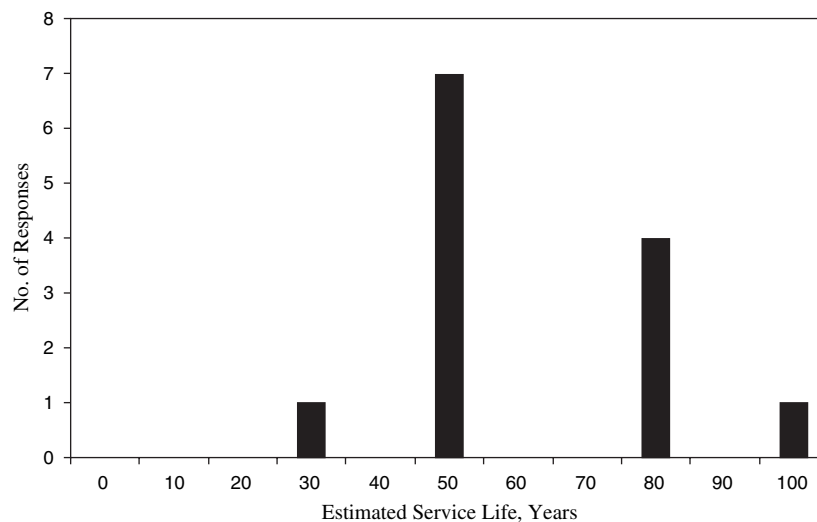


FIGURE 79 Estimated service life of concrete drainage pipe.



FIGURE 80 Estimated service life of corrugated metal drainage pipe.

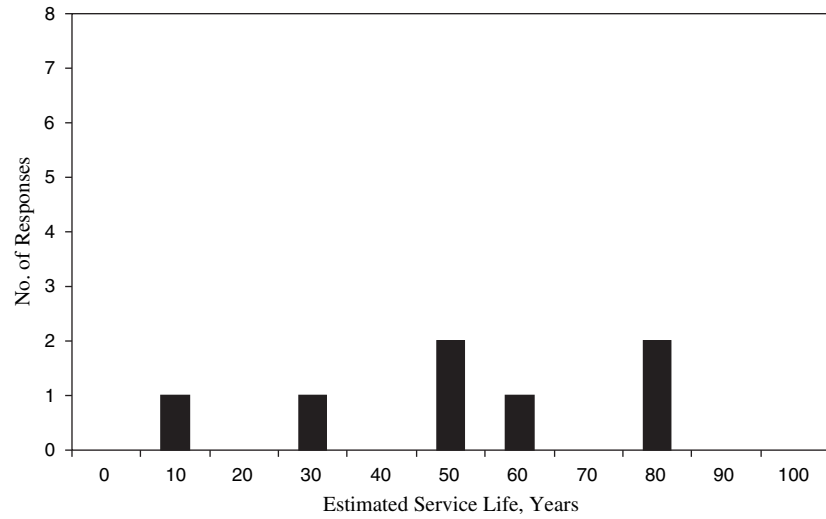


FIGURE 81 Estimated service life of small diameter plastic drainage pipe.

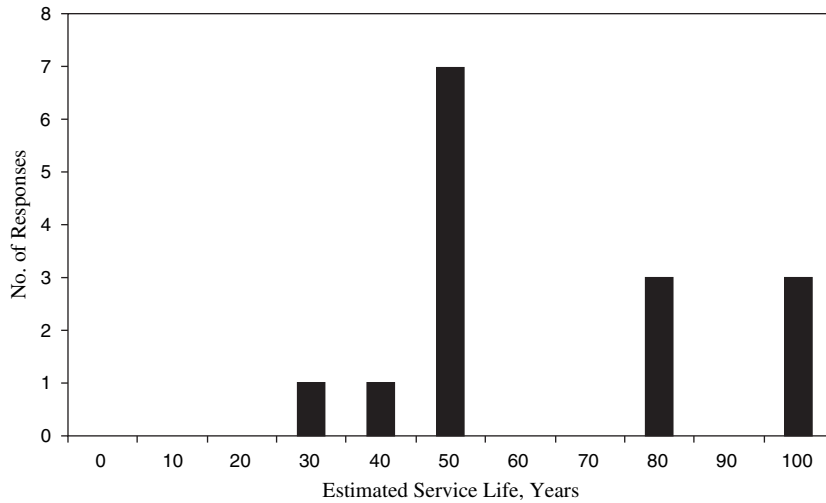


FIGURE 82 Estimated service life of reinforced concrete box culverts.

to determine the recommended types of pipe material, coatings, and other installation details. Agencies differ, however, in the manner and degree to which they simplify the results for practical use in design. Following are examples of different ways to incorporate service life in design recommendations, as drawn from the literature:

- For each combination of type of pipe material and level of corrosion resistance, Wyoming indicates whether the material is suitable for use in that corrosion environment, using a Yes–No convention. Service-life data are not explicitly shown (Wyant 2002, Table 10, p. 23).
- For each type of highway facility (Interstate, arterial, collector, etc.) and pipe function (i.e., drainage application or installation), Arkansas lists the recommended type(s) of pipe material. Service-life data are not explicitly shown (Wyant 2002, Table 11, p. 24).
- Mississippi identifies service-life criteria in years for each drainage application. In each case, allowable materials alternates are listed, together with specific technical requirements (*MDOT Pipe Culvert . . . 2005*).
- Louisiana lists design service life for each combination of drainage application and type of pipe material and pipe joint. Values range from 30 to 70 years (Wyant 2002, Table 12, p. 25).
- Montana’s service-life guidelines explicitly consider pH value and resistivity. For each combination of pH and resistivity, usage options are listed for four types of culvert materials: steel, aluminized steel, aluminum, or concrete. The options are stated simply: OK, No, or reference to a note specifying additional technical information; for example, whether to use a coating on steel or aluminized steel pipe, and type of cement needed on concrete pipe (Wyant 2002, Table 13, p. 26).
- New York State’s approach is to divide the state into two zones based on annual metal loss rates for steel pipe, and to estimate the anticipated service life for steel pipes as a function of pipe wall thickness (gauge), type of steel pipe (e.g., galvanized–metallic coated and galvanized with polymer coating), and the two geographic zones (Wyant 2002, Tables 14 and 15, p. 26).
- Utah DOT’s material selection for metal and for concrete pipe employs sets of parametric curves that relate pH, resistivity, and percent soluble salts to expected service life for different classes of metal and concrete pipe. Metal pipe classes are based on corrugated or structural plate pipe and different metallic and nonmetallic coatings. Concrete pipe classes are based on the use of Type II or Type V cement, depending on measured sulfate levels (Wyant 2002, Figures F6 and F7, pp. 73–74).
- California provides a set of curves that are functions of pH and resistivity, and that indicate the minimum thickness of metal pipe needed for a 50-year, maintenance-free service life (Wyant 2002, Figure F2, p. 70). These curves have been developed based on a testing procedure developed by Caltrans to estimate steel culvert service life. This service life is based on the estimated time to the

first perforation of the metal pipe resulting from corrosion (*Method for Estimating . . . 1999*). Although some other agencies use the Caltrans method for their own determinations of service life, experience in other states has shown that in some regions of the country the method is too conservative, whereas in others it is too liberal (e.g., because of the prevalence of soft water). These results demonstrate the importance of using local information whenever possible; nonetheless, the Caltrans method is still judged to be the most reasonable for general use (*Corrugated Steel Pipe Handbook 2005*).

- Many studies of culvert performance and that of other in-ground structures have also been done in Canada, including the following as reported in the *Corrugated Steel Pipe Handbook 2005*):
 - A study of CSP in Southwestern Ontario conducted by Golder in 1967, which showed that the California method did correctly predict service life in that local area.
 - A 1993 study of remaining coating thickness on 21 steel plate and galvanized bin-type retaining walls, all more than 20 years old (with the oldest, 60 years old), conducted by the British Columbia Ministry of Transportation and Highways. The investigations also included tests of soil and water pH and resistivity. Results indicated an expected service life of more than 100 years on all but two structures, both of which had already exhibited abrasion significant enough to reduce expected life.
 - A study of zinc coating loss on 201 CSP installations by Alberta in 1988, which also investigated soil and water pH, resistivity, and electrical potential between the pipe and the soil. The study concluded that a minimum service life of 50 years would be attained in more than 80% of the installations, and that the average service life across these pipes would exceed 80 years.
- The service life of a culvert pipe may be extended by increasing the thickness of metal pipe walls, paving the metal pipe invert, applying supplementary coatings to metal or concrete pipe, or specifying a reaction-resistant type of cement and aggregate in concrete pipe and cast-in-place structures. Guidelines on treatment options and the expected “add-on” service life are included, for example, in *NCHRP Synthesis 303* (Wyant 2002, Table 16, p. 5; Figure F3, p. 70), the *CSP Durability Guide* (2000, p. 5), and the *Corrugated Steel Pipe Handbook 2005*, Table 8.3, p. 353).

Durability Studies

A number of agencies have conducted research on the service life of culverts and what factors are critical to culvert performance. Through research and analytic models, they have sought to understand the complicated relationships underlying culvert durability on an objective, field-verified basis. Following are examples drawn from Missouri, Montana, Ohio, and California, among other agencies.

Missouri DOT

The Missouri DOT has been studying the durability and performance of galvanized CSP and reinforced concrete pipe since the 1930s. Its findings have suggested a service life of 50 years for CSP and almost 100 years for reinforced concrete pipe. However, an attempt to model service life as a function of variables such as pH, abrasion, soil resistivity, chemical properties of runoff, and watershed characteristics was unsuccessful. “No single parameter or combination of parameters accurately predicted service life in all areas of the state” (Cahoon et al. 2002, p. 199). Missouri has also used HDPE since 1983, and the material is still under evaluation. Recently the department installed large-diameter (60-in.) HDPE pipes for evaluation, particularly to monitor pipe wall deflections and joint separation for this flexible material (Blackwell and Yin 2002).

Montana DOT

The Montana DOT (MDT) specifies a culvert design life of 75 years. Using its service-life estimation procedure, which is based on corrosion, MDT can assess materials options for proposed culverts and evaluate current and anticipated performance of existing culverts. MDT’s method is based on American Iron and Steel Institute (AISI) formulas, which calculate service life as a function of resistivity alone for soil with pH of at least 7.3, and of resistivity and pH for soil pH values of less than 7.3. Using these equations with values of pH and resistivity determined from soil sample collection and laboratory testing, it analyzes service life for various pipe materials and recommended coatings and treatments. For example, CSP is considered with a galvanized, aluminized, bituminous, or polymeric coating. If none of these options can meet the 75-year criterion, then other pipe materials are recommended; for example, aluminum or concrete. Although this method has provided a way for MDT to analyze the effects of corrosion, it does not address other damage mechanisms (Hepfner 2001; Cahoon et al. 2002, p. 199; Wyant 2002).

In a separate study of corrosion of CSP, a consultant reviewed MDT’s soil sampling, testing, and analysis methods to recommend improved design practice (Hepfner 2001). The study was motivated by a number of premature CSP failures in Montana. In the overview of existing agency practice, it was noted that there existed a wide variation in materials selection criteria, and a lack of standardized procedures for identifying potentially corrosive environments and evaluating suitable pipe materials to meet design criteria. More specifically, the complexity in pipe–soil interactions that can lead to corrosion, and the variety of sample preparation and testing methods for resistivity were described, an important determination for corrosion analyses. In applying different testing methods to MDT soil samples, it was demonstrated that the differences are not only in terms of resistivity values themselves, but also in the recommended pipe material that would result from the use of the respective resistivity values.

The study recommended that MDT adopt an AASHTO procedure for resistivity testing, and that soil sampling include the materials to be used around the pipe and under the conditions (e.g., moisture, chemical transfer, and bacterial growth) that are expected to pertain at the culvert location in the field. In the longer term, the study recommended development of a database of corrosion-related data, including soil resistivity, pH, chloride and sulfate concentrations, soil type, location, and sampling depth, and mapping of these data to a statewide soil survey map. The study also recommended use of “early warning system” field monitoring to warn of impending corrosion so that remedial measures such as cathodic protection can be installed before the need for more expensive culvert replacement. These detection devices would be installed at locations of questionable soil characteristics or where historical performance of galvanized steel pipe fails to measure up to analytical predictions of service life. These field data could also be used to refine pipe corrosion models (Hepfner 2001).

MDT has also sponsored university research on a condition index for rural culverts. The index is defined on a scale of 1 to 5, where 5 denotes excellent condition, and 1 poor condition. The method employs a spreadsheet to compute a pipe’s condition index based on a number of key inspection variables as discussed earlier, including age, degree of scour at the outlet, evidence of past major hydraulic or structural failure, degree of corrosion, extent of invert wear, physical blockage, sedimentation, joint separation, and physical damage. Average daily traffic and detour length for culvert repair or replacement are also used as weights on the condition result to reflect road-user impacts. These variables are rated according to qualitative assessments (e.g., no damage, minor damage, or major damage), ranges of condition (e.g., five ranges of numbers of vehicles crossing the culvert—0–500, 501–2,000, and so forth), percentage values, and other similarly general assessment measures (Cahoon et al. 2002; Baker et al. 2006a,b).

Ohio DOT

Ohio has been analyzing data on culvert performance for more than two decades. Its 1982 report on culvert pipe durability represented a 10-year study of 1,600 culverts from around the state, some of which had been installed before 1940 (Meacham et al. 1982). Data collected under this study contributed to the development of models to predict pipe service life for different pipe materials and characteristics, as well as soil and water properties (Hurd 1986a,b, 1988; *Precast Concrete Pipe Durability* 1991). For example, the models for concrete pipe included pipe age, pipe vertical diameter, invert slope, water pH, the depth of sediment, and flow velocity as independent variables (Gabriel and Moran 1998). The models for metal pipe included pipe age, pipe wall thickness, water pH, and abrasion as independent variables (Mitchell et al. 2005).

The culvert rating approach used by the Ohio DOT since 1982 was updated in 2003, and followed by the development of a culvert risk assessment methodology (Mitchell et al. 2005). The analyses contributing to this methodology included linear as well as nonlinear regression of field performance data that were collected under the new inspection procedure. This new procedure was based on a 0–9 scale to rate pipe conditions (with 9 denoting excellent condition and 0 indicating failure), whereas the earlier procedure before 2003 had employed a 4-point scale (good, fair, poor, critical, with 1 denoting good, and 4 indicating critical). The risk assessment was calculated by taking the original average culvert rating, based on inspection results, and adjusting it for factors that can indicate a reduction in remaining expected life: current age, water pH, abrasiveness, and the pipe cover height-to-vertical diameter ratio (reflecting a greater risk to motorists if this ratio is smaller). In addition to these methodological investigations, the study also recommended an expanded inspection protocol (revising the 2003 procedures) that would consider 30 to 33 items rather than the 16 items in the current Ohio DOT inspection manual. These recommendations were developed for concrete, metal, and plastic pipe used by the Ohio DOT. The culvert inspections conducted in this study indicated that concrete culverts have a service life of 70–80 years, and metal culverts 60–65 years (Mitchell et al. 2005).

California DOT (Caltrans)

In California Test Method 643, service life is based on the estimated time to the first perforation of the metal pipe as a result of corrosion (*Method for Estimating* . . . 1999; Wyant 2002). This test method incorporates a set of curves that indicate the minimum thickness of metal pipe needed for a 50-year, maintenance-free service life, and that are functions of pH and resistivity. The testing procedure and curves were developed based on field studies of the performance of 7,000 culverts that began in the 1950s and were subsequently updated to yield today's standardized procedure (Beaton and Stratfull 1962; Ault and Ellor 2000). Although other agencies use the Caltrans method or variations of this method for their own determinations of service life, experience in other states has shown that in some regions of the country the method is too conservative, whereas in others it is too liberal. These results demonstrate the importance of using local information whenever possible; nonetheless, the Caltrans method is still judged to be the most reasonable for general use (*Corrugated Steel Pipe Handbook* 2005). The California method "is now the most widely accepted method to determine culvert durability" (Ault and Ellor 2000, p. 51). The FHWA study also found that the California method works satisfactorily in several locations nationwide, but can over-predict or under-predict service life in others. This is perhaps not surprising, because the California method was based on statistically average values of variables among the randomly sampled culverts in the field studies and does not predict durability well in extreme conditions.

Other Examples

The FHWA study identified other predictive models that have been developed by Florida and AISI, both of which are similar to the California method, but introduce specific variations. FDOT has developed models to directly predict the service life of concrete pipe, aluminized Type 2 corrugated steel, and aluminum alloy culverts (Ault and Ellor 2000). FDOT has also conducted supplementary studies on the effects of seawater on the durability of reinforced concrete culvert pipe (Sagüés et al. 2001). The AISI method uses a chart similar to California's, but applies a different criterion for when a pipe is judged to reach its service life. The AISI predictions are thus double those of the California method. Other organizations [New York, Colorado, and the National Corrugated Steel Pipe Association (NCSPA)] have developed procedures based on a service-life concept; however, these are structured to aid in selecting the most appropriate materials rather than to predict a value of culvert life itself (Ault and Ellor 2000). The North Carolina DOT also attempted to derive service-life prediction models for four types of pipe in three geographical regions of the state, but was unsuccessful. Its recommendations for further work included the development of databases on site-specific information regarding soil and water chemistry and physical drainage characteristics (Gabriel and Moran 1998). *NCHRP Synthesis Reports 254* and *303* and the 1996 FHWA study describe these several approaches to analyzing service life. The FHWA study also describes software that agencies have developed to perform related computations.

Durability studies have been conducted for other pipe materials. The use of HDPE by Missouri was mentioned earlier. Although this material has been in use in the United States for more than 35 years (*Design Service Life* . . . 2003) and is applied in transportation facility drainage in more than 40 states (Reddy 1999), agencies are continuing to evaluate its performance under field conditions and for larger pipe diameters. Although the durability of a high-quality plastic material itself can yield potentially long service lives (exceeding 100 years for corrugated HDPE pipe—*Design Service Life* . . . 2003; Gabriel 2005), there are several concerns regarding performance under field conditions, including the following (Reddy 1999):

- Pipe-wall deflection, joint separation, and potential buckling of the pipe owing to improper installation and backfilling, or vehicle live loads.
- Stress cracking, as a result of improper installation and backfilling, which can lead to catastrophic failure.
- Creep of the plastic material and creep rupture.

The study acknowledges the complexity of the problem and the need for additional laboratory, analytic (computer simulation), and field investigations (Reddy 1999). The Wisconsin DOT has also installed large-diameter (48-in.) HDPE pipe, and if performance results continue to be favorable, will

expand their application (Wilson 2000). The importance of proper installation, including preparation of the bedding soil, use of appropriate backfill material and procedures, and providing sufficient cover, have been emphasized in an evaluation of 45 HDPE highway drainage pipes in South Carolina (Gassman et al. 2002). An investigation of the in-service performance of HDPE pipes in six states has been conducted on behalf of the American Concrete Pipe Association (ACPA), documenting pipe-wall deflection; distresses such as buckling, bulging, and cracking; joint separation; and misalignment (Nelson and Krauss 2002).

Performance studies have also been conducted for the following materials:

- PolyRib, a small-diameter pipe manufactured from polymer-coated galvanized steel, which showed favorable results (Brockenbrough 2002).
- Aluminized steel pipe, in studies conducted by the manufacturer (Morris and Bednar 1982) and by a research consultant for the FHWA (Ault and Ellor 2000).

Criteria for Determining Service Life

NCHRP Synthesis 254 discusses the concept of culvert service life as applied to each type of major pipe material: concrete pipe, steel pipe (including CSP and spiral-rib steel pipe, metallic-coated, nonmetallic coated, lined, and paved), Alclad aluminum pipe (Alclad is an alloy that is bonded to the aluminum alloy core that provides cathodic protection to the aluminum pipe) and aluminum structural plate, plastic pipe (including HDPE, PVC, and acrylonitrile-butadiene-styrene), ductile iron, and clay. Because different damage mechanisms affect these materials, the selection of particular mechanisms as well as the threshold values that define service-life criteria can vary among transportation agencies. The following are examples regarding reinforced concrete pipe (Gabriel and Moran 1998):

- California uses the debonding of reinforcing bars as its measure of service life.
- Colorado bases service life on functionality, relying on a committee of professionals to determine whether the pipe still meets its intended purpose.
- Missouri defines service life as the time until pipe replacement.
- North Carolina defines service life as the age beyond which 80% of pipes may be expected to experience functional failure.
- Mississippi assumes that concrete pipe will last the life of the highway facility.

Analogous examples of the diversity among agency service-life criteria are given in *NCHRP Synthesis 254* for other pipe materials.

Variability in assessing culvert durability is subject as well to natural causes, as illustrated by the following statements:

Durability is not defined as clearly as structural and hydraulic standards for drainage pipe systems, because it includes the performance of the components of concrete and reinforced concrete structures. Durability deals with life expectancy and the endurance characteristics of a material or structure. Among other considerations, the varying nature of climate, weathering, soils and geology, fluid chemistry, product installation techniques, in-plant production, material mixes, and raw material quality cloud the development of a way to define durability and predict performance (*Why Concrete Pipe?* 2006).

... the corrosivity of an environment is based on multiple, independent (and interdependent) variables and their interaction. No single parameter dominates the corrosion process, and therefore a combination of individual indicators is needed to accurately evaluate the corrosive potential of a particular environment.

The inherent complexity of soil corrosion [of corrugated metal culvert pipes] creates great difficulties in estimating a reasonably valid service life... for a given site. No single corrosion contributing factor can be utilized to assess corrosion potential of a metal pipe/soil system. At the present, corrosion assessment is typically based on experience; no singular, standardized methodology is used in highway departments or private consulting firms (Hepfner 2001).

Assessing Remaining Service Life for an Existing Culvert

To apply the service-life concept in asset management, a method is needed to determine where an asset is in its service life—that is, how much life is consumed and how much remains. Agencies were presented with a number of ways to determine the current status of an asset regarding its service life, and asked to rank each method by relevance to their agency. The result is shown in Table 25.

Under “Other factors,” agencies reported the following:

- Kansas—Culverts of 10–20 ft in size or span are inspected every other year, and smaller pipes are inspected occasionally, to identify potential problems. Although an “estimated service life” is not used to project impending failures, an effort is made to identify the end of the actual, practical service life through regular inspection.
- Pennsylvania—The culvert condition is analyzed using a matrix to determine the treatment and cost.
- Texas—Culvert condition is analyzed when the road is expanded or rehabilitated.

Although several states have long-standing and continuing programs to assess culvert condition and infer remaining service life, most agencies do not apply service life in their routine culvert management. Seventy percent of the respondents to the question addressed in Figure 78 either reported that they do not use service life or left this item blank. This result echoes findings of an earlier survey reported in *NCHRP*

TABLE 25
RANKING OF METHODS TO DETERMINE WHERE CULVERTS ARE IN
THEIR SERVICE LIVES.

Rank	Factor
1	Assets are repaired or replaced as soon as they fail without regard to service life
2	The agency does not use/does not monitor service life for this type of asset
3	Monitor condition of the asset occasionally
4	Monitor condition of the asset on a periodic schedule
5	Other factors
6	Compare current age of asset with the maximum age that defines service life

Synthesis 303. When asked whether they predicted service life as part of their decision process for selecting culvert remedial treatments, only 13 of 55 agencies (24%) responded affirmatively. Most of these reported using service-life data provided by manufacturers. When it is used, service life generally informs decisions on relining or replacing metal culverts, although some agencies (e.g., Utah) may also apply service life to concrete pipe. *NCHRP Synthesis 303* reported that service life is to date rarely used with plastic pipe. The two local agencies that responded affirmatively in the *NCHRP Synthesis 303* survey to use of service life noted that they apply their respective state DOT's data and procedures (Wyant 2002).

NCHRP Synthesis 303 reported that only 5 of 56 respondents (9%) had a standard set of guidelines to select the most appropriate culvert repair method, and 4 of 56 respondents (7%) standard guidelines to select the most appropriate rehabilitation method. However, a somewhat larger number, 15 agencies (27%), noted that they do consider several factors in making decisions on pipe rehabilitation, including hydraulic capacity, traffic volume, height of fill, service life (12 of these 15 agencies), and risk assessment (Wyant 2002).

The ORITE survey addressed factors affecting state DOT decisions on culvert replacement, with the following rates of affirmative response (numbers do not sum to 100% because agencies could select more than one response):

- Degree of culvert material degradation: 80%.
- Roadway surface conditions over the culvert: 50%.
- Deflections in the culvert: 38%.
- The sum of numerical rating scores: 23%.
- Culvert age: 8%.
- Other factors including joint conditions, fish passage issues, roadway expansion/rehabilitation/replacement, failure or imminent failure of the culvert, inadequate flow capacity, replacement criteria used for bridge class structures, and video inspection results: 33%.

Only in a relatively small number of instances were any of these criteria identified as the sole basis for decisions on culvert replacement. In most cases, agencies reported multiple criteria driving culvert replacement (Mitchell et al. 2005).

On the related issue of identifying the extension in service life owing to maintenance, agencies provided some examples of current practice in their responses to the synthesis survey:

- Ohio field paves CMP inverts before complete failure and assumes 75 years of additional life for the structure.
- New Brunswick expects 50 or more years of additional life after rehabilitating a culvert using a concrete invert or aluminum alloy and grout slip-lining.
- Saskatchewan has used cathodic protection to prolong the life of corrugated steel pipes.

Impacts of Culvert Performance

Although the value of proper culvert performance to the public appears to be well understood in concept (Table 23), there is relatively little guidance on how to demonstrate these benefits analytically for highway assets, let alone to mount compelling arguments publicly for the benefits of stronger culvert management. Viewed in another way, there are relatively few examples in the literature of methods to analyze and communicate the consequences of culvert failure, even though it is well understood that potential impacts to the road surface, highway embankment, and resulting mobility of road users can be severe. Forensic studies of pipe failures at specific locations appear in the literature (e.g., Freeman 2003, addressing the problem of backfill in the culvert trench). Several cases of culvert failure were reviewed in a study of LCCA to culverts, identifying the significant component of total costs that is attributable to road-user delays (Perrin and Jhaveri 2004). The concept of incremental road-user cost owing to closures resulting from culvert failures is recognized implicitly by factors such as traffic volume and detour length that are included in the rating systems discussed earlier. Caltrans' inspection rating guide includes a photograph of pavement

and foundation failure resulting from a failed culvert (*Caltrans Supplement . . . 2003*). From an environmental perspective, the benefits of an effective culvert and drainage management system for hydrologic analysis and better storm water management have also been recognized (Venner 2005).

A general approach to deal with impacts of failure has been recommended based on LCCA, including culvert replacement costs and road-user delay costs. However, this proposal is acknowledged to be but a beginning, and the state of practice generally leaves much room for advancement. A survey conducted as part of the LCCA study indicated that only 4 of 25 respondents reported that they employ some type of least-cost procedure for culvert material selection. Fifteen of the 25 agencies in the LCCA survey reported that they document culvert failures; however, the level of detail varies greatly from one agency to another. The assumed service life of different pipe materials, as well as the unit costs of these

materials used in the LCCA procedures, likewise varied among agencies (Perrin and Jhaveri 2004). The American Concrete Pipe Association describes LCCA methods developed by the U.S. Army Corps of Engineers and ASTM to analyze the most cost-effective, long-term investment options for alternate pipe materials, structures, and systems (*Design Data 25 . . . 2002*). Although these methods consider several engineering and economic factors for agency first cost, remedial costs while in service, and residual costs, there is no consideration in either method of the benefits or other impacts of culvert performance to road users and the public.

INFORMATION TECHNOLOGY SUPPORT

Agencies participating in the study survey identified their key IT capabilities for culverts as shown in Figure 83. Physical measures, age, inspection data, GIS-generated maps, and

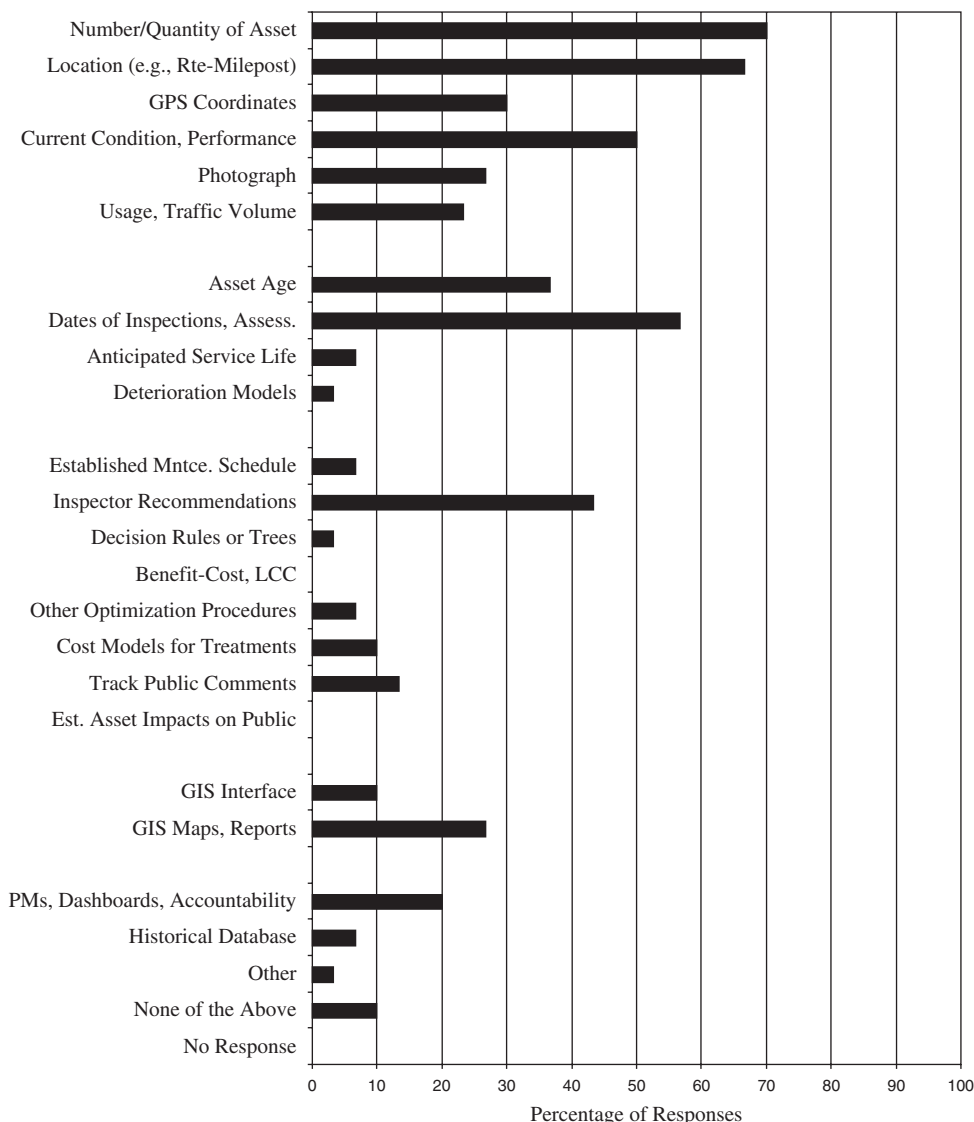


FIGURE 83 IT capabilities to help manage culverts. GPS = global positioning system; LCC = life-cycle cost; GIS = geographic information system; PMs = performance measures.

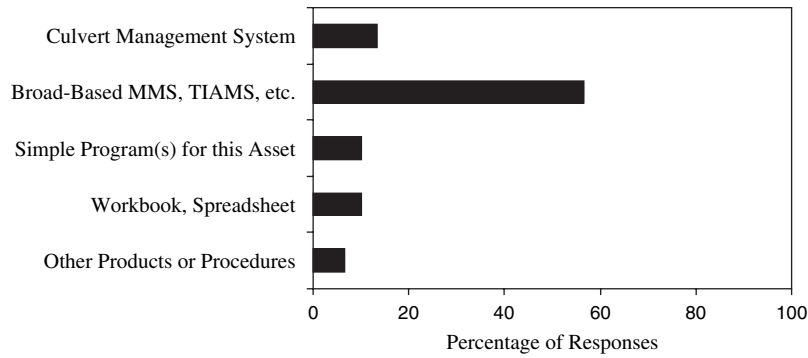


FIGURE 84 Types of analytic tools to support culvert management. MMS = maintenance management system; TIAMS = transportation infrastructure asset management system.

performance/accountability reports such as dashboards were the most prevalent items selected. Agencies characterized their IT systems for culverts as shown in Figure 84. The greatest number of responses pertained to broad-based management systems (such as maintenance management systems).

The agencies that reported using a culvert management system or a maintenance management or transportation infrastructure asset management system that includes culverts are listed here.

- Culvert Management System
 - New York State DOT
 - Ohio DOT
 - Oregon DOT
 - New Brunswick DOT.
- Maintenance or Asset Management System That Includes Culverts
 - Arkansas DOT
 - Florida DOT
 - Iowa DOT
 - Maryland SHA
 - Minnesota DOT
 - North Carolina DOT
 - Pennsylvania DOT
 - Texas DOT
 - Utah DOT
 - Vermont AOT
 - Virginia DOT
 - Colorado DOT Region 4
 - New Brunswick DOT
 - Saskatchewan Highways and Transportation
 - Dakota County, Nebraska
 - City of Jacksonville, Florida
 - City of Portland, Oregon.

“Other” options mentioned by agencies included the following:

- Ohio is in the initial start-up phase of establishing a culvert inventory system.

- Texas accesses inventory information from its inventory database and maintenance expenditures from its maintenance management system.

The earlier survey summarized in *NCHRP Synthesis 303* reported that 11 of 57 state, federal, and local respondents, or 19%, had a management system that made use of pipe assessment data gathered by the agency (Wyant 2002). Several states are reported in the literature as having established culvert pipe management systems, including California, Connecticut, Maine, Minnesota, New York, North Carolina, and Pennsylvania (Beaver and McGrath 2005), and the Maryland SHA (Venner 2005). Initial work to develop such systems is underway in Utah (Beaver and McGrath 2005) and New Jersey. The work for the New Jersey DOT is intended to produce a Culvert Information Management System, a component of the New Jersey DOT’s Transportation Asset Management System. The project has therefore developed an initial set of survival probability curves for CSP in urban areas based on data from an ASTM study, although the authors emphasize that a more definitive set of curves will need to be estimated from actual historical data or accelerated test results in the future. Preliminary technical and cost data and decision rules have also been proposed, defining a framework for further Culvert Information Management System development (Meegoda et al. 2005).

The ORITE survey, which asked about computerized databases rather than management systems, indicated that 23 of 40 DOTs (58% of those responding) had such capabilities. These databases include culvert-specific storehouses (e.g., developed in Microsoft Access® in California and Vermont), and the Pontis® database for culverts larger than 10-ft span, with smaller culverts addressed in a separate database (Minnesota). Washington State reported that it is beginning to use GPS to track the location of culverts (Mitchell et al. 2005). MDOT is also proposing to include culverts in a GPS-based database of roadside assets and features (see chapter eight). Examples of software used to implement particular design procedures or service-life calculations have been compiled in an FHWA study (Ault and

Ellor 2000). Louisiana has developed an expert system to analyze the costs of installing cathodic protection on its metal culverts (Garber and Smith 1999).

GIS are just beginning to be used to organize, display, and analyze hydraulic data for culvert design. In a survey of state DOTs conducted as part of a GIS drainage-application development for the Texas DOT, only 10 of 32 respondents (31%) reported using GIS, mainly for mapping and data management. Of these, only Maryland was applying its GIS for hydraulic analysis (Olivera and Maidment 1998).

KNOWLEDGE GAPS AND RESEARCH NEEDS

Over the long term, industry sees a strong role for technology to improve culvert products and installation procedures. The TRB Millennium paper addressing culverts and drainage structures provided a vision of potential advances that can be anticipated in the future (Hill 2000):

- Improved materials for concrete pipe, including improved concrete mixes, greater use of polymeric and epoxy coatings, and synthetic fiber reinforcement of the concrete and polymeric coatings, all of which will increase durability and strength.
- Substantial changes in metal pipes, including greater structural economy through the use of higher-strength, lighter-gauge materials; improved metallic, nonmetallic, and organic coatings; increased abrasion resistance; greater use of automation and tighter manufacturing tolerances to aid jointing and installation, including onsite manufacturing and assembly in some installations; and prevalence of hydraulically smooth pipe profiles.
- Improved culvert installation, involving methods such as trenchless technology, more automated control of backfilling, tighter joints, or jointless pipe.
- As a result of the above advances, improved durability such that a 100-year design life will become a minimum requirement.
- Greater use of computer-assisted design of culvert systems, including use of satellite imaging and GPS data for pipe location and sizing, to better relate drainage design to water resource management and potential environmental impacts.

Within the shorter term, knowledge gaps and research needs tend to focus more on management needs than technology. Agencies at all governmental levels that responded to the synthesis survey provided a number of comments in this regard for culverts.

- Basic management data and tools—There is a need for better condition and performance data and analytic tools to support culvert and pipe management. Many agencies cited data needs that include a complete inventory in terms of number, size, and date of installation (therefore

age); condition of culverts; records of maintenance and resources used; evaluations of both the structural and the hydraulic performance of culverts; models of deterioration or service life and life-cycle cost; and institution of a periodic inspection program. Several agencies mentioned an important need for periodic inspection and a comprehensive and consistent assessment of this infrastructure, but recognized funding and personnel limitations to do this. Analytic tools are also needed to interpret the data, help prioritize repair or replacement, and assist in managing the asset.

- Stormwater infrastructure performance—The initial selection of culvert material can be complicated by local factors, and evaluation of performance needs to recognize these and other complexities of in-service infrastructure. The life of steel culverts is affected by both soil type and the content of runoff materials. Knowledge of these effects is specific to certain sites and is acquired only after the fact. Research on life expectancy needs to account for these various conditions. This point is reinforced by New Brunswick, noting that durability must be related to water chemistry and pipe exposure thereto. Ohio notes that simple equations (or procedures) of service-life expectancy that require very little field data are most desirable. Determination of both the pH and abrasiveness of runoff carried in the culvert are difficult to determine for most designers, and soil resistivities are even more difficult. Texas noted that it has had few failures of pipe culverts or box culverts, and most of these are the result of corroded galvanized metal pipe. New Mexico likewise does not have many failing culverts; they are generally replaced in road reconstruction before they wear out. Again, the lack of a periodic culvert inspection program is a major gap in knowledge.
- Applying performance to management—Because culvert performance varies across the country, agencies saw an issue in how to apply performance information to management and communication. Oregon voiced a need to develop standardized methods for determining the remaining culvert service life of different materials. New York indicated a need to define a state of good repair both for individual culverts and for the inventory as a whole. This would enable the agency to define performance goals and targets, and to analyze the impacts of different maintenance strategies on system performance in terms of to what degree these targets have been met. Ohio noted that managers may not be fully aware of how a missing invert or poor pipe joints can collapse a road. Tampa observed that the lack of a reliable funding source inhibits attainment of the level of service that would accomplish a standard measure of performance.
- Broader culvert performance management—Several agencies commented on the broader implications of culvert management to the hydrology of a region. Michigan noted that there is no evaluation of the impact of changing land use on the drainage area to the culvert.

Furthermore, there is inadequate or no evaluation of the impacts of extending existing culverts during road reconstruction, in terms of changes to the structural and hydraulic characteristics of a culvert. Dakota County, Nebraska, commented that there should be more involvement in culvert management with the Natural Resources Conservation Service (a unit of the U.S. Department of Agriculture).

- Agency evaluation of materials and performance—Several agencies identified the need for research in how agencies evaluate culvert materials and performance. Maryland noted that the determination of service life for different culvert materials should be based on field performance. Most research today, by contrast, is conducted in controlled environments. Performance based on actual site conditions, accounting for the variability in water and sediment among locations, is not widely known. Vermont identified a need for research on new methods and materials to repair and rehabilitate culverts in place to extend service life. Saskatchewan proposed research involving field assessments to validate lifespan predictions by the manufacturing industry.

This more immediate focus on management needs is echoed in a recent research problem statement for culverts. This research topic calls for the development of recommended rehabilitation techniques for concrete, steel, and plastic pipe. The research would include the establishment of critical design criteria for each of several possible failure mechanisms in each pipe material, development of test methods to determine the performance of remedial treatments as well as environmental effects on pipe materials that affect durability, and conduct of accelerated testing of the remedial

treatments in the laboratory and the field (*Committee Research Problem Statements* 2005).

The literature has identified the need for materials-related research as well as improved installation procedures for culverts, and a better understanding of the role of drainage culverts in the water resource environment. The TRB Millennium Paper on culverts and drainage structures based its projections on a future culvert service-life requirement of at least 100 years and a need for hydraulically smooth walls. New coatings can be expected to lengthen service life and be more abrasion resistant. Joints in pipe will be more tightly gasketed, welded, or eliminated in jointless pipe; onsite manufacture or “in-the-ground manufacturing” of a water conduit are also foreseen. New installation procedures will improve the quality and economy of installation. These innovative procedures will include gains in trenchless technology (directional boring, tunneling, and jacking), as well as in open-trench installation, with greater use of automation and improved control of backfill. Environmental considerations will recognize water as a precious resource, and seek to minimize effects on stream flow (including fish passage), control flow rates, and focus more on recharging groundwater resources where technically possible rather than releasing water into nonusable bodies (e.g., salt water or polluted water) (Hill 2000).

Ongoing research is also identifying better techniques for rehabilitating pipes. A research study investigated materials for cost-effective, non-flammable pipe liners to rehabilitate corroded metal pipes. After considering a number of different coatings and pipe liners, the researchers concluded that the best solution was to reline the metal pipe with HDPE pipe and use concrete end caps to resist grass fires (“Cost Effective . . .” 2005).

SIDEWALKS

OVERVIEW

Sidewalks provide a safe, convenient way for pedestrians to move about on a path that is physically separated from vehicular traffic on roads and streets. Sidewalks allow easy access to homes, schools, work places, and shopping and recreational areas. When the physical features of the sidewalk—walkway, curbs, curb cuts, and ramps—are coordinated with street lighting, traffic signals, signs, and pavement markings, an environment is created where pedestrians can proceed along the walkway and cross streets conveniently and safely. Sidewalks serve all groups of the population—children, adults, the elderly, and those with disabilities. For this reason, the design, upgrading, and maintenance of sidewalks and related features (curbs, curb cuts, and ramps) must conform to the Americans with Disabilities Act (ADA, 28 CFR Part 35).

Agencies that participated in the study survey were asked to rank in order of importance the transportation objectives that are served by sidewalks. The composite results across all responding agencies are given in Table 26. New York pointed out, as part of their survey response, that compliance with ADA maintenance requirements should be understood as an aspect of the transportation objectives represented in Table 26.

Meeting these objectives calls on agencies to observe standards, technical recommendations, and guidelines from a variety of sources. Figures 85 and 86 present agencies' perceptions of those sources of guidance that are the important drivers of engineering and management decisions regarding sidewalks. Results are shown for two key aspects of asset management: new construction and installation, and maintenance and rehabilitation, respectively.

The importance of ADA, national standards, state and local public policy, and especially individual agency policies, standards, guidelines, and procedures, is evident in these results. AASHTO guidelines for pedestrian facilities include the design and maintenance of sidewalks (*A Policy on Geometric Design* . . . 2004). The FHWA has developed a software tool, PEDSAFE, to help practitioners identify and select countermeasures that promote greater pedestrian mobility and safety, and that can be tailored to local site situations, identified safety problems, or desired changes in behavior (Harkey and Zegeer 2004). Canadian guidance for sidewalks is found in an InfraGuide Best-Practice document for sidewalk design, construction, and maintenance [*National*

Guide to Sustainable Municipal Infrastructure (InfraGuide) 2004]. The city of Portland (Oregon) noted that ADA requirements should be seen as an explicit aspect of both construction and maintenance guidance. The city of Edmonton noted that Canadian guidance includes the InfraGuide Best-Practice guide mentioned previously and the TAC's Urban Supplement (Geometric). [Author's note: As this report was going into production, users of the InfraGuide were informed that it was being discontinued owing to a lack of continued funding. The website is no longer available.]

MANAGEMENT PRACTICES

Synthesis Survey Findings

Maintenance of sidewalks is characterized by a sharing of responsibility among public and private groups, and can vary by locale. The distribution of work and maintenance management responsibility that was reported by agencies participating in the study survey is shown in Figure 87. The major sharing of responsibility occurs between DOTs and local governments. (Canadian provincial ministries did not respond to this question.) Both DOTs and local agencies contract with private firms, with a mixed practice as to whether contractors exercise management responsibility. The "Other" category refers to property owners (or their local subdivisions), who are responsible for maintaining the portion of the sidewalk that fronts their property. The city of Portland notes that it maintains corners and the free-standing curb; however, the property owner maintains the sidewalk.

Other aspects of asset management practice are revealed through agencies' methods of budgeting for preservation, operation, and maintenance of sidewalks, and their approaches to preserving and maintaining sidewalks once in service.

Survey results for the budgeting method are shown in Figure 88. Explanations of the abbreviated budgeting process descriptions in this figure are given in chapter two. The largest number of responding agencies at all levels of government chose the "staff judgments, political priorities, and citizen demands" option, but overall the results in Figure 88 appear to have a somewhat indefinite quality. More than 25% of the responding agencies indicated "no specific budgeting approach," and more than 20% selected "Other." Based on the accompanying comments by agencies, this ambivalence appeared to be because (1) not all agencies maintain sidewalks; (2) there is no specific,

TABLE 26
PRIORITY OF TRANSPORTATION OBJECTIVES SERVED
BY SIDEWALKS

Rank	Factor
1	Pedestrian and cyclist safety; accident and accident risk reduction
2	Pedestrian and cyclist comfort and convenience
3	Increased accessibility to employment
4	Increased accessibility to transit, bus, and rail
5	More efficient travel, reduced time and congestion
6	Local aesthetics and appeal
7	Improved air quality
8	Other

assigned budget for sidewalks that would require a structured process; and (3) sidewalk expenditures are not large enough to be overly concerned about budgeting.

Agency approaches to sidewalk preservation and maintenance are tallied in Figure 89. Immediate correction of problems and a prioritized approach to correcting problems were equally the strongest responses, followed by worst-first and deferred maintenance approaches. No agency selected preventive maintenance as a description of its strategy. Agencies explained their characterizations by clarifying how and when they are used. For example:

- Maryland (prioritized approach)—The State Highway Administration will reconstruct sidewalks in a one-time effort to improve safety and pedestrian accessibility. Local subdivisions must then accept maintenance of both new and reconstructed sidewalks.
- Edmonton (prioritized approach)—It is really a reactive approach. Priority is given to areas of high-pedestrian use; for example, hospitals or senior-citizen lodges. The agency does not attempt to meet any performance targets. A perennial backlog exists.
- Portland (worst-first approach)—This is used for curb repair and has a limited budget. (Other): This includes the sidewalk posting program, with a 20-year cycle.

- Iowa (prioritized approach)—Applied to Interstate rest area sidewalks.
- Tampa (prioritized approach)—Our prioritization program focuses on repairing the most severe and highly traveled sidewalks first. All repairs are made within 12 months of request.

Sidewalk Management Plans and Guidelines

City of Portland, Oregon

The city of Portland’s Office of Transportation (PDOT) has developed a Sidewalk System Management Plan as part of its approach to comprehensive asset management (*Portland Transportation Asset Management 2004*). Sidewalks are recognized as building more cohesive neighborhoods, adding value to homes, and encouraging walking. The plan comprises several parts:

- Asset trends and updates, describing the physical asset, the status of current inventory, condition, unmet needs, current performance, and budget and expenditure history.
- Standards, roles, and responsibilities, covering the several bureaus within PDOT regarding sidewalk planning, design, construction, inspection, and maintenance.
- Effectiveness and efficiencies, comparing Portland’s program with those of other jurisdictions, relating condition to various service levels, and highlighting opportunities for innovation and further operational efficiencies.
- Emerging issues and action plan, outlining identified needs, actions, and priorities.
- Appendices, which describe specific policies, procedures, selection criteria, and other details.

In its plan, Portland notes a unique aspect of its sidewalk preservation management: proactive inspections that notify property owners if repairs to their sidewalks are needed. By contrast, other jurisdictions surveyed by Portland rely on public complaints to warn of needed repairs. PDOT tracks the

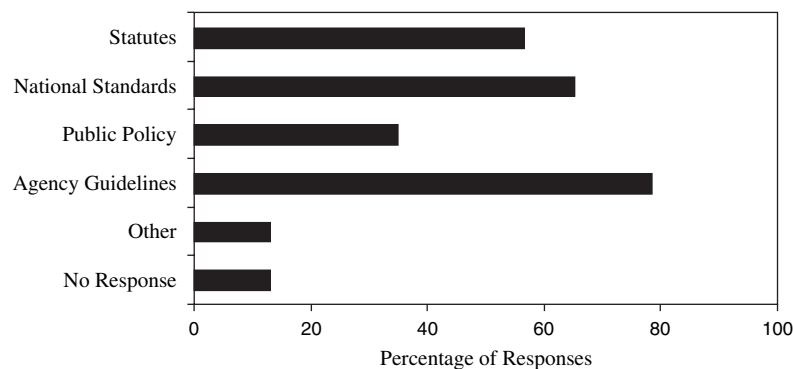


FIGURE 85 Technical management guidance for new construction of sidewalks.

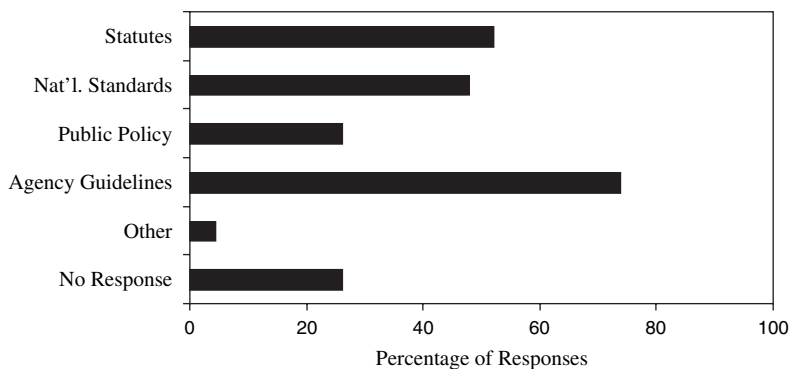


FIGURE 86 Technical management guidance for maintenance and rehabilitation of sidewalks.

value of its sidewalk assets in terms of replacement value, as it does other infrastructure assets. As of July 2003, the replacement value of its sidewalk system was \$1.2 billion, second only to pavement as the taxpayers' greatest investment in their urban transportation infrastructure.

The objectives of Portland's sidewalk program are to:

- Protect the public from injury by identifying hazards and ensuring their timely repair;
- Protect the taxpayer from the expense of liability as a result of sidewalk-related personal injury;
- Protect individual property owners by notifying them that a hazardous condition exists and by assisting with correction of that hazard;
- Protect the general public's investment in the transportation system, which includes sidewalks, corners, and curbs; and
- Manage the maintenance of sidewalks, corners, curbs, and driveways in a way that protects street trees and other desirable vegetation whenever possible.

PDOT has no sidewalk system condition assessment. Rather, the condition of curbs and corners is based on the professional judgment of PDOT staff, accounting for the sidewalk material, identified redevelopment projects, and anticipated damage from tree roots. Needs identified in its Management Plan account for the estimated backlog of work on curbs and corners; repairs to the sidewalk itself are the responsibility of the property owner.

Levels of service for the sidewalk system are expressed in terms of the estimated backlog which, when combined with the projected rate of annual repair, yield the anticipated time in years to eliminate the backlog. With budget constraints, PDOT has found it necessary to cut back on its inspections and essentially to forego curb repair. Resources have been directed instead to reconstructing corners to meet ADA requirements, including ramps and, as of January 2003, tactile warning devices. The agency also absorbs additions to sidewalk inventory with no corresponding increase in budget (*Portland Transportation Asset Management 2004*).

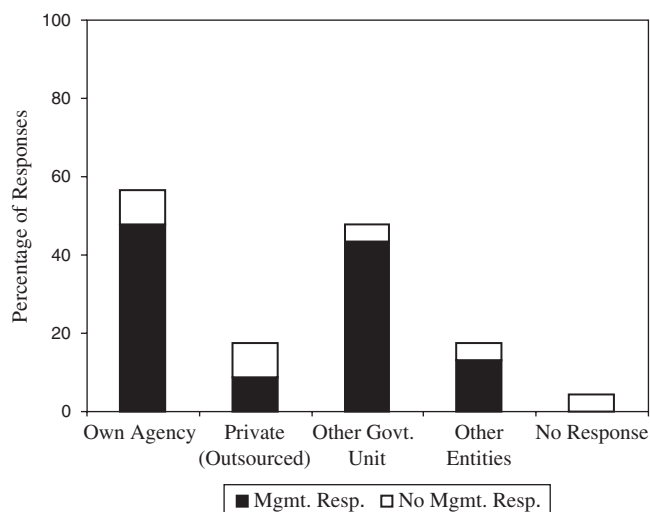


FIGURE 87 Responsibility for maintaining sidewalks once in service.

Halifax Regional Municipality, Canada

The Halifax Regional Municipality has several infrastructure management programs for the civil facilities that it owns ("Infrastructure Management" 2006). Sidewalk and curb management are included as part as roadway management, together with pavements, traffic lights, and traffic signs. Halifax maintains an inventory of sidewalk length by material type and monitors their condition.

Condition rating for concrete sidewalks (the most prevalent type) is based on distresses such as spalling, minor and major faulting, minor and major cracking, and good and poor patching. Slabs with no distresses are noted as "good slabs." Rating is done by inspectors who walk the sidewalk with handheld counters on which to record the number of distresses observed. Data are entered into a PDA onsite; at the office the PDA data are downloaded to a database. The data are used to compute the percentage of slabs that are defective

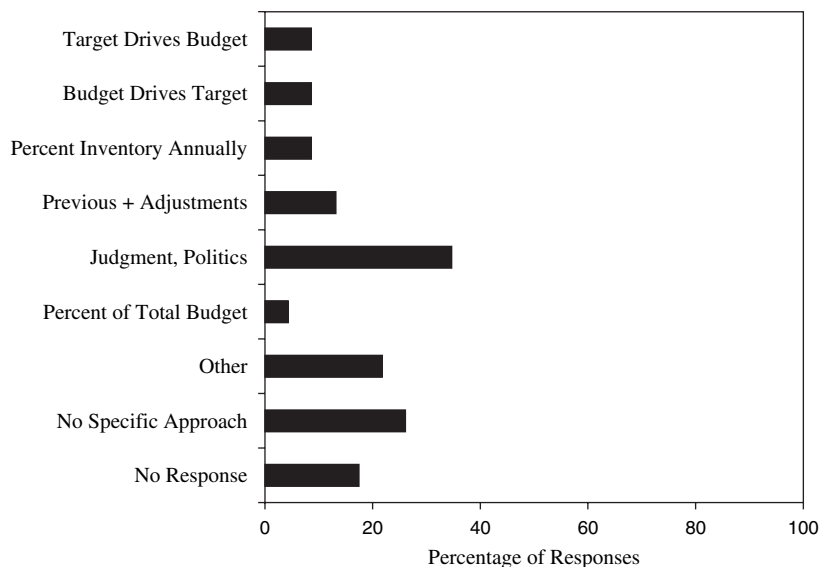


FIGURE 88 Annual budgeting method for sidewalk preservation and maintenance.

and a Sidewalk Deficiency Rating, which is computed by weighting the major defective slabs by a value of 1, and the minor defective slabs by a value of 0.25. These ratings are used to determine which sidewalk sections will be considered for capital repairs.

Asphalt sidewalks are rated on a more subjective basis. The condition of the entire section of a sidewalk is observed and the sidewalk is rated good, fair, or poor (“Infrastructure Management” 2006).

Brisbane City Council, Australia

The city of Brisbane is developing a *Strategic Asset Management Plan* (2003) for its footpaths. Because this plan is still in draft form, details are not provided here. However, Brisbane

is considering a management approach based on customer-oriented levels of service. These levels of service are based on the physical condition of the sidewalk, in terms of the severity of defects. Brisbane has also estimated the replacement value of sidewalk assets, and is formulating a scheduled replacement plan based on service lives for each type of material (concrete, asphalt, pavers). It has also developed a risk management matrix, which identifies specific risk events, their likelihood and driving factors, and proposed methods to mitigate these risks.

English Walking Programs

The English Department for Transport and Department of the Environment, Transport, and the Regions have produced publications that encourage walking and provide guidance to local

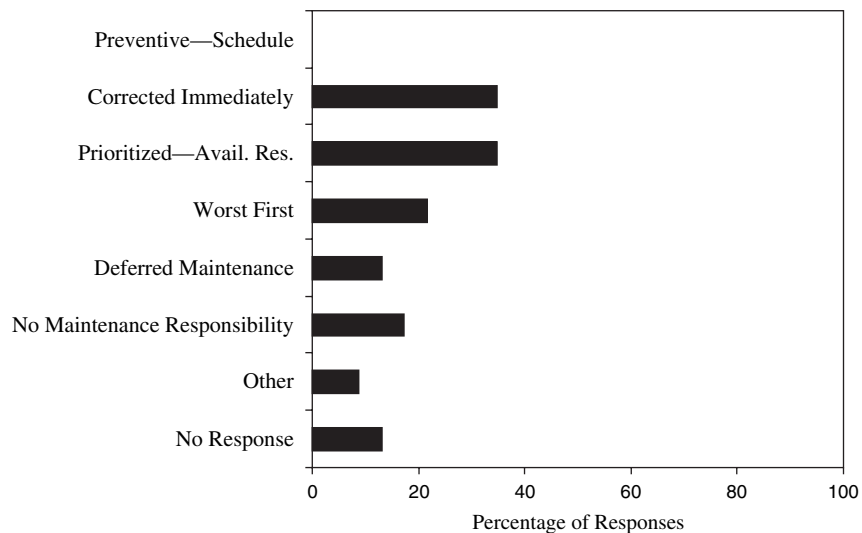


FIGURE 89 Approach to maintaining and preserving sidewalks.

agencies on planning, strategies, and techniques for sidewalks. The Department of the Environment, Transport, and the Regions document offers general guidance across a number of topics, including the benefits of walking, need for planning in both transportation and land use, the value of partnerships and candidate partners, practical actions that can be taken in land use and transportation to provide attractive and practical sidewalks, and methods to influence people’s attitudes toward walking and involving the public through local organizations, businesses, and social groups to feel “ownership” for the sidewalk program (*Encouraging Walking . . .* 2000). The Department of Transport documents approach the issue from a transportation focus, including best practices on accessibility of facilities to all pedestrians as part of a broader strategy on inclusive mobility (*Inclusive Mobility . . .* 2002), and structuring of the walking strategy in terms of objectives, measures, outcomes, and performance indicators (“Framework . . .” n.d.).

MEASURING ASSET PERFORMANCE

Measures of Sidewalk Performance

The information provided by agencies on performance measurement of sidewalks is summarized in Figure 90, based on categories of performance factors similar to those described

in chapter two. Measures of physical condition and conformity with ADA requirements were clear leaders among survey respondents, with associated qualitative measures and customer complaints also making a strong showing. Amplifying on these responses:

- Florida uses a performance index based on cracking.
- Iowa includes a condition measurement of faulting. It also maintains a toll-free customer comment telephone number.
- Vermont uses a qualitative rating based on setback from the roadway shoulder. Oregon also uses a physical measure of separation from traffic.

Florida has investigated a Pedestrian Level of Service concept to understand what factors are considered by pedestrians as contributing to safety and comfort (Landis et al. 2001). Although perceptions of many characteristics of the sidewalk likely influence pedestrians’ judgments (e.g., architectural interest, shade in daytime, good lighting and amenities at night, and presence of other pedestrians), FDOT was interested in formulating a level of service based on readily measurable road and sidewalk characteristics. FDOT limited the study to the roadway environment between intersections. The following items were tested using regression

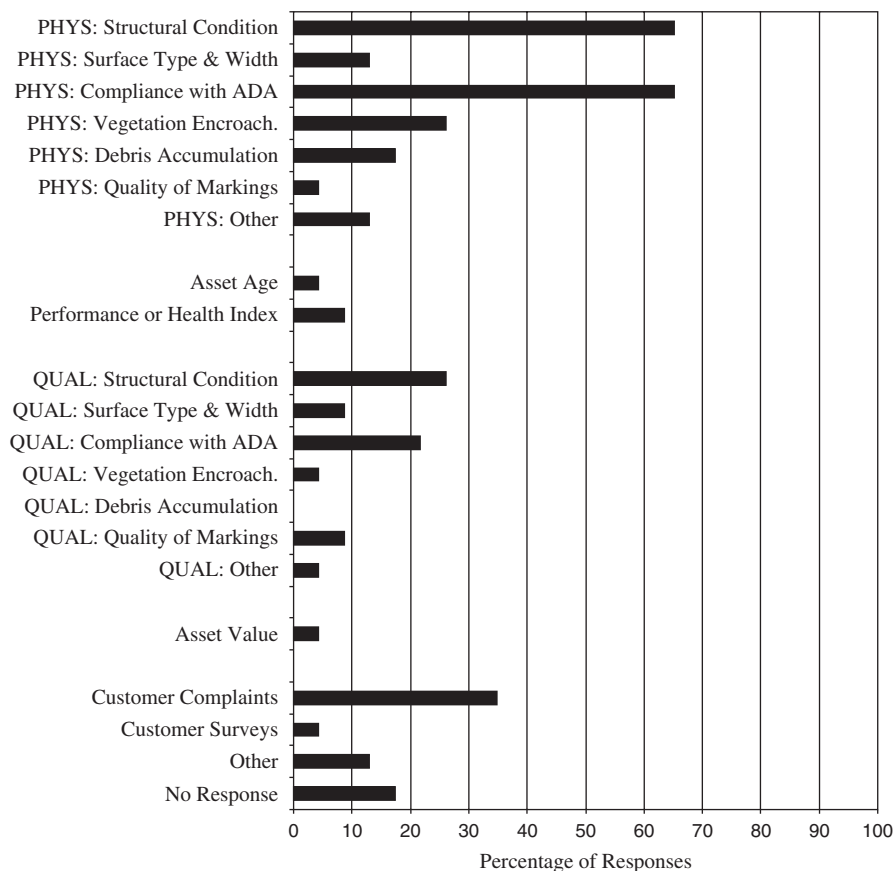


FIGURE 90 Measuring performance of sidewalks. PHYS = physical; QUAL = qualitative.

analysis of these factors versus pedestrians' ratings of sidewalk courses:

- Presence of a sidewalk,
- Lateral separation of the sidewalk from motor vehicle traffic,
- Barriers and buffers between pedestrians and motor vehicle traffic,
- Motor vehicle volume and composition,
- Effects of motor vehicle traffic speed, and
- Driveway frequency and access volume.

All of these factors, with the exception of driveway frequency and access volume, were found to be statistically significant. FDOT developed a series of model equations based on the regression analyses to incorporate the contributions of these factors within a computed pedestrian level of service value. There are several potential uses of this level of service concept: providing the pedestrian component of FDOT's statewide multimodal evaluation; influencing roadway cross-sectional design, as well as the design of specific features (e.g., width of sidewalks); prioritizing needs for sidewalk retrofit construction; and "completing the picture" in conjunction with other measures of sidewalk capacity and quality (e.g., walkability audits) (Landis et al. 2001).

Frequency and Method of Measurement

The frequencies with which physical performance measures are addressed are shown in Figure 91. Edmonton uses varying frequencies: once every 2 years for arterials and collectors; once every 4 years for local streets. As another example, Portland inspects sidewalks on a 20-year cycle, supplemented by a complaint-driven process.

The methods used by responding agencies to assess sidewalk condition and performance are reported in Figure 92.

Although visual inspections and customer complaints are the most common methods used, physical measurements are applied as well, at least in part to meet ADA requirements. Hawaii reported using a measuring tape and digital level for this purpose. Vermont employs Roadware-Visadata and Surveyor measuring tools for its photologging.

ASSET SERVICE LIFE

Information on service life was obtained in the study survey for three major components of sidewalks: (1) the sidewalk itself, (2) the curb, and (3) corners in urban areas, including ramps. Reporting agencies were also asked to identify how they determine service-life values. Responses to this question are shown in Figure 93. Among the 25% of reporting agencies that identified at least one method, their emphasis was on collective agency knowledge, whether represented by their experience with sidewalk infrastructure (e.g., a database of observed historical service lives) or by the professional judgment of their staffs. LCCA analyses were also noted as a source of information, but to a lesser degree.

Comprehensive service-life data reported by agencies in the study survey are given in Table 27. Examples of the distributions of estimated service lives for two sidewalk materials are shown in Figure 94 for concrete sidewalks and in Figure 95 for asphalt sidewalks. The labels on the horizontal axis give the upper values of each range of service-life data. For example, if these labels are 0, 5, 10, 15 . . . , then the column labeled 5 shows the number of responses for estimated service life of zero to 5 years; the column labeled 10, the number of responses for estimated service life of more than 5 to 10 years; the column labeled 15, the number of responses for estimated service life of more than 10 to 15 years; and so forth. It should be noted again that the data in Table 27 and Figures 94 and 95 may be derived in part from the professional judgment of agency personnel.

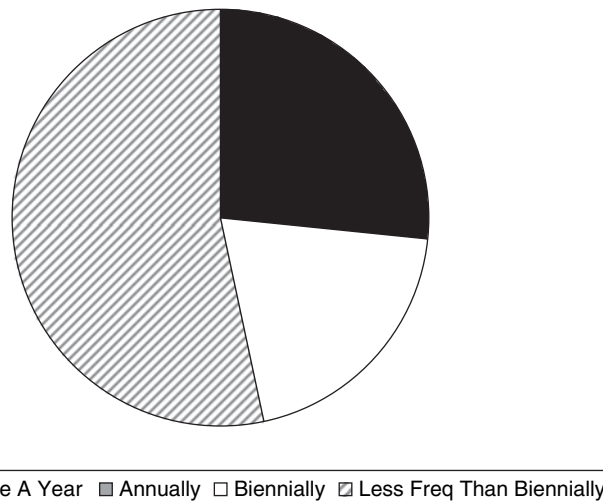


FIGURE 91 Frequency of physical condition assessments of sidewalks.

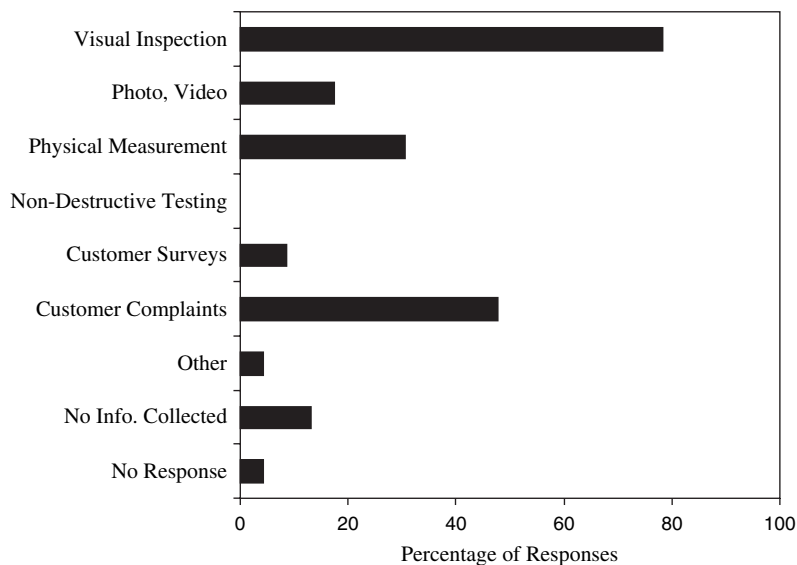


FIGURE 92 Data collection methods for sidewalk condition and performance.

To apply the service-life concept in asset management, a method is needed to determine where an asset is in its service life—that is, how much life is consumed, and how much remains. Agencies were presented with a number of ways to determine the current status of an asset regarding its service life and asked to rank each method by relevance to their agency. The result for sidewalks is shown in Table 28 (note two instances of ties).

On the related issue of identifying the extension in service life owing to maintenance, only one of the 23 reporting agencies for this asset responded affirmatively. Edmonton noted that as the result of requiring a gravel base for sidewalks, they estimate a doubling of service life as a result.

INFORMATION TECHNOLOGY SUPPORT

Agencies participating in the study survey identified their key IT capabilities as shown in Figure 96. One-half of the responding agencies identified specific IT capabilities supporting sidewalk management. For the most part these included inventory and location information, as well as recommendations of inspectors and an ability to track public comments. A number of respondents also reported information on sidewalk condition, photographs, and GIS-based maps.

Agencies characterized their IT systems for sidewalks as shown in Figure 97. Workbooks or spreadsheets were the most numerous types of procedures, with the remainder divided

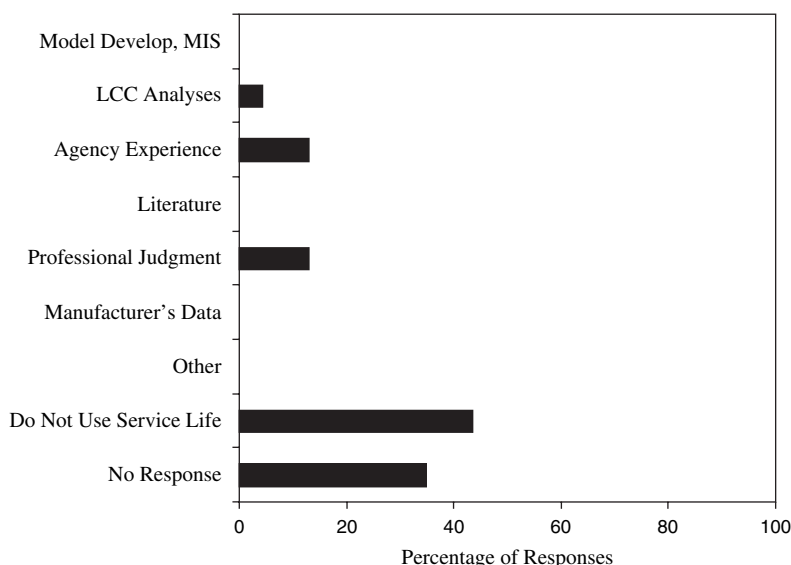


FIGURE 93 Sources for determining service lives of sidewalks. MIS = management information systems; LCC = life-cycle cost.

TABLE 27
ESTIMATED SERVICE LIVES OF SIDEWALK COMPONENTS

Component and Material	No. of Responses	Minimum (Years)	Maximum (Years)	Mean (Years)	Median (Years)	Mode (Years)
Sidewalks						
Concrete	7	20	60	34.3	25	20
Asphalt	5	5	20	11.4	10	10
Brick or block	2	20	20	20	20	20
Gravel, crushed rock	1	—	—	10	—	—
Curbs						
Concrete	7	10	60	29.3	20	20
Asphalt	2	5	15	10	10	—
Granite block	1	—	—	20	—	—
Corners (urban)						
Concrete curbs	6	10	50	26.7	20	20
Granite curbs	1	—	—	20	—	—
Curb with concrete ramp	4	20	50	27.5	20	20
Curb with stone or brick ramp	2	20	20	20	20	20

Notes: —, value is undefined for the particular distribution. When distribution is based on only one data point, its value is shown in the Mean column.

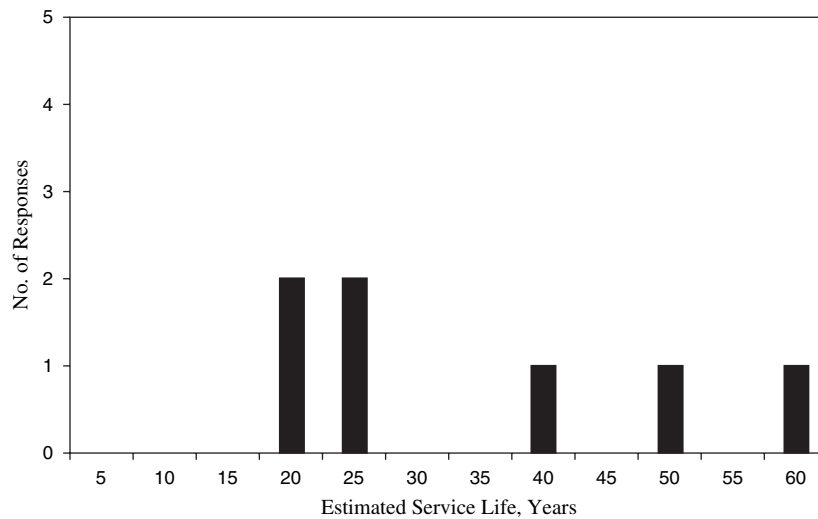


FIGURE 94 Estimated service life of concrete sidewalks.

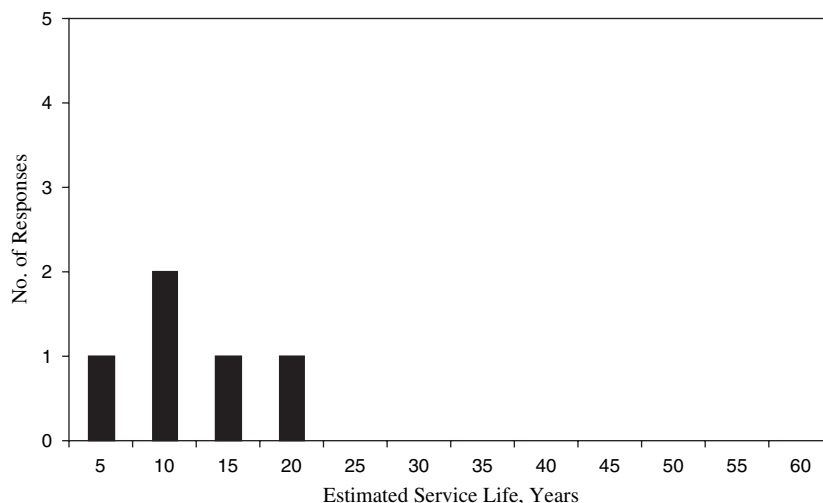


FIGURE 95 Estimated service life of asphalt sidewalks.

between broad-based systems and simple programs. The agencies that reported using a sidewalk management system or a maintenance management or transportation infrastructure asset management system that includes sidewalks are listed here.

- Sidewalk Management System—None.
- Maintenance or Asset Management System That Includes Sidewalks
 - New Mexico DOT
 - City of Edmonton, Alberta
 - City of Portland, Oregon.

Other capabilities included devices such as straight-line diagrams.

The city of Fond du Lac, Wisconsin, has developed a sidewalk management system that combines two branches of technology—a database and mobile GIS capabilities—to provide a solution that supports field as well as office needs (Weis 2005).

- The management system assists in several phases of sidewalk management, encompassing field inspection of sidewalk condition, preparation of inspection reports to be sent to property owners, preparation of condemnation letters for deficient sidewalk sections to be replaced, documentation of construction repairs, and preparation of tax assessment notices.
- The field capabilities are built around a handheld computer that has an electronic data collection form for recording sidewalk defects. The computer also has mobile GIS software and a GPS, which is synchronized to the GIS on an office computer that is linked to the sidewalk management database. A parcel map is used as a base map by the GIS.
- The inspector records the sidewalk condition on the electronic data forms, creating records of observed defects. The GIS associates these defect records with a parcel, and parcel information is added to the inspection form. The inspector also takes digital photographs of each defect, which are stored with the defect information for the parcel. The information is automatically

TABLE 28
RANKING OF METHODS TO DETERMINE WHERE SIDEWALKS ARE IN THEIR SERVICE LIVES

Rank	Factor
1	The agency does not use/does not monitor service life for this type of asset
2	Assets are repaired or replaced as soon as they fail without regard to service life
3	Monitor condition of the asset occasionally
3	Service life is often determined more by functional obsolescence than by wear and tear
5	Compare current age of asset with the maximum age that defines service life
6	Monitor condition of the asset on a periodic schedule
7	Apply deterioration models to estimate where the asset is on “the curve”
7	Other factors

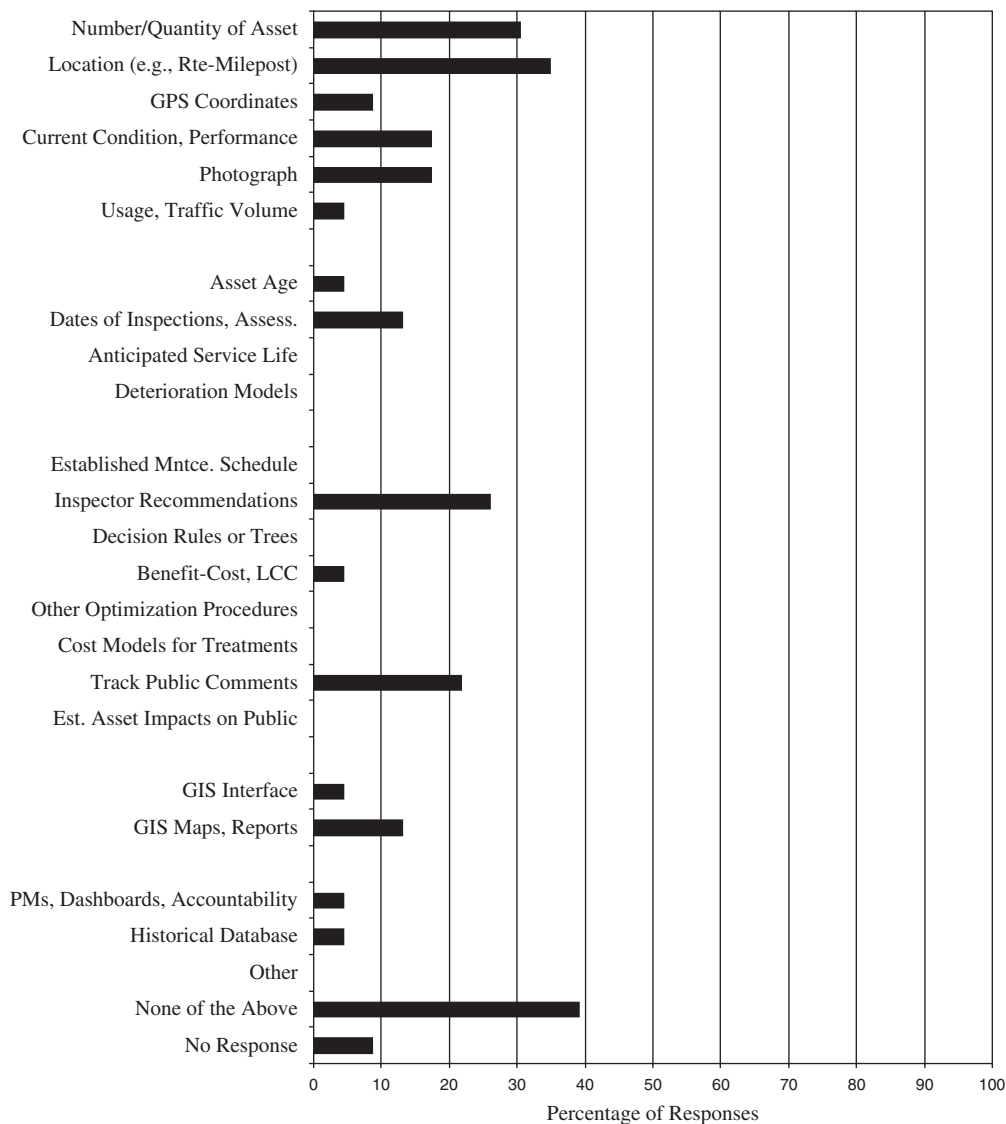


FIGURE 96 IT capabilities to help manage sidewalks. GPS = global positioning system; LCC = life-cycle cost; GIS = geographic information system; PMs = performance measures.

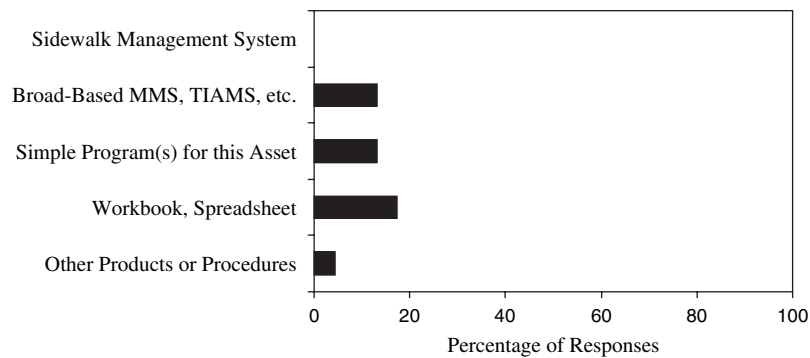


FIGURE 97 Types of analytic tools to support sidewalk management. MMS = maintenance management system; TIAMS = transportation infrastructure asset management system.

transferred from the mobile computer to the office computer and the management system database.

- At the office, the inspection data are entered into the central sidewalk database. Through a link to the tax database, the system obtains the name and address of the parcel owner, which is input to the inspection reports, condemnation letters, and assessment notices that are generated by the system for mailing.
- The database analytic procedures automatically estimate bid quantities and repair costs based on measurements of defects recorded on the inspection form. Total payments due the contractor and property owner assessments for repairs are calculated from as-built measurements that are input for each defect. Quantities and calculations are automatically updated whenever these data are modified.
- The office database can be queried to produce custom reports and maps of sidewalk network condition.

KNOWLEDGE GAPS AND RESEARCH NEEDS

Agencies at all governmental levels identified a number of knowledge gaps and resulting needs for research. These comments have been organized by topic area and compiled and summarized here.

- General information—Several respondents identified the need for basic information on sidewalks; for example, inventory quantity, location, condition, and jurisdiction.
- One agency mentioned the need for performance data over longer time periods. In areas where sidewalk maintenance is the responsibility of property owners, information is needed on the measures taken by subdivisions to enforce laws on sidewalk maintenance. There is a general lack of information on life expectancy of sidewalks.
- Asset management—A city noted that they prefer to manage sidewalks as an asset rather than respond to service needs. Several local and state agencies identified additional information needs to develop a more comprehensive asset management approach. These ideas included more complete information on current sidewalk status (e.g., location, age, condition, and last maintenance performed), important attributes other than just the physical characteristics of the sidewalk—that is, a true walkability index—and development of an electronic sidewalk management system with optimization capabilities. Others cited impediments, however, included lack of funding and competition for attention by other assets.
- Engineering information—Agencies noted a need for additional or better engineering information on sidewalks, including field data collection devices, requirements for base materials under the sidewalk, better service-life information, and life-cycle analyses of alternative materials such as rubber (e.g., for textured surfacing to meet ADA requirements).
- Institutional information—One agency suggested research on the uniformity of codes and practices throughout the country in assigning maintenance responsibilities and related enforcement practices.

SELECTED ASSETS IN THE CONTEXT OF ASSET MANAGEMENT

OVERVIEW

One objective of this synthesis study has been to gain a better understanding of the state of practice for managing transportation infrastructure assets other than pavements and bridges. The state of practice has been presented in chapters two through seven, respectively, for each of the six types of assets that are the focus of this study: traffic signals, roadway lighting, signs, pavement markings, drainage culverts, and sidewalks. These results have been aggregated across all assets and are presented here as a composite of findings in the section, “Synthesis of Current Practice.”

Other objectives of this study were to identify best practices and to document gaps in existing knowledge and needs for further research. To provide a framework for analyzing these aspects of the study, we have applied the framework of asset management that was introduced in chapter one. Information on agencies’ practices in the context of a comprehensive asset management approach was obtained from the following sources:

- Inclusion of a separate part of the synthesis survey that asked open-ended questions regarding:
 - Participants’ use of asset management;
 - What they saw as gaps in knowledge, research needs, and other impediments to better management practice; and
 - Any other assets (other than pavements and bridges) to which they apply techniques that include a knowledge of service life and predictions of future condition and resource needs.
- A literature review of U.S. and international practices in asset management, focusing particularly on non-pavement, non-bridge assets.

This information is summarized in the following section, “Synthesis of Current Practice.” Subsequent sections discuss the following:

- A description of current initiatives in asset management, including existing systems already in place, systems currently being developed by agencies, and applications of legacy systems and procedures to asset management.
- A review of international experience as identified by an international scan team that visited cities, states/

provinces, and national transportation agencies in Canada, England, Australia, and New Zealand. There is also a brief description of Canada’s InfraGuide resource.

- A discussion of the importance of selected assets and possible ways to provide better information on their value and performance impacts.
- A description of the public involvement process and its role in asset management.
- A compilation of overarching knowledge gaps, other impediments to asset management, and research needs that cut across asset classes, as identified by respondents to the study survey.
- As a final step, all of the findings of this study are brought together in a review matrix based on the criteria presented in Table 1. This review matrix evaluates the maturity of current practice in managing the six selected assets, and potential improvements that can be made in several areas.

SYNTHESIS OF CURRENT PRACTICE

Previous chapters have covered the results of the synthesis survey and literature review for each individual selected asset. In this section we summarize the survey results and reviews of the literature are summarized across all six assets, considering common themes that emerge from the several sets of findings, as well as contrasting indications of practice among assets and across agencies.

Management Approaches

Although management practices across the selected assets share a number of common attributes, there is a mixed picture in how far different agencies have progressed in their procedures and ability to provide information about such assets.

- Agencies were relatively consistent in listing the policy goals that they felt are most important with respect to selected assets and the sources of guidance they rely on for managing these assets. Safety, travel efficiency and convenience, and asset preservation were cited consistently as driving forces in installing and managing these assets effectively. The most important sources of management guidance were believed to be agency policies, procedures, and guidelines (for both new installations

and maintenance and rehabilitation of existing assets), national standards, and federal and state statutes.

- Many of these selected assets are maintained and operated through a blend of public- and private-sector responsibility. The owning agency, private contractors, and other levels of government share in managing and conducting work on these assets, although the degree of respective involvement and the assignment of decision-making authority among these groups vary by type of asset.
- Although some agencies have developed comprehensive asset management approaches for selected assets, others lack information on even basic aspects of these assets, such as annual expenditures and inventory quantity. One reason may be that some agencies view these selected assets as components of a larger transportation “asset,” such as a road or intersection, and inventory and expenditure data are not kept at the level of detail of the asset itself. (More will be said on this point later.) Where agencies do have such information, as in maintenance management systems, the data may be incomplete from a life-cycle perspective; for example, they may encompass annual maintenance expenditures, but not the capital costs of new installations or replacement. The examples of asset inventory data that were submitted by agencies represented widely ranging practices in how assets are classified and to what level of detail.
- Agencies reported that they apply a mix of approaches to managing and budgeting for selected assets. Preventive maintenance, repair immediately upon failure, prioritization of existing needs according to resource availability, and worst-first repair strategies are the major management approaches that are applied to these assets. Individual agencies may employ a blend of these approaches for each type of selected asset, basing the decision of which method to use on criteria such as the priority of the asset, the type of damage occurring, the functional class of the road on which it is located, and the judgment of responsible district managers. Similarly, agencies use a mix of budgeting methods, with the major approaches including applying the previous year’s budget plus inflation and other adjustments, and basing budgets on a combination of agency professional judgment, political inputs, and public comments. Although budgeting based on asset condition or some related measure such as level of service is employed by some agencies, it is not the main philosophy for any of the selected assets. Many agencies reported that they use a combination of approaches rather than a single budgeting method.

Asset Condition and Service Life

Agencies provided information on how they characterize asset condition, how they collect these condition data, and

how they apply estimated service life, if at all. Common threads in practices across selected assets included the following:

- Agencies reported that the condition of selected assets is identified generally by physical condition (quantitative and qualitative measures), the number of customer complaints, asset age, and some characteristic of operational performance such as reliability or conformance to standard. Other types of measures are used for specific assets as described in the previous chapters, but these are the main measures used across the board.
- The predominant method of data collection for a selected asset condition is visual inspection. Customer complaints were reported as the second-most-used method, followed by some type of physical measurement, nondestructive testing, photologging, or videologging.
- Many agencies provided information about the expected service life of asset components, even if they do not use service life formally in their management systems. Although information on service life is potentially available from several sources, the survey results indicated a strong reliance on agency experience and staff professional judgment in estimating service-life values.
- When the survey results from all agencies were combined, virtually all asset components were characterized by a distribution of estimated service lives, in many cases with a considerable spread between minimum and maximum values. This situation may be in part the result of differences in materials or technology that are used among agencies, a lack of standardized methods or criteria for defining service life, and resulting reliance on staff judgment. This variability in service-life data from the survey is mirrored by corresponding data in the literature.
- When asked how they determine where selected assets are in their service lives, agencies responded in several ways:
 - Some noted that they monitor service-life condition on a periodic or at least an occasional basis.
 - Others responded that service life itself is not an issue for one of the following reasons: (1) assets are addressed immediately on failure or on a set schedule, (2) the actual useful life is determined more by functional performance rather than by physical condition, or (3) they do not use service life in their management procedures.
 - Attempts to model service life have produced mixed results, owing to variability in the underlying performance data.
- Analytic methods for predicting or evaluating service life do exist, but these are used primarily at the design and installation phase of selected assets. This information may not be carried over into subsequent operation and maintenance.

Information Technology and Modeling Support

As a practical matter, IT is critical to asset management. Agencies responded in the following ways regarding their IT capabilities for the selected assets of this study:

- The most prevalent IT capabilities address inventory quantity and location, current asset condition and age, photographic documentation for certain assets, inspection and maintenance data, and tracking of public comments.
- The state of practice in IT for selected assets is not as well developed as that for pavements and bridges. There were relatively few reports of management systems that integrate features typically found in pavement and bridge management, including:
 - Deterioration and cost models;
 - Economic decision-support tools such as life-cycle analysis or benefit–cost analysis; and
 - Models of the impacts of asset condition and performance; for example, on mobility, safety, and benefits to the general public.
- Several types of IT tools are used by reporting agencies, including asset-specific management systems, more broad-based management systems such as maintenance management or transportation infrastructure asset management systems that encompass other assets as well as the selected assets, and simple programs and spreadsheet workbooks. In many instances agencies reported more than one type of system in use; for example, within different parts of the organization such as central office and districts.
- For better or worse, agencies' IT capabilities to manage selected assets are influenced by the characteristics of their legacy systems. In a positive response, FDOT noted its ability to apply its Maintenance Rating Program (MRP) approach to several of the selected assets, drawing on the functionality of its existing maintenance management system. In a negative sense, several other agencies noted that their existing systems lack an inventory of assets, not only precluding the use of this information for management, but also providing no existing organizational and procedural framework to undertake data collection.

INITIATIVES IN ASSET MANAGEMENT

The synthesis survey participants were asked to relate their management practices for selected assets to their efforts in broader asset management, to identify other assets for which they have developed performance-based management approaches, and what overarching issues need to be addressed to improve management practice. These responses were supplemented by a review of the literature in U.S. and international asset management practice, particularly for non-pavement, non-bridge assets. The following sections describe information resources and practices by agencies that have instituted an asset

management approach for selected assets, efforts that are now underway to develop such an approach for selected assets, and agencies that are applying legacy systems to provide an existing performance-based approach for selected assets.

Current Asset Management Approaches, Systems, and Guidelines

Asset Management Data Collection Guide

AASHTO Task Force 45, comprising representatives of AASHTO, American Road and Transportation Builders Association, and Associated General Contractors of America, has developed a comprehensive *Asset Management Data Collection Guide* (2006). This document provides detailed guidance on condition assessment for non-electronic highway assets. In terms of the six selected assets, it covers culverts, signs, and pavement markings (striping as well as pavement markers). For each asset, it presents a definition of the asset, its inventory attributes, condition attributes, and descriptions of potential condition states or performance targets. In terms of survey comments described in previous chapters regarding the need for standardization of methods and data, the *Guide* takes several steps in this direction. In addition, it provides a standard vocabulary for describing assets and a uniform technical basis for evaluating assets in the field.

City of Portland (Oregon)

The city of Portland has a comprehensive asset management approach for each of its assets. This approach is based on the development of asset management plans that provide general information on asset current status and trends in inventory, condition, and asset value, by component if appropriate; related budget and staffing history; standards and current service levels; statistics and comparisons with peer jurisdictions regarding organizational efficiency; predictions of asset condition as a function of varying service levels and assumptions; and overall program direction. With respect to the selected assets in this study, plans to date have been prepared for traffic signals, street lights, signs, pavement markings, and sidewalks. These plans are the basis of subsequent identification and ranking of needs, benefit–cost analyses of different level-of-service strategies in conjunction with needs to produce 5-year program forecasts, and resulting recommendations for capital and operating budgets (*Portland Transportation . . . 2004*).

These plans are supplemented annually by a condition and status report for each asset, updating information on asset condition, changes in replacement value, and unmet needs. This information is used in Portland's planning, policy development, and implementation and monitoring of strategic action plans (*Portland Transportation . . . 2004*).

Although this framework is comprehensive, not all data have not yet been collected, nor are there sufficient reporting

and analysis tools in place to have a truly comprehensive asset management program. A set of work management tools is linked to a GIS-based inventory for each asset class. Each asset class has a map and data layer in the GIS. New assets are created from the mapping-application side of the asset management system. Labor, equipment, and materials are tracked at asset-specific and nonasset-specific levels. Programming decisions in signs and pavement markings are currently focused on managing asset growth by instituting improved documentation of capital and maintenance processes. The tools available lack only the resources to gather and enter into the system so that more advanced asset management practices can be incorporated into the decision-making process.

Portland is one of the few survey respondents that use asset valuation as an element of its asset management.

New Mexico DOT Road Feature Inventory

The FHWA recently completed a series of case studies of roadway safety hardware, specifically looking at instances where integrated databases were applied in the management of these assets. The FHWA study is of interest, because there is substantial overlap between roadway safety hardware and the selected assets covered in this study: signs; signals; roadway lighting; support structures for signs, signals, and lighting; and pavement markings are included in both populations.

One of the FHWA study's cases, for the New Mexico DOT, illustrates the capabilities of what could fairly be called a state-of-the-art system. A data collection van is used to collect images of the roadway and roadside for inclusion in New Mexico's Road Feature Inventory (RFI). The RFI contains both images and data that are used to support maintenance management and ease legal liability. At the time of report publication, the RFI contained more than 5 million images. The images are used in two basic ways: for reporting and for a "Virtual Drive" along a selected highway. These capabilities are available to all departments within the DOT to help them fulfill their roles in asset management (Hensing and Rowshan 2005).

Ongoing Efforts to Develop an Asset Management Approach

City of Edmonton

The city of Edmonton has formal management systems for pavement, bridges, vehicles, and buildings. The management systems for other infrastructure assets are in various stages of development and, although there is currently no overall corporate electronic asset management system, the data from each of the asset stewardship areas is synthesized by the Office of Infrastructure into a common format. Although the quality of data varies, senior management and the city council can get a

sense of the relative value, condition, functionality, capacity, and risk exposure of all the corporation's assets. For example, condition information from each asset area is distilled into percentages of "Very Good," "Good," "Fair," "Poor," and "Very Poor" inventory. This standardized rating system applies across the corporation and provides a valuable tool to support improved decision making. This information can assist in the prioritization of projects through the capital budget.

The city is implementing an innovative prioritization tool with the intent of using both the inventory and the financial information as input to a risk model as a way of prioritizing projects to assign available funding. The objective of this exercise is to remove some of the subjectivity from the allocation of budget dollars and to provide decision makers with the information to make the tough decisions.

This complex risk model examines the infrastructure assets owned and/or operated by a particular infrastructure area. These assets are further classified into groups, where each group comprises assets with similar performance characteristics. The deterioration of each of the assets in a group is modeled to reflect current conditions, the natural aging process, the actual use and performance history, and the rehabilitation strategy applied to that asset. These models are used to predict the assets' conditions and the expected failures within the asset over time. A "severity" indicator is estimated for each asset to represent the level of exposure to risk the city faces as a result of the asset's state.

The application of a severity indicator in combination with the current budget and a long-range financial investment plan enables the city to predict the future state and condition of infrastructure assets in relation to various investment scenarios. By determining the severity of the risks associated with current infrastructure investment, the civic administration will be able to compare disparate infrastructure elements on a corporate level and determine which critical areas require the most urgent action.

Maryland SHA

Each of the six asset categories covered by this synthesis has a dedicated fund category for the asset and a dedicated fund manager(s). Several of the asset categories have direct agency business plan objectives, establishing a service-level objective for the asset. Expenditures are based on need, but annual budget allocations for each asset category, although considering needs, tend to be adjustments to historical allocations. Tradeoff analyses between asset categories are not formally done.

The SHA is now conducting internal assessments of its highway assets, including five of the selected assets in this study: culverts, lighting, pavement markings, signs, and traffic signals. Each assessment of an individual asset summarizes information about the asset in the following areas:

- Overview of the asset—the main categories of assets, approximate quantities, asset value, and general information.
- Inventory information—what data are inventoried or not inventoried, how these data are used, how inventory data are collected and at what level of effort and cost, geographic referencing, level of confidence in inventory data, and frequency of update.
- Condition information—what data are collected and how they are used, information that is not collected, information that should be collected, what performance measures and outcomes pertain, level of effort and cost of collection, sampling strategy, level of confidence in the data, update frequency, and IT support.
- Deterioration modeling issues—what models exist, capability to project 5 years out, level of confidence in these projects, and any studies needed to enable reasonable deterioration estimates to be made.
- Decision making—descriptions of how programs for the asset are now developed, how proposed actions are identified, relationship between capital and maintenance actions, how funding needs are established and linked to performance outcomes, how the program is delivered, and problems inhibiting selection of the best strategy.
- Strengths and opportunities for improvement.

This effort represents a work in progress. However, the draft materials that have been reviewed as part of the study survey indicate a strong attempt to deal with many of the issues raised in previous chapters, and in many cases reflect the findings on the current status of management of these selected assets.

Michigan DOT

MDOT has embarked on a program to develop GIS-based inventories of physical items with statewide uniformity, consistency, and thoroughness. The effort is referred to as the Statewide Physical Features Inventory, or SPFI. The main purpose of SPFI is to understand “where things are” on the highway system in a consistent, unambiguous, and rigorous way. To date, 22 items have been proposed for inclusion in this effort; however, this proposed list is likely to adjust over time. Among the selected assets it includes culverts, lighting, pavement markings, signs, and traffic signals. Other items include billboards, permanent concrete barriers, excess property, pavement cores, water-quality monitoring wells, snowmobile crossings, and weigh stations. Each item will be located with the aid of a GPS device.

One purpose served by this proposal is to be able to fix the location of these items precisely for purposes of program cost tracking and auditing, particularly where contractors are performing maintenance. A higher degree of accountability is introduced if these items can be identified by precise location. The approach has clear benefits for asset management as well, in that it satisfies the need for a basic management capability

identified in the surveys: a record of the inventory and location of highway assets, their condition, and an accumulating history of maintenance work performed and costs. Moreover, it provides a platform for quick, accurate, and timely updates of inventory information as work is being done statewide. In addition to maintenance management, this information can be applied to strategic planning of the specific asset and future maintenance project selection.

One issue that MDOT staff has had to address in deciding which items to include in SPFI is whether the item is an “asset” in its own right, or a “feature” of some other asset. The designation of asset or feature influences to what extent and detail the department tracks information about the item, if at all, in its database. Although MDOT raised this issue explicitly in follow-up discussions to its survey responses regarding SPFI, other agencies have identified related issues as to what priority and resources are due the selected assets.

Michigan has conducted a field trial to build a guardrail inventory using the SPFI approach. The trial demonstrated the feasibility of accurate and efficient field data collection using available resources; for example, co-ops, state workers, Youth Corps, and similar groups. An issue that MDOT is now working on is to enlist the cooperation of contractors performing maintenance so that they can electronically record information on work completed on these assets by location and upload the information to MDOT databases so that the asset inventory can be updated.

NYSDOT

A Maintenance Asset Management Information System (MAMIS) is being customized for use at NYSDOT and was scheduled to go into production use during 2006. This system upgrade replaces mainframe legacy system capabilities.

MAMIS will be used for work management, accomplishment reporting, and time and attendance. The system enables work planning to be linked to the department’s five Priority Results Areas, and completed work can be assessed in terms of the Priority Results Areas as well. The work management component is a management engine that enables a manager to review all needs from work plans, inventory and condition inspection systems, routine patrols, or service requests, and then apply filters to those needs to select which work will be done. The user can then assign the work to either state forces by means of a work order or to contractor forces through a contract order, and the work can be tracked to completion and accomplishments reported. Work and contract orders can be combined into projects for costing, bonding, or emergency relief purposes.

A parallel project is also ongoing to inventory and inspect key assets such as culverts, guide rail, ditches, signs, and

environmental/vegetation management areas to enhance asset management capabilities in MAMIS. As in-house and contracted work gangs complete work orders on assets, they will incrementally populate the MAMIS system with physical inventory, condition, and performance attributes of those assets. These enhancements will be integrated into the system, but will also be available to stand-alone users. The ability to assess regional needs will be used in the budget allocation process as well. The system will be available at the maintenance supervisory level to assist supervisors in making more informed work selection decisions.

Other Survey Responses

Other comments regarding ongoing work in asset management were reported by the following agencies:

Selected assets are about to be tracked with our new software implementation of SAP.

— Colorado DOT Region 3

NCDOT is currently in the process of developing Performance Measures for these elements.

— North Carolina DOT

At this time, the Oregon Department of Transportation (ODOT) is not utilizing a comprehensive approach to manage its assets. However, ODOT has recognized its importance and identified strategic priorities by approving a Department-wide Asset Management Strategic Plan. A draft Implementation Plan has been presented for consideration and is currently undergoing refinement.

— Oregon DOT

We are presently working on a methodology to include most of these selected assets in our comprehensive Asset Management System.

— Utah DOT

Applications of Legacy Systems and Procedures

FDOT

FDOT refers to its strategic planning and management process as policy planning, although it has many of the attributes of asset management. It relies on a network of plans and programs that are internally coordinated within a framework of goals and objectives. Goals define overarching concepts such as system preservation, mobility and economic competitiveness, and organizational excellence and customer focus. Within each goal are one or more objectives that identify specific targets for attainment by the DOT and other state agencies. These objectives include targets for pavement and bridge condition and satisfaction of maintenance standards (Pagano et al. 2004).

Florida's maintenance management approach embodies an MRP. An MRP is a systematic process for rating highway elements by a numerical level of service, with appropriate weighting factors accounting for the type of facility (i.e., road

classification) and the specific characteristic being rated (Stivers et al. 1999). Weighted scores are tallied by all elements on a highway segment and by district on a 0–100 scale. The survey responses from FDOT indicated that the following selected assets are managed through the MRP process: culverts, lighting, signs, pavement markings, and sidewalks. Each district has a target of maintaining a minimum rating of 80 for all elements and 70 for each characteristic. Each district is allocated a budget for each characteristic based on inventory. When the district fails to meet its target, its expenditures are reviewed versus the budgeted amount, and it is expected to allocate more funding for that area. If on a statewide basis the budgeted amount fails to meet the target and is judged to be insufficient, then the budget may be increased for that characteristic. MRP is measured three times a year by sampling.

NYS DOT

NYS DOT uses the biennial update of the Statewide Transportation Improvement Program and metropolitan area Transportation Improvement Programs as the administrative framework for asset management. The 11 regional offices and 13 metropolitan planning organizations receive capital allocations, policy guidance, and performance targets. Capital program committees evaluate candidate investments and propose a recommended program for statewide adoption by executive management. The capital investment candidates are heavily oriented to infrastructure renewal and preservation. As a general rule, maintenance and operations take precedence over service extensions and system betterments. Assuring a state of good repair for assets is a policy objective for all modes.

The operating budget process for highway maintenance is an annual process. Regions receive allocations and program them to meet identified needs.

South Carolina DOT

Elements of the department's asset management approach include:

- A highway maintenance management system addressing all maintenance activities,
- A signals inventory, and
- A roadway inventory management system.

MnDOT

The MnDOT Transportation Plan (2008–2030) is performance-based. The six areas addressed in this survey are included in this plan. From this plan a 10-year work program is developed, followed by the 3-year State Transportation Improvement Program. At this time, performance measures and targets have not been fully developed for each of these areas.

INTERNATIONAL EXPERIENCE

In 2005, a team sponsored by the FHWA, AASHTO, and NCHRP conducted an international scan of transportation asset management practice in Australia, Canada, England, and New Zealand. The scan included visits with agencies at the national, provincial or state, and local levels. The report produced by this team contains a substantial amount of information on asset management as a business process as well as an organizational culture. Consequently, it looked not only at the technical aspects of asset performance and repair, but also more broadly at the factors that encourage asset management in the institutional and political context in which the agency operates, the role of asset plans, supporting management systems, and interactions with the public (Geiger et al. 2005).

Although there are many aspects of asset management that are discussed in the scan report, the following items provide examples of how agencies in Europe, Australia, and Canada approach asset management, the role of transportation asset management within broad public policy, and how international agencies deal with selected assets. The material in the following sections (with the exception of the *InfraGuide*) is taken from the report of the international scan team (Geiger et al. 2005).

Asset Management Principles and Plans

Basic approaches to asset management are described here for several national, state-level, and municipal agencies. Several elements are common across these approaches, such as a strategic view of asset performance and life-cycle cost, involvement of the community in the decision-making process, and a goal of using resources wisely and sustainably.

- England—In its key principles of asset management, England includes strategic management with a long-term view and a reliance on life-cycle costing, defining and tracking of levels of service, managing for risk of failure or loss of use of an asset, working toward a sustainable use of physical resources, and understanding asset management as a process of continuous improvement.
- New South Wales Roads and Traffic Authority (RTA)—RTA recognizes that transportation competes for scarce public funding with other governmental functions such as health and education, and views asset management as a way to strengthen the position of transportation in this resource allocation. Asset management is seen as an integrated systems approach to maintain, upgrade, and operate physical assets cost-effectively in responding to customer levels-of-service targets. Doing this requires both engineering information (e.g., deterioration models) and economic analyses.
- Victoria, Australia (VicRoads)—The transportation asset management practices of VicRoads follow “optimal asset management” concepts put forth by the

Department of Treasury. These concepts include defining levels of service to be delivered by assets in consultation with the community; applying life-cycle analyses in decision making; balancing competing needs across governmental functions by evaluating options and their outcomes; monitoring, evaluating, and improving service delivery; managing risk to ensure continuity of service; using resources sustainably; and undertaking a process of continuous improvement.

- City of Brisbane, Queensland, Australia—Brisbane sees asset management as providing a strategic direction and consistent framework for its facility planning, enabling it to meet community expectations for services. Asset management works to preserve assets at the lowest life-cycle cost, and helps the city to improve the use of its asset portfolio and dispose of surplus assets. Brisbane has developed comprehensive 10-year asset management plans for its transportation assets. For example, its traffic signals and electronic control devices plan includes sections on levels of service (including customer expectation as well as legislative requirements, and comparisons between current and desired levels); an analysis of future demand; a life-cycle management plan; discussion of risk management; a financial summary related to the asset in terms of its valuation and expenditures for capital repair, maintenance, and renewal; asset management practices and systems; and plan improvement and monitoring. Brisbane has developed a tradeoff analysis to prioritize needs and help the city council determine the optimal mix of investments. This analysis is based on deficiencies and assessments of risks as compared with desired levels of service.
- City of Edmonton, Alberta, Canada—Edmonton has based its asset management approach on maintaining a state of good repair of its assets and ensuring adequate funding of development and rehabilitation programs that are effective and efficient. Major drivers of asset management include the need to use limited funding wisely, to communicate the linkage between funding and service levels to the public, and to compare investment options. Edmonton has likewise developed asset management plans, as well as a sophisticated set of analytic tools and the ability to conduct scenario or “what-if?” analyses. Its performance measures reflect condition, functionality, and demand capacity for all asset categories.

Asset Valuation

Asset valuation is used by a number of other countries as a component of their transportation infrastructure management. The scan team visited several agencies that apply an asset valuation approach, although specific methods differ, particularly regarding the degree to which management systems are used as a basis for determining remaining service life, and what definition of cost is used. These agencies were also dealing

with questions on matters such as service life, similar to the U.S. concerns described in chapters two through seven. An overview of different infrastructure asset valuation techniques was described in a recent paper (Cowe Falls and Haas 2000).

- Transit New Zealand (TNZ) (an agency responsible for highways and roads) has organized its asset valuation procedures within an Asset Valuation Manual. One-third of the network is revalued each year. Replacement costs are calculated from agency contract data, unit cost records, and identified databases, including drainage culverts and traffic facilities (Geiger et al. 2005, Table 5). How to define service life remains an issue, however. Among the questions being dealt with are the threshold value at which useful life can be considered to be exhausted and how to apply a concept of remaining useful life to systems such as ITS.
- The specific techniques to be used in asset valuation are still under discussion. For example, the New South Wales RTA has concerns about straight-line depreciation and the use of accounting standards as the basis of asset valuation. Although it continues to report asset value to the Department of Treasury according to the accounting rules and straight-line depreciation, it nonetheless uses its asset management systems to rank work priorities.
- Queensland's Main Roads has actually reached an agreement with the Department of Treasury to use its management system outputs to compute remaining service life for pavements as the basis of its asset valuation.
- Edmonton, Alberta, uses the replacement value of its assets as the basis of asset valuation. Using this approach, it has computed that transportation and streets are the second-largest component of the 12 asset categories for which the city is responsible.

Performance-Based Management of Selected Assets

The scan team observed a number of examples of how asset management processes and performance measures (including levels of service) were applied to selected assets.

- English local road agencies devote considerable attention to roadway lighting management. In England, 80% of local governments are reported to have a street light database. A Roads Liaison Group has recommended that local agencies use national performance indicators for asset management, plus others to address specific local conditions. Although one group of performance measures addresses service delivery and is intended for internal agency use, a second group deals with the condition and performance of the roadway lighting network and is intended for public dissemination. These measures are in the following categories:
 - The total number of faults identified through inspection, customer reports, and other sources;
 - Percentage of lights working as planned;
 - Total number of failed or faulty service connections; and
 - Total number and cost of damaging incidents as a result of vehicle crashes and vandalism.
- The English Highways Agency has likewise given attention to its roadway lighting system. Approximately 32% of lighting standards are more than 30 years old, their expected useful life. Work is proceeding to develop deterioration models for roadway lighting to help agencies prioritize investment needs.
- The scan team also observed that more attention appears to be given in England to sidewalks and appurtenances than is typically done in the United States. England also appears to lead U.S. agencies in applying performance measures in asset management.
- Gloucestershire was an early advocate of asset management and its use in transport planning. Its county council has produced a statement of objectives, list of desired outcomes, definition of asset resources, and identification of risks associated with asset condition. Core assets that were defined included a number of items similar to selected assets; that is, street lighting, pedestrian guardrails, traffic signals, road markings and RPMs, urban sidewalks and paths, signs and bollards, urban bike paths, and drainage data. Gloucestershire has also performed a gap analysis comparing current versus desired level of service, the cost of closing the gap, and the resulting benefits to the public. An implementation plan will identify priorities and needed resources.
- TNZ prepares monthly traffic light reports showing progress in key performance measures. The degree of progress is denoted by green (OK), yellow (warning), and red (action required) color symbols applied to measures of current status as well as directional trends.
- Queensland Main Roads includes selected assets explicitly in its asset management process. Transportation asset management is used for long-range planning and alignment of Main Roads actions with public policy goals, mid-range corridor planning and stewardship of existing assets, and near-term development of its 5-year Roads Implementation Program. Specific modules for roadside amenities, traffic control systems, and signage are included in Main Roads' asset management system.
- Brisbane's asset management program has been instrumental in providing the city council with information it needs to understand road transportation investment decisions across all assets. A particularly relevant aspect of this process has been to give importance to assets that normally do not receive much attention, including signs, signals, and pavement markings. The asset management process is assisted by an asset steering committee and is informed by community outreach and public input.
- Edmonton tracks the conditions of several selected assets and components in its asset management systems including sidewalks, street lights, traffic signals, and traffic signs. It considers asset performance in three dimensions:

physical condition (and the ability to meet intended service levels), functionality, and demand versus capacity.

- VicRoads (Victoria, Australia) applies a comprehensive asset management approach based on life-cycle analyses, desired or target levels of service, and strong analytic capabilities. With respect to the selected assets of this study, it appears that VicRoads is able to apply service-life data that exhibit a range of values—for example, mechanical and electrical systems with lives estimated at 10 to 30 years, and tolling instrumentation with lives of 3–10 years.

Organizational and Institutional Aspects

The English Highways Agency provides guidance for asset management at a top management level through its Business Plan. Responsibility for asset management within each operational area of the road network is vested in a managing agent, a private consultant with typically a 5-year contract to work with the agency's maintenance contractor for the operational area. In a variant of this arrangement, the managing agent and the maintenance contractor are combined within what is called a managing agent contractor. There is also considerable local government and professional association involvement in supporting asset management and providing technical assistance in England.

Queensland Main Roads has established a Road Asset Maintenance Steering Committee to oversee development of asset management policy. The responsible unit within the agency is the Road Network Management Division, supported by many other units providing data and expertise.

TNZ has an organizational structure that encompasses four major groups or divisions: transport planning, network operations (where asset management responsibility is located), capital projects, and organizational support. This structure is mirrored in the regional offices. Approximately 50 individuals with asset management responsibilities are distributed among central and regional offices. The importance attributed to asset management in TNZ is reflected in other agencies throughout the country. New Zealand exhibited perhaps the greatest degree of integration of asset management principles and techniques in the agencies' business processes that was observed by the scan team in its visits. As in England, there is considerable support for asset management from local governments and professional associations.

Specific asset management responsibility is also assigned within the RTA (in its Directorate of Road Network Infrastructure), VicRoads (in its Road System Management Group, one of four core business areas), Brisbane (in the Transport and Traffic Program, with guidance on asset stewardship from an asset steering committee set up by city government), and Edmonton (in the Office of Infrastructure, established in March 2000). [Author's note: As this report was going into production, users of the InfraGuide were in-

formed that it was being discontinued owing to lack of continued funding. The website is no longer available.]

Canada's InfraGuide

InfraGuide is a web-based resource providing access to best practices and other documents for a variety of infrastructure, including roads and sidewalks (www.infraguide.ca). It was established through a collaboration of Infrastructure Canada, the Federation of Canadian Municipalities, the Canadian Public Works Association, and the Canadian National Research Council. InfraGuide links users to published best practices, pending best practices, and other resources related to asset condition, performance, and management. As an example, the Canadian guidelines for sidewalks referenced in chapter seven are a best practices document available through InfraGuide.

IMPORTANCE OF SELECTED ASSETS

Given limited resources, prospects for advancing the management practices for selected assets are clouded, according to survey responses in chapters two through seven and in the section in this chapter titled "Knowledge Gaps, Impediments, and Research Needs." Moreover, it is difficult to gain increased attention and priority for these assets. Expenditures for signals, lighting, signs, markings, culverts, and sidewalks are not well itemized, and in any case are not felt to be a significant percentage of an agency's annual transportation budget. Furthermore, there is a lack of good information that could build a stronger awareness of the value of these assets in serving mobility, safety, and public well-being. It is apparent from the survey comments that budget-related arguments do not, by themselves, build a compelling case for needed investment in selected assets. Rather, the research in this study indicates other approaches that may offer a better way to demonstrate the importance of these assets and the need for stronger asset management.

- Replacement value—Although many jurisdictions overseas employ asset replacement value as a key component of their transportation asset management—including selected assets—comparatively few agencies in the United States do so. In the responses received in the study survey, only three cities mentioned using asset value. Replacement value is not the same as the asset value called for by the Governmental Accounting Standards Board (GASB) Statement No. 34 financial reporting requirements (1999). Replacement value is management-oriented rather than accounting-oriented, and gains or losses in value can be coordinated with results computed by management systems as an effective, ongoing component of asset management.
- Public impacts—The level of performance of the six selected assets addressed in this study have very strong implications for the public. These impacts affect transportation facility users in terms of mobility, safety, and

comfort. They also affect the general public in terms of safety and security (e.g., a community's ability to deliver police, fire-fighting, and ambulance services quickly when needed), protection of property from flooding (which requires adequate, well-maintained culvert hydraulic and structural capacity), and environmental protection (e.g., reduced air pollution resulting from a well-functioning transportation system supported by effective signalization, signage, illumination, and pavement marking guidance; and fish passages and animal crossings provided by culverts). If performance degrades to failure of one of these assets, results can be severe; for example, a road closure owing to slope instability or pavement foundation cave-in at a collapsed culvert, or gridlock with a failed signal system. Culverts on the U.S. highway system are now beginning to approach their design lives, something that has not happened on a major scale in modern times.

- Need to accommodate changes in demand—Chapters two through seven describe standards, guidelines, and procedures to design selected assets to meet anticipated demand. Ideally, these assets are upgraded or replaced to meet expected new demands; for example, in traffic volume and composition. However, changes in demand on selected assets will be undergoing fundamental shifts that have no historical precedent. A major example is the aging of the Baby Boomers, with implications for pedestrian as well as motor vehicle driver behavior. This behavior needs to be better understood, with appropriate responses in terms of the materials, systems, and operational characteristics of selected assets. Another example is the changing land use surrounding highways and street networks, and the growing recognition of fresh, pure water as a scarce resource. Culverts need to be designed, built, and maintained not only to protect the highway investment, but also to protect drainage courses and unpolluted water sources in the face of changing land-use patterns.

PUBLIC INVOLVEMENT

Encouraging public involvement in transportation policy decisions has been a force in the United States for more than 30 years, with power shifting from the federal government to the states and the empowerment of community groups to have a say in policies that affect them. There are several benefits of a well-designed and well-implemented program of public involvement (O'Connor et al. 2000):

- Greater likelihood of citizen buy-in to policies, a feeling of public ownership and awareness of issues, and the likelihood of sustained public support over time.
- Incorporation of community values in policy decisions.
- More efficient decision processes and project implementation owing to reduced risk of litigation and reduced need to revisit and reopen past decisions.

- Enhanced agency credibility among stakeholders and greater mutual understanding of positions and thinking.

Several guiding principles have evolved for successful community outreach and public involvement initiatives (O'Connor et al. 2000):

- Understand the strong linkages but the distinctions that must be maintained among public involvement, public information, and public relations.
- Conduct public involvement as an honest broker, providing the public with ample opportunity to be heard, informing the public of options and constraints, engaging in a dialogue, listening to feedback, working through differences, and allowing the process to influence decisions and outcomes.
- Ensure that public involvement is as inclusive as possible, proactively encompassing a broad group of decision makers and stakeholders.
- Keep communications respectful and encourage mutual respect throughout the process.
- Begin public involvement early in project or policy development and maintain it throughout development.
- Ensure that participants understand the decision process that the agency will be undertaking. The process should be defined, structured, and transparent, and key milestones and decision points should be clearly explained.
- Although public involvement programs need to serve as honest brokers with no predetermined outcomes, the agency must also provide leadership throughout the process to ensure that participants understand agency policy, perspectives, and procedures. Agencies must also budget sufficient staff and dollar resources for this effort.

Public involvement has been shown to benefit transportation asset management programs and decisions. Within the United States, for example, Hillsborough County, Florida, found that effective public involvement was instrumental in maintaining funding and community support for development of its asset management system (*Economics in Asset Management* . . . 2005). In its performance audit of Portland's service efforts and accomplishments, which include transportation and parking and their asset management programs, the city auditor conducts both citizen surveys and business surveys. Results of these two surveys are incorporated directly in the discussion of each city goal and agency performance in meeting that goal (*City of Portland* . . . 2005). The international scan team likewise observed several ways in which community participation is solicited in asset management deliberations. For example, a research effort in Victoria examined public expectations for levels of service of several assets. Tools used to gain this information included interviews with stakeholders, focus groups, and a conjoint analysis that allowed participants to conduct tradeoff analyses across levels of service of these several assets. This conjoint analysis allowed VicRoads to infer a preferred redistribution of available resources across assets and among

different asset management activities. Brisbane uses public presentations and focus groups to obtain input from the community on its asset management efforts.

KNOWLEDGE GAPS, IMPEDIMENTS, AND RESEARCH NEEDS

The gaps in existing knowledge, impediments to improved asset management, and research needs associated with each of the selected assets were identified in chapters two through seven, respectively. Additionally, synthesis survey participants were asked their opinions on overarching issues and research needs related to asset management broadly defined. Their responses are paraphrased here, organized by major topic area: Budgeting and Resource Availability; Management Priorities; Organizational Roles and Responsibilities; Information and Analytic Capabilities; and Performance Measures, Tradeoffs, and Decision Criteria.

Budgeting and Resource Availability

Edmonton suggested improvements in budgeting practice, and several other agencies focused on the lack of financial, human, and data resources as a major impediment to better asset management practice, particularly for the selected assets.

It would help to require improved alignment of capital and operating budgets to infrastructure categories to better assess use of budget.

— City of Edmonton

Providing resources for these assets is a challenge. There are inadequate financial and staff resources to manage these assets that are sometimes viewed as ancillary to the pavement infrastructure.

— Saskatchewan H&T

What is needed is dedication of resources to data gathering and maintenance analysis.

— Colorado DOT Region 3

If dollars could be assigned to signal poles and mast arms and beacons, conduit, wiring... we could make asset management decisions.

— Colorado DOT Region 4

There is a concern that the resources needed to establish a comprehensive asset management program may be better applied to other needed areas.

— Iowa DOT

Better management is impeded by limited staff and resources to track, report, and maintain these assets.

— Kansas DOT

The primary institutional issue is that other Departmental priorities are using all available resources and then some. Moving on to systematically managing the classes of assets under study in Topic 37-03 is presently beyond the scope of effort that can be sustained by both the affected program areas and our information technology office. We have to wrap up some of the ongoing

transportation management system upgrades before starting development of new systems.

— NYSDOT

There must be a realistic assessment of the resources needed to support a comprehensive asset management program. The concept of “data as an asset” is often skipped, leading to the underestimation of data management needs. If, as in PDOT’s case, asset management is an outgrowth of a variety of discontinuous activities (inventory, condition monitoring, financial models, etc.), the process gets “kick-started” and behind on data collection from the start. From there, it is an up-hill battle to acquire qualified staff to support the “new” asset management program because the initial belief was that asset management was going to save the agency money. Lacking an initial full assessment of benefits and costs of this system impedes the progress of the agency while asset data get older and less credible.

— City of Portland

There is a lack of perceived need, manpower, and funding to initiate and maintain inventories.

— West Virginia DOT

Management Priorities

Several agencies listed various management issues that affect their organization’s treatment of selected assets, including a perceived low priority of these assets compared with other management needs, difficulties in translating between focused views of assets (agency “stovepipes”) and more global perspectives of agency priorities, and the lack of an overall asset management approach within the agency.

Individual infrastructure elements require individualized analyses, causing difficulty in presenting an overall corporate picture to relate one disparate asset to another.

— City of Edmonton

Organizationally, these assets have been a low priority in comparison to pavement and bridge management. Highway maintenance functions have employed performance measurement methods to assure consistent service levels across the 12 districts and 88 counties. This management process utilizes condition surveys and quality assurance reviews to ensure compliance with statewide policies.

— Ohio DOT

At present, major overarching gaps in knowledge include (1) lack of data defined, collected, and stored in a consistent manner; (2) lack of a global view by individual business lines of organizational priorities; and (3) lack of effective analysis tools.

— Oregon DOT

There is no specific guideline or a written strategy to implement overall asset management in a near future.

— Quebec Ministry of Transportation

Texas’ large size and overwhelming quantities of inventory make it difficult to manage down to the level of assets such as sidewalks, guardrails, signs, etc. As we develop better management tools, information will probably be kept in greater detail at the District level (25 Districts in Texas, each averaging 7,600 lane-miles).

— Texas DOT

Some of these ancillary assets such as culverts, sidewalks, and signs can be tied into other projects such as paving and roadway. That minimizes cost and disruption to the public. For that to happen, however, good advance coordination between the organizational stovepipes is required. (If the coordination is not done early in the process, it becomes “scope creep.”) We need to consider all assets associated with and around a project, and we need procedures that encourage that coordination. We have a GIS database of most assets, but need to better utilize it.

Far more attention is given to pavement, bridge, and roadway since that is where most expenditures are. Ancillary assets are sometimes lacking a good inventory and condition rating.

— Vermont AOT

Organizational Roles and Responsibilities

The agencies here noted that organizational and human resource issues, particularly in staffing needed functions in asset management, are impediments to introducing or improving asset management.

While mentioned above as a management issue, the lack of a global view by individual business lines of organizational priorities is also an organizational issue.

— Oregon DOT

A gap exists in the area of organizational structure and related Human Resources issues. PDOT needs to properly capture asset management skills in job class descriptions to be able to retain and recruit qualified staff. Asset managers are appointed from different levels of responsibility within the organization. While cross-disciplinary and inter-divisional asset teams have worked well together, asset management as a distinct function is yet to be identified except at the Asset Management Coordinator level. Roles have been defined for Asset Manager and Asset Management Coordinator, but we have not hired for either function. We have identified a need for field data collection devices and programs/processes to support field data collection. However, we lack the actual capability in this area, which is critical to improving the timeliness and accuracy of basic asset data.

— PDOT

Asset management is not explicitly part of our planning. No department has been put in charge of implementing asset management on a defined schedule.

— Quebec Ministry of Transportation

Information and Analytic Capabilities

Agencies cited several gaps and ideas for research involving IT, data collection and processing, and analytic methods and tools.

Better tools are needed to conduct tradeoff analyses among asset categories. The issue of setting appropriate service level targets also needs to be looked at more. For example, our agency has a service objective to maintain 98 percent of regulatory signs functioning as intended. Is 98 percent an appropriate number? Should it be higher or lower?

— Maryland SHA

There is no repository where information on these features is accessible. Inventories for these smaller assets are incomplete,

are organized so others cannot use them, or are out of date. This is to be rectified in the next 2–3 years. [Note: Refer to the discussion of MDOT’s SPFI initiative earlier in this chapter.]

— MDOT

We lack a functional database for some of the six selected assets. It is also questionable whether a database is needed. It may not be cost-effective to develop a comprehensive database and monitoring system to replace an adequately functioning replacement cycle.

— MnDOT

NYSDOT has chosen to focus its transportation asset management technology improvement projects in areas other than the asset classes being highlighted in Topic 37-03. (1) The MAMIS project has been a large multi-year system development effort. (2) A Highway Data Management System upgrade has also been ongoing for more than 5 years to cover both the pavement management and traffic monitoring programs. (3) Phase 1 of a bridge inventory and inspection system project was put into production about 18 months ago. Phase 2 of that project is updating the field equipment and data acquisition software used by bridge inspectors. Phase 3 will deal with analysis of investment candidates throughout the maintenance, preservation, and replacement cycle. (4) New York’s safety management system is being upgraded with high-accuracy statewide base mapping, electronic ticketing, electronic crash records creation, and electronic judicial processing of traffic violations. This has resulted in a much more robust linear referencing system, including connection-details topology. (5) New York has invested heavily in developing an e-government portal for use by our customers who need permits to transport large or heavy loads on highways. The goal of reduced labor costs per permit remains elusive, despite heavy investment in this technology project. (6) NYSDOT is starting a technology project now to update our Artemis 9000 project management application with best-in-class capabilities. The upgraded project management system will continue to interface with our Program Management System that was developed during the 1990s. (7) Congestion management is an important performance measurement and reporting subject in New York. Ongoing investment in the Condition Acquisition and Reporting (CARS) platform, in a pooled fund effort with other states, is a major ongoing Information Technology project.

— NYSDOT

An inexpensive assessment method using a van with videologging or cameras would be useful.

— North Carolina DOT

While mentioned above as a management issue, the lack of effective analysis tools is also noted here as an Information Technology issue.

— Oregon DOT

[While the substance of this comment is noted above as a resource availability matter, it also has data implications and is repeated here.] The concept of “data as an asset” is often skipped, leading to the underestimation of data management needs. If, as in PDOT’s case, asset management is an outgrowth of a variety of discontinuous activities (inventory, condition monitoring, financial models, etc.), the process gets “kick-started” and behind on data collection from the start.

— City of Portland

Over the years, the Ministry of Transportation has implemented management systems in specific areas (bridges, pavements, etc.) and inventory systems for all of the assets mentioned in this survey except for roadside signs. These systems could be integrated within a broader vision of asset management with minor adjustments, and some inventory or management systems already have

integrated asset management functions. However, there is no specific guideline or written strategy to implement overall asset management in a near future.

— Quebec Ministry of Transportation

Development of automated condition assessment tools could certainly assist with managing our assets. For instance, sign condition is now a visual measurement, mostly done during the day. Faded or mildewed signs are obvious as well as leaning signs, etc. However, it should be possible to develop, using digital photographic technology, equipment that would count the signs, measure if they are leaning, and also measure retroreflectivity. This would take the subjectivity out of our ratings.

— Texas DOT

Performance Measures, Tradeoffs, and Decision Criteria

Several agencies focused on the need for better information on gauging asset performance and incorporating this concept within decision-support methods, particularly optimization of resource allocation and tradeoff analyses.

To optimize resources across asset categories requires that the optimization be based on criteria that can transcend asset categories. Determining appropriate criteria and service level objectives is difficult. Research on the entire area of optimization of resources among asset categories from a practitioner's perspective would be useful.

— Maryland SHA

The research we are most interested in is how to develop performance measures for our assets using lowest life-cycle costs. This work is essential to develop meaningful performance targets as we move forward with performance-based planning.

— MnDOT

NYSDOT is participating in both of the AASHTOware asset management projects that are now starting up. The continuation of NCHRP Project 20-57's Report 545 with its program-level and project-level tradeoff model development is of keen interest. Similarly, an AASHTOware approach to managing the highway maintenance function holds promise to reduce technology system development costs for the states.

Prioritization of investment candidates across all classes of transportation assets (e.g., guideways, traffic control systems, revenue rolling stock, terminals, etc.) and all program areas (e.g., operations, maintenance, system preservation, service improvement) requires a common measure of performance on which to sort the candidates into priority order. Development of ranking criteria will be a very tall order, in that the subject matter expert committees that now make the tradeoff decisions rely on extensive knowledge of their assets and performance that is not easily boiled down to an attribute a computer program can use to sort on.

— NYSDOT

Data collection and data maintenance costs affect the agency's ability to track selected assets at the individual asset level. The agency has responded by using policies to govern maintenance and replacement cycles. The identification of key business rules, such as cost-effective replacement cycles, may assist agencies to govern effectively.

— Ohio DOT

Establishment of a rating system that would permit evaluation of cross-category asset conditions and treatment tradeoffs would be useful.

— Oregon DOT

It would be helpful to know how states are linking these assets to other roadway features and evaluating the overall roadway segment. How do these ancillary assets influence larger project selection?

— Vermont AOT

MATURITY OF ASSET MANAGEMENT

Chapters two through seven have described several aspects of the management of selected assets. To put these in the context of asset management, we return to the maturity diagram of Table 1. The state-of-art practices in Table 1 have been consolidated and listed in the left-hand data column of Table 29. In the right-hand data column of Table 29 are two sets of information:

- The current state of practice across all of the selected assets, summarized very briefly; and
- Potential improvements that could fill the gap between current state of practice and the state of the art. These improvements are also informed by the information in chapters two through seven.

Table 29 is greatly simplified because it encompasses all six selected assets, which clearly differ from one another in many ways. Nonetheless, the table is useful to get an idea of how management practices for selected assets compare, for example, with pavement and bridge management in the level of attainment of asset management. Clearly, many gaps need to be filled, echoing comments reported in the synthesis survey and other recent surveys. In certain cases, the concepts of asset management may need to be developed in new ways to accommodate different types of assets, such as electronic controls on traffic signals; systems of assets, such as signal systems or culvert systems, where impacts must be seen more broadly and issues of component compatibility become important; and new ways of combining assets and introducing new classes of assets, as has been proposed in novel concepts of peripheral roadway lighting combined with pavement markings and embedded roadway lighting. Table 29 should therefore be interpreted as a high-level overview, with the more detailed discussion of each asset in chapters two through seven, respectively.

OTHER NON-PAVEMENT, NON-BRIDGE ASSETS

Although the six categories of selected assets were the primary focus of this study, examples of innovative management methods for other non-pavement, non-bridge assets that were identified during the course of the work were noted as well. Several examples have already been cited in the discussion of comprehensive asset management approaches. A further example is a guardrail inventory management system developed

TABLE 29
COMPARISON: STATE OF THE ART AND STATE OF PRACTICE

Aspect of Infrastructure Management	State-of-the-Art Asset Management	State of Practice Across Selected Assets and Potential Improvements in Practice
Policy Guidance	<ul style="list-style-type: none"> Guidance moves beyond wish lists ” to provide clear governmental priorities among competing goals, objectives, and initiatives. Long-range planning, agency strategic planning, and decisions on program funding and resource allocation are fully integrated horizontally (across agency units) and vertically (top management, managerial, and technical levels) under the umbrella of this guidance. Human factors understanding of asset performance requirements extend to different population groups. Public outreach extends to identifying governmental priorities at a broad program level. 	<p>STATE OF PRACTICE</p> <ul style="list-style-type: none"> Technical guidance on asset construction or installation exists across all assets. Maintenance and operation guidelines exist to some degree at national level, more typically at agency level. Human factors guidance is beginning to emerge (e.g., regarding pedestrians), but more is needed. <p>POTENTIAL IMPROVEMENTS</p> <ul style="list-style-type: none"> More performance-based guidance; e.g., relating retroreflectivity levels to crashes and culvert condition to risk of road failure. To the extent feasible, greater standardization in critical performance thresholds and criteria, test procedures, and component compatibility requirements.
Asset Life-Cycle Focus	<ul style="list-style-type: none"> Project decisions are based on maximization of life-cycle benefits or minimization of life-cycle costs, plus consideration of other (nonquantitative) impacts. Life-cycle impacts to the public are considered in decisions on management options. The life-cycle framework enables analysis of certain tradeoffs (e.g., capital-maintenance, benefits-to-costs). 	<p>STATE OF PRACTICE</p> <ul style="list-style-type: none"> Examples of life-cycle cost analysis (LCCA) have been developed for specific assets, components, and materials. <p>POTENTIAL IMPROVEMENTS</p> <ul style="list-style-type: none"> Incorporation of public benefits or impacts within the LCCA framework. More definitive and reliable data to support LCCA. Incorporation of LCCA within decision-support tools.
Asset Performance and Costs	<ul style="list-style-type: none"> Causal factors affecting asset deterioration are reasonably well understood based on published research and agency’s own experience. Models can predict deterioration of assets, needs for treatments, associated costs, and improvement in asset condition or extension of service life. These models are incorporated within life-cycle decision-support systems or tools. Resulting information on asset performance and cost can be easily processed or summarized for use by different agency organizational units and levels, as well as for external accountability reporting and public information. Management systems are applied to identify strategies for attaining performance targets within available resources. Asset performance is understood throughout the agency organization and by executive and legislative stakeholders. 	<p>STATE OF PRACTICE</p> <ul style="list-style-type: none"> Significant work has been done in certain assets to understand performance of different materials or components. Variability in site-specific conditions and in performance data to date has precluded development of reliable performance or deterioration models. Difficulties in reliably measuring condition also have inhibited a more analytic approach to performance. National retroreflectivity calibration standard may improve reliability of sign and pavement marking readings. <p>POTENTIAL IMPROVEMENTS</p> <ul style="list-style-type: none"> More rapid and reliable measurement and data collection techniques. Development of practical, reliable methods to predict service life, accounting for site- or system-specific factors, but avoiding complicated requirements in each individual calculation. Development of more robust analytic tools or management systems, perhaps guided by a user-community panel. Broader concept of asset performance, encompassing electric/electronic systems, real-time operational changes, and component compatibility issues. Understanding of performance at a network or system level (e.g., hydrological performance of a culvert network, performance of a signal system, performance of combinations of assets; e.g., signals, signs, lighting, and pavement markings).

(continued)

TABLE 29 (continued)

Aspect of Infrastructure Management	State-of-the-Art Asset Management	State of Practice Across Selected Assets and Potential Improvements in Practice
Impacts of Asset Performance	<ul style="list-style-type: none"> Agency has attained or acquired a body of research on impacts of asset performance in different situations, climates, road classes, etc. Predictive models of impacts are fully incorporated in life-cycle procedures to optimize decisions on construction, rehabilitation, and maintenance. 	<p>STATE OF PRACTICE</p> <ul style="list-style-type: none"> Impacts are understood qualitatively, and research has contributed to an analytic understanding in some cases. Complexity of problem can lead to apparent inconsistencies in actual versus predicted results. Impact models by and large have not yet been incorporated within LCCA or management systems. <p>POTENTIAL IMPROVEMENTS</p> <ul style="list-style-type: none"> Additional research to clarify impacts in different site situations and among different population groups. A greater focus on system-level impacts (e.g., effects of signal systems as opposed to individual signalized intersections; impacts of a systems approach that combines lighting, pavement markings, signs, and signals; hydrological and water quality impacts of a culvert drainage network).
Resource Allocation, Budgeting, and Project Selection	<ul style="list-style-type: none"> Budget development conforms to applicable law, funding eligibility, and agency planning and programming guidelines. Program development is built on an explicit relationship between proposed budget and target level of service or performance, with implications for achieving defined policy objectives. Ranking or prioritization criteria are closely aligned with policy objectives and performance targets. Cross-program tradeoffs are explicitly considered, in addition to prioritization of projects within each program. Level of service considers customer needs and perceptions, in addition to other public-policy and agency priorities. Resource allocation and budgeting process is fully vertically aligned, with project prioritization criteria, tradeoff analyses, and performance measures and targets in full agreement with policy goals and objectives. Devices such as GIS-based maps and dashboards are used to communicate budget results and program impacts to stakeholders and the public. Budgeting results and forecast program impacts are communicated to stakeholders and the public. 	<p>STATE OF PRACTICE</p> <ul style="list-style-type: none"> Providing financial and staff resources can be challenging. Selected assets are viewed in some agencies as secondary to the pavement infrastructure. Budgeting relies to some degree on asset inventory, condition, or level of service, but performance-based factors are not the primary drivers. Other factors (prior year's budget, staff judgment, public comments and complaints, and political inputs) play an important role. Lack of basic inventory and related asset information in many U.S. agencies precludes more advanced budgeting techniques. International agencies are ahead in having information on asset performance and use of prioritization and tradeoff analyses. <p>POTENTIAL IMPROVEMENTS</p> <ul style="list-style-type: none"> Strengthened budgeting and resource allocation will require improvements in data collection, analytic tool development, and organizational processes described in other items. Existing or easily developed tools (e.g., GIS, dashboards) can be developed to communicate asset performance, costs, and proposed improvements.
Organization	<ul style="list-style-type: none"> Cross-functional asset management responsibility exists, briefs top management on status Recognition and commitment to sustainable management of assets among employees, management, and elected officials. Asset manager role within the agency is explicitly recognized and assigned, and asset management training occurs regularly and reaches all employees, managers, and elected officials. Succession planning takes into account the role of asset managers. 	<p>STATE OF PRACTICE</p> <ul style="list-style-type: none"> Some reporting organizations did not have a defined individual responsible for asset management. It is not clear to what degree sustainable management and cross-functional communication are practiced. International agencies provide examples of different organizational structures. <p>POTENTIAL IMPROVEMENTS</p> <ul style="list-style-type: none"> Continue promoting asset management as an effective business process applicable to selected assets. Communicate international experience more widely, including different organizational models.
Performance Measurement	<ul style="list-style-type: none"> Body of performance measures is well established and incorporated in business and decision processes as the basis for accountability reporting internally and externally, and to support policy formulation, prioritization and tradeoff analyses, resource allocation, and public feedback. Measures are expressed in various forms for different audiences, including reports, trend lines, dashboards, maps, and other devices. 	<p>STATE OF PRACTICE</p> <ul style="list-style-type: none"> Most agencies have data on physical condition of selected assets, with other measures as appropriate to each asset. <p>POTENTIAL IMPROVEMENTS</p> <ul style="list-style-type: none"> Strengthened performance measures based on improvements in measurement, data collection, and analytic tools. Performance measures based on impacts of asset performance as well as asset condition.

(continued)

TABLE 29 (continued)

Aspect of Infrastructure Management	State-of-the-Art Asset Management	State of Practice Across Selected Assets and Potential Improvements in Practice
Information Technology and Data Collection and Processing	<ul style="list-style-type: none"> Models and engineering relationships discussed in previous items have evolved to sophisticated management systems, incorporating engineering and economic models, life-cycle concepts, and decision-support procedures (e.g., optimization, heuristics, decision rules, or trees). Asset management systems are organized on an integrating platform (e.g., GIS or web-based portals) for internal and possibly external access to information. The agency maintains complete, current, and accurate data on asset inventory, condition, performance, cost, and work accomplishment. Data are updated on a predetermined schedule or by established criteria. Sampling techniques may also be employed. There is an appropriate mix of data collection technology (e.g., visual, physical, automated measurement, and remote sensing) to ensure high-quality data and cost-effective coverage. Data supporting infrastructure asset management are fully integrated within a unified scheme; e.g., through data warehousing. Information on customer perceptions is updated regularly through surveys, focus groups, complaint tracking, or other methods. 	<p>STATE OF PRACTICE</p> <ul style="list-style-type: none"> Agencies collect data on asset condition generally on a regular basis, with increasing use of automation. State of practice in analytic modeling varies widely, ranging from well-developed databases, tools, and systems to lack of basic inventory and expenditure information. Economic analyses tend to be stand-alone applications, typically not integrated in a management system. Where management systems are applied, they are likely maintenance management applications, which tend to be focused on current condition and project targets and budgets in the short term. Other existing tools are on a variety of platforms, and do not have standardized components or capabilities. Several agencies have asset management systems underway for selected assets. Research groups have applied simulation to understanding the performance of selected assets, but care is needed to include all effects that occur in complicated field situations. <p>POTENTIAL IMPROVEMENTS</p> <ul style="list-style-type: none"> Better analytic tools require engineering and economic modeling of performance and impacts (discussed earlier), and need to be tailored to individual assets as well as the nature of the selected asset system, as discussed previously. Where maintenance management systems are used, need to overcome shortcomings (e.g., lack of inventory, short-term analysis horizon) and provide life-cycle comparisons of different materials or system options. Incorporate more sophisticated human factors aspects within more robust simulation techniques, analytic tools, and management systems.

by the Idaho Transportation Department. This system, referred to as “Grail,” relies on an automated videologging system. A vehicle traveling at normal highway speed obtains high-quality digital photo images of guardrail conditions, combined with GPS location, road curvature, and distance-traveled data for use with GIS and traffic-related applications. The system helps the department managers identify damaged or obsolete guardrail sections on Interstate and National Highway System highways that can affect motorist safety. Moreover, this system enables Idaho Transportation Department managers to maintain a complete and accurate guardrail inventory with very efficient use of resources (*Transportation Asset Management System* . . . 2005).

Synthesis survey participants were also asked to identify other non-pavement, non-bridge assets that they manage using estimates of service life and predictions of future condition and resource needs. Following are their comments:

Infrastructure inventory data [are] collected on an annual basis for all the assets owned and managed by the city of Edmonton. The infrastructure elements include drainage (sanitary, storm and combined sewers, and wastewater treatment), road right-of-way (road, sidewalks, bridges), parks, transit, fleet, buildings, traffic control, recreations facilities, affordable housing, waste management, tech-

nology equipment, and other (library material, emergency response equipment, etc.). Essential information collected for these assets includes quantity, unit of measure, replacement value, average age and expected life, and condition assessment in three categories: physical condition, demand/capacity, and functionality.

In addition, financial information is collected for each of these infrastructure elements showing investment needs through the next 10 years and whether categorized as a growth, rehabilitation, or other project. The city is also implementing an innovative prioritization tool as described in the earlier section on ongoing asset management efforts.

— City of Edmonton

Ohio employs asset management techniques in its management of transportation buildings, waste treatment, and other long-term facilities. Performance measures are also used to monitor each of our critical functions through the Organizational Performance Index. This collection of performance measures tracks results, including various condition levels and work programs at the district level. These indicators are in turn used by managers to identify and support funding or process improvement needs.

— Ohio DOT

Other agencies mentioned their management of facilities such as rest areas (Minnesota and Texas) and picnic areas (Texas).

CONCLUSIONS

Based on the survey of U.S. and Canadian transportation agencies that was conducted as part of this study, and a review of related material, a picture emerges of considerable interest and activity to develop stronger management approaches for transportation infrastructure assets, but with a recognition that some basic information and capabilities are currently lacking.

The literature review indicates that management of these assets can be complicated in several ways.

- From an engineering and technical standpoint, selected assets comprise a number of components and materials, serve in many different environments across the United States and Canada, and are subject to many different types of deterioration. Developing models that adequately explain these deterioration mechanisms and that can predict service lives for the complete range of possible conditions is a major challenge. This complexity is true for the physical and chemical processes that affect culverts; the compatibility issues that can affect signal and lighting systems; and the traffic, weather, dirt, solar radiation, and other factors that affect the retroreflectivity of signs and pavement markings.
- From a human factors perspective, the selected assets that affect mobility and safety can have complicated impacts that are still being researched. The increase in the elderly population has already been recognized in ongoing work to ensure that signs, pavement markings, traffic signals, and roadway lighting are helpful to all driver and pedestrian populations. Care must be taken to enhance visibility at night and driver comprehension of messages and guidance provided by these devices, avoiding confusion and unintended effects.
- From an organizational, institutional, and procedural view, selected assets present challenges in management, coordination, and data compilation. Responsibility for these assets is typically diffused among public- and private-sector organizations, complicating the ability to understand the “big picture.”

Agencies that responded to the survey were clearly interested in the management of these selected assets. Several have already developed management systems specifically directed at one or more of these classes of infrastructure. Others have incorporated these selected assets within agency-wide asset management systems or enhanced maintenance management systems. Others are now in the process of developing an asset

management approach for these assets. At a minimum, agencies rely on existing maintenance management systems or other analytic and data gathering tools such as spreadsheet workbooks and paper log books to track and manage these selected assets.

Agencies that responded to the survey agreed substantially on why these selected assets should be managed. Many provided exactly the same or very similar rankings of the transportation goals served by these assets. However, estimates of technical data such as asset service life varied across agencies.

Although there is a basic pool of information that could form the nucleus of an asset management approach, these agencies reported that additional work is needed in a number of areas. Specific findings and conclusions of the study follow.

- State of knowledge. A body of knowledge exists that describes the performance of the selected assets, methods of inspection, available techniques for maintenance and rehabilitation, and other aspects of asset management. However, many agencies believe that this information is variable, to some degree inconsistently defined, and incomplete. The acceptability and use of this knowledge is therefore not as extensive as might be expected. Examples of this variability and inconsistency are easily seen in the service-life data that have been compiled in the study survey.
- Inventory. The lack of an inventory of these selected assets was viewed by many agencies as one of the key issues to address. Developing an inventory database itself is not the main problem, although several agencies mentioned this as a need within their own organizations. Rather, the heart of the matter is how to keep the inventory current and accurate. In addition to the financial and human resources needed, a key challenge is the constantly changing status of these assets. Customer calls arrive daily to report damaged or missing assets. Construction projects and maintenance continually repair or replace these assets. Manufacturers offer a continual stream of new products and updates for several of these assets. Legacy management systems may not include the types of data and frequency of update needed to track the inventory of these assets effectively. The need for a comprehensive, accurate, and current inventory, including data on number and location of assets, their age, maintenance and cost histories, current condition

- and history, performance, inspection schedule, inspector's recommendations, and so forth, is seen as a basic step to understanding the service life of assets and the best approaches to their management over time.
- Management capabilities and information. Although research continues on understanding and modeling service-life behavior of these assets and implications for performance, agencies participating in the survey mentioned several management capabilities and types of information that are needed.
 - One key theme across these assets was the need for standardization—in measures of condition and performance, in measurement techniques, and in threshold values or criteria for determining when an asset has failed. Greater uniformity was felt to be a stepping stone to more consistent values of service life and to more effective measurement and reporting of product reliability in these assets.
 - Service lives and decision criteria such as minimum acceptable values need to be evaluated under actual field conditions. A related need is to better understand the actual needs of drivers, cyclists, or pedestrians regarding selected asset attributes under different conditions (day vs. night, weather, ambient lighting, background color, etc.).
 - Additional information and modeling tools would provide better decision support. Agencies mentioned models to help determine best maintenance policies (e.g., group replacement versus “break-repair”), and tools and information to conduct benefit-cost and life-cycle analyses of alternative materials and products.
 - Simple, practical, streamlined tools could help agencies make investment decisions more easily, quickly, and efficiently. For example, although asset condition, performance, and service life are recognized as functions of several variables that in some cases are site-specific, agencies do not have the time or resources to conduct site inspections for every management decision. Managers need tools and procedures that embody the effects of these many variables within easy-to-use devices such as matrices or survival curves.
 - Beyond physical condition. Several agencies pointed out that the performance and service lives of these selected assets need to be understood in terms that go beyond physical condition. These comments are essentially at two levels:
 - At one level is the performance of a specific asset component or product. Because signals and lighting involve electronic components, their performance may be better gauged by measures such as functional obsolescence rather than the deterioration of a piece of hardware. Also, the energy costs of competing components are useful to know.
 - At a second level is the performance of the asset overall and its implications for the general public, not just motorists. Examples for different assets include the benefits of road and sidewalk illumination, the effect of the color of light on driving and security, the minimum retroreflectivity needed by different groups of drivers in signs and pavement markings, and the performance of culverts in preventing flooding as land use has evolved.
 - A dynamic commercial environment. For many of these assets, manufacturers continue to produce a stream of new products and updates, as noted earlier. Although these advances offer many potential benefits, they complicate the job of the asset manager. New methods and arrangements are needed to help agency asset managers field-verify existing products while dealing with the introduction of new products. Among the ideas that were suggested by survey respondents were the integration of manufacturers' data into agency asset management databases, tracking the evolution of materials attributes both at a component and a system level, standardizing the determination of service life and reliability (as noted earlier), and obtaining sufficient information to enable comparisons of one manufacturer's part compatibility to another.
 - Institutional factors. Almost all of these assets are maintained through institutional arrangements that potentially involve different public- and private-sector entities. Selected assets tend to be maintained through agreements with other levels of government and, selectively, with other private groups such as property owners or utility companies. These arrangements have implications for an agency's ability to be aware of current condition, maintenance history, and cost history; to enforce maintenance standards and requirements; and to communicate the current asset condition accurately to stakeholders and the public. Moreover, these allocations of maintenance responsibility vary across the country and may be embodied in state law. It is therefore difficult to attempt to move toward more uniformity in practice, and to share data on these institutional arrangements on a common basis.
 - New technology. Several agencies recognized that new technology potentially offers benefits in the management of selected assets. Technological solutions not only offer the possibility of improved, more economical performance, but they also could address some of the resource limitation issues (e.g., regarding inspections of assets) discussed previously. Examples included remote monitoring of the status of lighting systems, more efficient lighting based on light-emitting diode sources, lower-cost and more efficient ways to evaluate sign reflectivity, and new materials for rehabilitating culvert pipe. Agencies also recognized the need to evaluate new products under field conditions; for example, effects of wood preservative and deicing salt on retroreflective sheeting.
 - Better communication of priority. Communicating the priority of selected assets needs to be strengthened, both to inform resource allocation decisions on investments across assets and to obtain the additional resources needed to improve management practice for each selected asset.

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APPENDIX A

Survey Questionnaire

Agency: _____

Address: _____

City: _____ State: _____ Zip: _____

Questionnaire contact: _____

Position/title: _____

In case of questions please provide:

Tel: _____ Fax: _____ E-mail: _____

Date: _____

PURPOSE OF THIS QUESTIONNAIRE

In applying the elements of asset management, transportation agencies' strongest capabilities typically address pavements and bridges. These capabilities include relatively sophisticated management systems; detailed and comprehensive periodic inspections; supporting research programs by public and private sector organizations; and planning, programming, and budgeting procedures to resolve investment priorities and program tradeoffs. Similar capabilities are typically not widely available or deployed for other transportation assets in the United States, at least not to the scale seen for pavements and bridges, although there may be notable individual exceptions. The objective of this survey is to gain a better understanding of the state-of-the-practice for managing assets other than pavements and bridges, to identify best practices, and to document gaps in existing knowledge and research needs. Six types of assets will be investigated in depth, although unique or innovative management methods for other assets are also of interest. The six asset types that are the focus of this questionnaire are:

- Traffic signals, including structural components;
- Lighting, including structural components;
- Signs, both ground-mounted and overhead, including structural components;
- Pavement markings and lane striping;
- Drainage culverts and pipes (but not bridges); and
- Sidewalks.

Each survey part 1 through 6 addresses one of the asset types above. The survey has been designed to allow you to distribute individual parts of this survey to the respective managers responsible for each type of asset, if you wish. Part 7 covers broader aspects of asset management as they relate to these and other non-pavement, non-bridge assets. Part 7 can be filled out by yourself or another manager with broad-based knowledge of your agency's asset management practices.

COMPLETING THE QUESTIONNAIRE

Kindly respond to the questions to the best of your knowledge by clicking on a checkbox to mark it (or clear it) and by typing to fill in open fields. Advance to the next field by using the TAB key or a mouse-click. Most questions allow multiple responses—simply check or fill in all items that apply to your agency's situation. If an item does not apply to your agency's practice, just leave it blank. Two questions in each part call for a prioritized answer. In these cases, indicate the most important, most prevalent, or most applicable choice by inserting the number 1; then prioritize other responses in descending

order by inserting 2, 3, ... for the number of items that apply to your agency's practice. You do not have to prioritize all the items listed – only those that apply to your agency.

While the questionnaire sometimes gives examples for illustration (e.g., inventory units in Question 2), you should input only the units that your agency uses. Multiple fields are provided in case you track more than one variation within an asset class (e.g., "small signs" and "large signs," or "roadside signs" and "overhead signs"). If you track only one feature in each asset class, simply enter the inventory quantity and measurement unit for that item. If your agency does not have an inventory of a certain asset, leave the inventory response field blank. If your agency does not manage one or more of the six asset types listed above, simply check the box in Question 1 of the corresponding part of the survey and go to the next part.

Please return the survey by **Tuesday, February 28, 2006**, via e-mail, fax, or postal mail to:

Michael J. Markow
43 Rivers End Road
Teaticket, MA 02536-5858

E-mail: mjmarkow@adelphia.net
Phone (508) 540-5966
Fax (508) 540-5966 (please call beforehand)

Please include "*NCHRP Synthesis 37-03 Survey*" in the subject line of emails. Feel free to call or e-mail the P.I. if you have any questions on the survey.

ACRONYMS USED IN SURVEY

- AASHTO American Association of State Highway and Transportation Officials
- ACCP Asphalt-coated corrugated pipe
- ADAG Americans with Disabilities Act Guidelines
- CSCP Corrugated steel culvert pipe
- GIS Geographic information systems
- HCM Highway Capacity Manual
- HP Sodium High-pressure sodium
- ITE Institute of Traffic Engineers
- LP Sodium Low-pressure sodium
- MRR Maintenance, rehabilitation, and replacement
- MUTCD Manual of Uniform Traffic Control Devices

PART 1. TRAFFIC SIGNALS

1. What are the *key sources of technical guidance* for your management of traffic signals? (Check all that apply as *important drivers* of engineering and management decisions.) If your agency doesn't manage this asset, check this box and skip to Part 2.

For Construction or New Installation	For Maintenance and Rehabilitation
<input type="checkbox"/> Explicit requirements in state or federal law	<input type="checkbox"/> Explicit requirements in state or federal law
<input type="checkbox"/> National standards (e.g., AASHTO, ITE, HCM)	<input type="checkbox"/> National standards (e.g., AASHTO, ITE, HCM)
<input type="checkbox"/> Explicit requirements of statewide public policy	<input type="checkbox"/> Explicit requirements of statewide public policy
<input type="checkbox"/> Policies, standards, guidelines, and procedures established by your agency	<input type="checkbox"/> Policies, standards, guidelines, and procedures established by your agency
<input type="checkbox"/> Other: _____	<input type="checkbox"/> Other: _____

2. Understanding the scope of your effort will be helpful.

a. Approximate quantity and units of inventory (e.g., number of signal heads, number of signalized intersections or systems)	Qty: _____	Units: _____
	Qty: _____	Units: _____
	Qty: _____	Units: _____
	Qty: _____	Units: _____
b. Total highway/road/street annual budget	\$ _____	
c. Approximate amount spent annually on signal systems	\$ _____	
d. Percent of c. for new construction, new installation, or system expansion	_____	%
e. Percent of c. for MRR	_____	%

3. Which description(s) below best describe(s) your annual budgeting approach for *preservation, operation, and maintenance* of traffic signals?

<input type="checkbox"/> Budget recommendations based upon the cost to achieve a performance target (i.e., target drives budget)
<input type="checkbox"/> Budget recommendations maximize the performance target that can be achieved for the available funding (i.e., budget drives target)
<input type="checkbox"/> Budget recommendations based upon addressing a percentage of the inventory each year
<input type="checkbox"/> Budget recommendations based upon previous year's budget plus inflation and other adjustments
<input type="checkbox"/> Budget recommendations based upon staff judgments, political priorities, and citizen demands
<input type="checkbox"/> Budget recommendations based upon a percentage of the total anticipated budget
<input type="checkbox"/> Other approach (describe briefly): _____

<input type="checkbox"/> No specific approach

4. What descriptions characterize your approach to preserving/maintaining (including re-timing) traffic signals? (Check all that apply, adding comments if needed.)

Approach	Comments (optional)
<input type="checkbox"/> Preventive maintenance carried out on a set schedule	
<input type="checkbox"/> Immediate – repairs carried out as soon as possible after damage/failure is reported	
<input type="checkbox"/> Corrective – repairs prioritized and scheduled to meet performance targets subject to resource constraints	
<input type="checkbox"/> “Worst-first” – limited number of repairs each year, but backlog exists	
<input type="checkbox"/> Deferred maintenance – little or no work performed annually	
<input type="checkbox"/> This agency does not maintain traffic signals	
<input type="checkbox"/> Other: _____	

5. Who maintains the traffic signals after they are built or installed? (Check all that apply.)

Organization Conducting Work	Does the Selected Organization Have <i>Management Responsibility</i> for What Work to Perform?	
<input type="checkbox"/> Your agency	<input type="checkbox"/> Yes	<input type="checkbox"/> No
<input type="checkbox"/> Private contractor (outsourced)	<input type="checkbox"/> Yes	<input type="checkbox"/> No
<input type="checkbox"/> Another level of government (e.g., inter-governmental agreement)	<input type="checkbox"/> Yes	<input type="checkbox"/> No
<input type="checkbox"/> Other: _____	<input type="checkbox"/> Yes	<input type="checkbox"/> No

6. How do you measure performance of traffic signals? (Check all that apply.) For selected performance measures, indicate also the frequency of data collection/computation.

<p>PHYSICAL CONDITION:</p> <p><input type="checkbox"/> Structural condition (mast arms, poles)</p> <p><input type="checkbox"/> Corrosion</p> <p><input type="checkbox"/> Non-functional components</p> <p><input type="checkbox"/> Use- or time-related (e.g., dirt accumulation)</p> <p><input type="checkbox"/> Other: _____</p>	<p>If you use a measure of physical condition, you gather this information:</p> <p><input type="checkbox"/> More than once a year</p> <p><input type="checkbox"/> Annually</p> <p><input type="checkbox"/> Biennially</p> <p><input type="checkbox"/> Less frequently than biennially</p>
<p><input type="checkbox"/> AGE</p>	
<p><input type="checkbox"/> HOURS IN SERVICE</p>	
<p><input type="checkbox"/> OPERATIONAL PERFORMANCE: e.g., proper timing</p>	<p>If you gauge operational performance, you monitor this:</p> <p><input type="checkbox"/> More than once a year</p> <p><input type="checkbox"/> Annually</p> <p><input type="checkbox"/> Biennially</p> <p><input type="checkbox"/> Less frequently than biennially</p>
<p><input type="checkbox"/> SYSTEM RELIABILITY: e.g., number of failures in some time period</p>	
<p><input type="checkbox"/> PERFORMANCE/HEALTH INDEX, which is based on:</p> <p>_____</p> <p>_____</p> <p>_____</p>	<p>If you use an index, you compute this index:</p> <p><input type="checkbox"/> More than once a year</p> <p><input type="checkbox"/> Annually</p> <p><input type="checkbox"/> Biennially</p> <p><input type="checkbox"/> Less frequently than biennially</p>
<p>QUALITATIVE RATINGS: e.g., Good-Fair-Poor, based on:</p> <p><input type="checkbox"/> Structural condition (mast arms, poles)</p> <p><input type="checkbox"/> Corrosion</p> <p><input type="checkbox"/> Inoperable components</p> <p><input type="checkbox"/> Use- or time-related (e.g., dirt accumulation)</p> <p><input type="checkbox"/> Other: _____</p>	<p>If you use a qualitative rating, you gather information for this rating:</p> <p><input type="checkbox"/> More than once a year</p> <p><input type="checkbox"/> Annually</p> <p><input type="checkbox"/> Biennially</p> <p><input type="checkbox"/> Less frequently than biennially</p>
<p><input type="checkbox"/> ASSET VALUE, in dollars</p>	<p>If you use asset value, you compute this value:</p> <p><input type="checkbox"/> More than once a year</p> <p><input type="checkbox"/> Annually</p> <p><input type="checkbox"/> Biennially</p> <p><input type="checkbox"/> Less frequently than biennially</p>
<p><input type="checkbox"/> CUSTOMER COMPLAINTS—number/frequency</p>	
<p><input type="checkbox"/> CUSTOMER SURVEYS</p>	<p>If you use customer surveys, you conduct these surveys:</p> <p><input type="checkbox"/> More than once a year</p> <p><input type="checkbox"/> Annually</p> <p><input type="checkbox"/> Biennially</p> <p><input type="checkbox"/> Less frequently than biennially</p>
<p><input type="checkbox"/> OTHER: _____</p> <p>_____</p>	<p>Frequency of measurement: _____</p> <p>_____</p>

7. What methods are used to collect and analyze information on traffic signal condition? (Check all that apply. If appropriate, please identify specific device or product technology used by your agency.)

- Visual inspections
- Photologging, videologging: _____
- Physical measurement: _____
- Non-destructive testing: _____
- Customer satisfaction surveys
- Customer complaints
- Other: _____
- No information is collected for these assets

8. If you use *service lives* (or *deterioration rates*) in your management of traffic signal components, how are their values determined? (Check all that apply.)

- As part of management system or analytical model development for traffic signals
- As a component of agency life-cycle-performance or -cost analyses comparing traffic signal products
- From agency experience: e.g., database of historical traffic signal service lives
- Obtained from literature
- Agency professional judgment
- Manufacturer's data
- Other (describe briefly): _____
- The agency does not use service life information for traffic signals

9. What is your agency's estimate of service life of traffic signals? Please enter information for the major components and materials used by your agency. Enter data only for components and materials that your agency uses; if there is no estimate of service life for an item used by your agency please enter "None." For components/materials *not* used by your agency, leave the **Service Life** field blank.

Mast Arms and Poles		Controller System		Signal Displays	
Type or Material	Service Life, yrs	Type or Material	Service Life, yrs	Type or Material	Service Life, yrs
Tubular steel mast arm		Pavement loop detector		Incandescent	
Tubular aluminum mast arm		Non-invasive detector		LED	
Wood pole and span-wire		Traffic controller		Signal heads	
Concrete pole and span-wire		Traffic controller cabinet		Other: _____	
Steel pole and span-wire		Twisted copper interconnect cable		Other: _____	
Other: _____		Fiber optic cable		Other: _____	
Other: _____		Other: _____		Other: _____	
Other: _____		Other: _____		Other: _____	

With regard to the above estimates: Materials and construction standards have changed over the years, and older assets may have materials inferior to those installed today. How do you account for this change in materials quality in determining the service life of various components?

10. How do you determine where a traffic signal is in its service life? (Prioritize responses: 1 = most important or most widely used; 2, 3, ... ≥ declining importance or prevalence of use.)

-
- Compare its age with the maximum age that defines service life
 - Compare service hours with maximum service hours that define service life
 - Apply deterioration models to estimate where the asset is on “the curve”
 - Monitor condition as described in Item 7 periodically every ____ months
 - Monitor condition as described in Item 7 occasionally
 - Assets are replaced on preventive-maintenance schedule every ____ months without regard to service life
 - Assets are repaired or replaced as soon as they fail without regard to service life
 - Service life is often determined more by functional obsolescence than by wear-and-tear
 - The agency does not use/does not monitor service life for this type of asset
 - Other: _____
-

11. Has your agency estimated the extension in service life (or improvement in condition) for this asset resulting from maintenance actions? Yes No

If Yes, please provide examples of these data (or attach or fax a copy of this information):

12. What information technology capabilities exist to help manage your agency's traffic signals? (Check all that apply.)

Inventory/database containing:

- Number/quantity of asset
- Location of these assets (e.g., route-milepost, reference point-offset, intersection)
- GPS coordinates
- Condition of these assets/current performance level
- Photograph
- Usage, traffic volume

- Asset age
- Dates of inspections/condition assessments
- Anticipated service life (lives)
- Deterioration models

Treatment selection/timing using:

- Established maintenance schedule
- Recommendations of inspectors
- Decision rules or "trees" based on forecast condition
- Benefit-cost procedures in life-cycle analyses
- Other optimization procedures for selecting treatments and their timing

- Cost models for maintenance, improvement, and replacement treatments

- Tracking of public comments/concerns/agency responses
- Models predicting impacts of asset condition to the public (e.g., improved safety, environmental impact)

- GIS interface
- GIS-based maps, reports

- Performance measurement/dashboards/accountability reporting
- Historical database for tracking costs, condition, etc. and/or estimating deterioration models

- Other: _____

- NONE OF THE ABOVE (skip next response; go directly to item 13)

Most or all of the capabilities identified above are:

- Organized within a traffic signal management system
- Organized within a broad-based management system (e.g., for maintenance or asset management) that includes traffic signals as well as other assets
- Contained within simple programs that address traffic signals
- Contained within worksheets or spreadsheets that address traffic signals
- Part of other products/procedures (describe briefly): _____

13. Maintaining traffic signals in good condition is important to several transportation objectives below. Please indicate the relative priority you assign to these objectives (1 = most important, then 2, 3, ... *n* for the number that apply to your agency):

-
- Preservation of the existing road infrastructure; reduced agency life-cycle costs
 - More efficient travel; maintain intended flow and operating speed; reduce travel time costs
 - Public safety; accident and accident risk reduction
 - Comfort and convenience of the traveling public (motorists, pedestrians, cyclists)
 - Road aesthetics and appeal
 - Other: _____
-

14. What are the major gaps in knowledge impeding better asset management for traffic signals?

15. What research needs to be done to improve the validity of service life estimates for traffic signals?

You have completed Part 1. Thank you!

PART 2. ROADWAY LIGHTING

1. What are the *key sources of technical guidance* for your management of roadway lighting? (Check all that apply as *important drivers* of engineering and management decisions.) If your agency doesn't manage this asset, check this box and skip to Part 3.

For Construction or New Installation	For Maintenance and Rehabilitation
<input type="checkbox"/> Explicit requirements in state or federal law	<input type="checkbox"/> Explicit requirements in state or federal law
<input type="checkbox"/> National standards (e.g., AASHTO, ITE)	<input type="checkbox"/> National standards (e.g., AASHTO, ITE)
<input type="checkbox"/> Explicit requirements of statewide public policy	<input type="checkbox"/> Explicit requirements of statewide public policy
<input type="checkbox"/> Policies, standards, guidelines, and procedures established by your agency	<input type="checkbox"/> Policies, standards, guidelines, and procedures established by your agency
<input type="checkbox"/> Other: _____	<input type="checkbox"/> Other: _____

2. Understanding the scope of your effort will be helpful.

a. Approximate quantity and units of inventory (e.g., number of light fixtures)	Qty: _____ Units: _____
	Qty: _____ Units: _____
	Qty: _____ Units: _____
	Qty: _____ Units: _____
b. Total highway/road/street annual budget	\$ _____
c. Approximate amount spent annually on road lighting	\$ _____
d. Percent of c. for new construction, new installation, or system expansion	_____ %
e. Percent of c. for MRR	_____ %

3. Which description(s) below best describe(s) your annual budgeting approach for *preservation, operation, and maintenance* of roadway lighting?

<input type="checkbox"/> Budget recommendations based upon the cost to achieve a performance target (i.e., target drives budget)
<input type="checkbox"/> Budget recommendations maximize the performance target that can be achieved for the available funding (i.e., budget drives target)
<input type="checkbox"/> Budget recommendations based upon addressing a percentage of the inventory each year
<input type="checkbox"/> Budget recommendations based upon previous year's budget plus inflation and other adjustments
<input type="checkbox"/> Budget recommendations based upon staff judgments, political priorities, and citizen demands
<input type="checkbox"/> Budget recommendations based upon a percentage of the total anticipated budget
<input type="checkbox"/> Other approach (describe briefly): _____

<input type="checkbox"/> No specific approach

4. What descriptions characterize your approach to preserving/maintaining roadway lighting? (Check all that apply, adding comments if needed.)

Approach	Comments (optional)
<input type="checkbox"/> Preventive maintenance carried out on a set schedule	
<input type="checkbox"/> Immediate – repairs carried out as soon as possible after damage/failure is reported	
<input type="checkbox"/> Corrective – repairs prioritized and scheduled to meet performance targets subject to resource constraints	
<input type="checkbox"/> “Worst-first” – limited number of repairs each year, but backlog exists	
<input type="checkbox"/> Deferred maintenance – little or no work performed annually	
<input type="checkbox"/> This agency does not maintain roadway lighting	
<input type="checkbox"/> Other: _____	

5. Who maintains the roadway lighting after it is built or installed? (Check all that apply.)

Organization Conducting Work	Does the Selected Organization Have <i>Management Responsibility</i> for What Work to Perform?	
<input type="checkbox"/> Your agency	<input type="checkbox"/> Yes	<input type="checkbox"/> No
<input type="checkbox"/> Private contractor (outsourced)	<input type="checkbox"/> Yes	<input type="checkbox"/> No
<input type="checkbox"/> Another level of government (e.g., inter-governmental agreement)	<input type="checkbox"/> Yes	<input type="checkbox"/> No
<input type="checkbox"/> Other: _____	<input type="checkbox"/> Yes	<input type="checkbox"/> No

6. How do you measure performance of roadway lighting? (Check all that apply.) For selected performance measures, indicate also the frequency of data collection/computation.

<p>PHYSICAL CONDITION:</p> <p><input type="checkbox"/> Structural condition (e.g., of posts and arms)</p> <p><input type="checkbox"/> Corrosion</p> <p><input type="checkbox"/> Non-functional components</p> <p><input type="checkbox"/> Use- or time-related: e.g., dirt accumulation</p> <p><input type="checkbox"/> Other: _____</p>	<p>If you use a measure of physical condition, you gather this information:</p> <p><input type="checkbox"/> More than once a year</p> <p><input type="checkbox"/> Annually</p> <p><input type="checkbox"/> Biennially</p> <p><input type="checkbox"/> Less frequently than biennially</p>
<p><input type="checkbox"/> AGE</p>	
<p><input type="checkbox"/> HOURS OF SERVICE</p>	
<p><input type="checkbox"/> PERFORMANCE/HEALTH INDEX, which is based on:</p> <p>_____</p> <p>_____</p> <p>_____</p> <p>_____</p>	<p>If you use an index, you compute this index:</p> <p><input type="checkbox"/> More than once a year</p> <p><input type="checkbox"/> Annually</p> <p><input type="checkbox"/> Biennially</p> <p><input type="checkbox"/> Less frequently than biennially</p>
<p><input type="checkbox"/> SYSTEM RELIABILITY: e.g., number of failures in some time period</p>	
<p>QUALITATIVE RATINGS: e.g., Good-Fair-Poor, based on:</p> <p><input type="checkbox"/> Structural condition (e.g., of posts and arms)</p> <p><input type="checkbox"/> Corrosion</p> <p><input type="checkbox"/> Non-functional components</p> <p><input type="checkbox"/> Use- or time-related: e.g., dirt accumulation</p> <p><input type="checkbox"/> Other: _____</p>	<p>If you use a qualitative rating, you gather information for this rating:</p> <p><input type="checkbox"/> More than once a year</p> <p><input type="checkbox"/> Annually</p> <p><input type="checkbox"/> Biennially</p> <p><input type="checkbox"/> Less frequently than biennially</p>
<p><input type="checkbox"/> ASSET VALUE, in dollars</p>	<p>If you use asset value, you compute this value:</p> <p><input type="checkbox"/> More than once a year</p> <p><input type="checkbox"/> Annually</p> <p><input type="checkbox"/> Biennially</p> <p><input type="checkbox"/> Less frequently than biennially</p>
<p><input type="checkbox"/> CUSTOMER COMPLAINTS—number/frequency</p>	
<p><input type="checkbox"/> CUSTOMER SURVEYS</p>	<p>If you use customer surveys, you conduct these surveys:</p> <p><input type="checkbox"/> More than once a year</p> <p><input type="checkbox"/> Annually</p> <p><input type="checkbox"/> Biennially</p> <p><input type="checkbox"/> Less frequently than biennially</p>
<p><input type="checkbox"/> OTHER: _____</p> <p>_____</p>	<p>Frequency of measurement: _____</p> <p>_____</p>

7. What methods are used to collect and analyze information on roadway lighting condition? (Check all that apply. If appropriate, please identify specific device or product technology used by your agency.)

-
- Visual inspections
 - Photologging, videologging: _____
 - Physical measurement: _____
 - Non-destructive testing: _____
 - Customer satisfaction surveys
 - Customer complaints
 - Other: _____
 - No information is collected for these assets
-

8. If you use *service lives* (or *deterioration rates*) in your management of roadway lighting components, how are their values determined? (Check all that apply.)

-
- As part of management system or analytical model development for roadway lighting
 - As a component of agency life-cycle performance or cost analyses comparing roadway lighting products
 - From agency experience: e.g., database of historical roadway lighting service lives
 - Obtained from literature
 - Agency professional judgment
 - Manufacturer's data
 - Other (describe briefly): _____
 - The agency does not use service life information for roadway lighting
-

9. What is your agency's estimate of service life of roadway lighting? Please enter information for the major components and materials used by your agency. Enter data only for components and materials that your agency uses; if there is no estimate of service life for an item used by your agency please enter "None." For components/materials *not* used by your agency, leave the **Service Life** field blank.

Post and Arms		Lamps		Other Parts	
Type or Material	Service Life, yrs	Type or Material	Service Life, yrs	Type or Material	Service Life, yrs
Tubular steel		Incandescent		Ballasts	
Tubular aluminum		Mercury vapor		Photocells	
Cast metal		HP sodium vapor		Control panels	
Wood posts		LP sodium vapor		Other: _____	
High-mast or tower		Metal halide		Other: _____	
Other: _____		Fluorescent		Other: _____	
Other: _____		Other: _____		Other: _____	

10. How do you determine where a roadway lighting pole or fixture is in its service life? (Prioritize responses: 1 = most important or most widely used; 2, 3, ... ≥ declining importance or prevalence of use.)

-
- Compare its age with the maximum age that defines service life
 - Compare service hours with maximum service hours that define service life
 - Apply deterioration models to estimate where the asset is on “the curve”
 - Monitor condition as described in Item 7 periodically every _____ months
 - Monitor condition as described in Item 7 occasionally
 - Assets are replaced on preventive-maintenance schedule every _____ months without regard to service life
 - Assets are repaired or replaced as soon as they fail without regard to service life
 - Service life is often determined more by functional obsolescence than by wear-and-tear
 - The agency does not use/does not monitor service life for this type of asset
 - Other: _____
-

11. Has your agency estimated the extension in service life (or improvement in condition) for this asset resulting from maintenance actions? Yes No

If Yes, please provide examples of these data (or attach or fax a copy of this information):

12. What information technology capabilities exist to help manage your agency's roadway lighting? (Check all that apply.)

Inventory/database containing:

- Number/quantity of asset
- Location of these assets (e.g., route-milepost, reference point-offset, intersection)
- GPS coordinates
- Condition of these assets/current performance level
- Photograph
- Usage, traffic volume

-
- Asset age
 - Dates of inspections/condition assessments
 - Anticipated service life (lives)
 - Deterioration models
-

Treatment selection/timing using:

- Established maintenance schedule
 - Recommendations of inspectors
 - Decision rules or "trees" based on forecast condition
 - Benefit-cost procedures in life-cycle analyses
 - Other optimization procedures for selecting treatments and their timing
-

- Cost models for maintenance, improvement, and replacement treatments
 - Tracking of public comments/concerns/agency responses
 - Models predicting impacts of asset condition to the public (e.g., improved safety, environmental impact)
-

- GIS interface
 - GIS-based maps, reports
-

- Performance measurement/dashboards/accountability reporting
 - Historical database for tracking costs, condition, etc., and/or estimating deterioration models
-

- Other: _____
-

- NONE OF THE ABOVE (skip next response; go directly to item 13)
-

Most or all of the capabilities identified above are:

- Organized within a roadway lighting management system
 - Organized within a broad-based management system (e.g., for maintenance or asset management) that includes roadway lighting as well as other assets
 - Contained within simple programs that address roadway lighting
 - Contained within worksheets or spreadsheets that address roadway lighting
 - Part of other products/procedures (describe briefly): _____
-

13. Maintaining roadway lighting in good condition is important to several transportation objectives below. Please indicate the relative priority you assign to these objectives (1 = most important, then 2, 3, ... *n* for the number that apply to your agency):

-
- Preservation of the existing road infrastructure; reduced agency life-cycle costs
 - More efficient travel; maintain intended flow and operating speed; reduce travel time costs
 - Public safety; accident and accident risk reduction
 - Comfort and convenience of the traveling public (motorists, pedestrians, cyclists)
 - Road aesthetics and appeal
 - Crime prevention
 - Other: _____
-

14. What are the major gaps in knowledge impeding better asset management for roadway lighting?

15. What research needs to be done to improve the validity of service life estimates for roadway lighting?

You have completed Part 2. Thank you!

PART 3. SIGNS

1. What are the *key sources of technical guidance* for your management of signs? (Check all that apply as *important drivers* of engineering and management decisions.) If your agency doesn't manage this asset, check this box and skip to Part 4.

For Construction or New Installation	For Maintenance and Rehabilitation
<input type="checkbox"/> Explicit requirements in state or federal law	<input type="checkbox"/> Explicit requirements in state or federal law
<input type="checkbox"/> National standards (e.g., AASHTO, MUTCD)	<input type="checkbox"/> National standards (e.g., AASHTO, MUTCD)
<input type="checkbox"/> Explicit requirements of statewide public policy	<input type="checkbox"/> Explicit requirements of statewide public policy
<input type="checkbox"/> Policies, standards, guidelines, and procedures established by your agency	<input type="checkbox"/> Policies, standards, guidelines, and procedures established by your agency
<input type="checkbox"/> Other: _____	<input type="checkbox"/> Other: _____

2. Understanding the scope of your effort will be helpful.

a. Approximate quantity and units of inventory (e.g., number of signs, sign area in square feet)	Qty: _____ Units: _____
	Qty: _____ Units: _____
	Qty: _____ Units: _____
	Qty: _____ Units: _____
b. Total highway/road/street annual budget	\$ _____
c. Approximate amount spent annually on signs	\$ _____
d. Percent of c. for new construction, new installation, or system expansion	_____ %
e. Percent of c. for MRR	_____ %

3. Which description(s) below best describe(s) your annual budgeting approach for *preservation, operation, and maintenance* of signs?

<input type="checkbox"/> Budget recommendations based upon the cost to achieve a performance target (i.e., target drives budget)
<input type="checkbox"/> Budget recommendations maximize the performance target that can be achieved for the available funding (i.e., budget drives target)
<input type="checkbox"/> Budget recommendations based upon addressing a percentage of the inventory each year
<input type="checkbox"/> Budget recommendations based upon previous year's budget plus inflation and other adjustments
<input type="checkbox"/> Budget recommendations based upon staff judgments, political priorities, and citizen demands
<input type="checkbox"/> Budget recommendations based upon a percentage of the total anticipated budget
<input type="checkbox"/> Other approach (describe briefly): _____

<input type="checkbox"/> No specific approach

4. What descriptions characterize your approach to preserving/maintaining signs? (Check all that apply, adding comments if needed.)

Approach	Comments (optional)
<input type="checkbox"/> Preventive maintenance carried out on a set schedule	
<input type="checkbox"/> Immediate – repairs carried out as soon as possible after damage/failure is reported	
<input type="checkbox"/> Corrective – repairs prioritized and scheduled to meet performance targets subject to resource constraints	
<input type="checkbox"/> “Worst-first” – limited number of repairs each year, but backlog exists	
<input type="checkbox"/> Deferred maintenance – little or no work performed annually	
<input type="checkbox"/> This agency does not maintain signs	
<input type="checkbox"/> Other: _____	

5. Who maintains the signs after they are built or installed? (Check all that apply.)

Organization Conducting Work	Does the Selected Organization Have <i>Management Responsibility</i> for What Work to Perform?	
<input type="checkbox"/> Your agency	<input type="checkbox"/> Yes	<input type="checkbox"/> No
<input type="checkbox"/> Private contractor (outsourced)	<input type="checkbox"/> Yes	<input type="checkbox"/> No
<input type="checkbox"/> Another level of government (e.g., inter-governmental agreement)	<input type="checkbox"/> Yes	<input type="checkbox"/> No
<input type="checkbox"/> Other: _____	<input type="checkbox"/> Yes	<input type="checkbox"/> No

6. How do you measure performance of a sign system? (Check all that apply.) For selected performance measures, indicate also the frequency of data collection/computation.

<p>PHYSICAL CONDITION:</p> <p><input type="checkbox"/> Retroreflectivity</p> <p><input type="checkbox"/> Color fading</p> <p><input type="checkbox"/> Daytime legibility</p> <p><input type="checkbox"/> Nighttime legibility</p> <p><input type="checkbox"/> Structural condition (sign panel or supports)</p> <p><input type="checkbox"/> Corrosion</p> <p><input type="checkbox"/> Dirt accumulation</p> <p><input type="checkbox"/> Vandalism</p> <p><input type="checkbox"/> Other: _____</p>	<p>If you use a measure of physical condition, you gather this information:</p> <p><input type="checkbox"/> More than once a year</p> <p><input type="checkbox"/> Annually</p> <p><input type="checkbox"/> Biennially</p> <p><input type="checkbox"/> Less frequently than biennially</p>
<p><input type="checkbox"/> AGE</p>	
<p><input type="checkbox"/> CONFORMANCE TO CURRENT STANDARDS/OBSOLESCENCE</p>	
<p><input type="checkbox"/> PERFORMANCE/HEALTH INDEX, which is based on:</p> <p>_____</p> <p>_____</p> <p>_____</p> <p>_____</p>	<p>If you use an index, you compute this index:</p> <p><input type="checkbox"/> More than once a year</p> <p><input type="checkbox"/> Annually</p> <p><input type="checkbox"/> Biennially</p> <p><input type="checkbox"/> Less frequently than biennially</p>
<p>QUALITATIVE RATINGS: e.g., Good-Fair-Poor, based on:</p> <p><input type="checkbox"/> Retroreflectivity</p> <p><input type="checkbox"/> Color fading</p> <p><input type="checkbox"/> Daytime legibility</p> <p><input type="checkbox"/> Nighttime legibility</p> <p><input type="checkbox"/> Structural condition (sign panel or supports)</p> <p><input type="checkbox"/> Corrosion</p> <p><input type="checkbox"/> Dirt accumulation</p> <p><input type="checkbox"/> Vandalism</p> <p><input type="checkbox"/> Other: _____</p>	<p>If you use a qualitative rating, you gather information for this rating:</p> <p><input type="checkbox"/> More than once a year</p> <p><input type="checkbox"/> Annually</p> <p><input type="checkbox"/> Biennially</p> <p><input type="checkbox"/> Less frequently than biennially</p>
<p><input type="checkbox"/> ASSET VALUE, in dollars</p>	<p>If you selected Asset Value, you compute this value:</p> <p><input type="checkbox"/> More than once a year</p> <p><input type="checkbox"/> Annually</p> <p><input type="checkbox"/> Biennially</p> <p><input type="checkbox"/> Less frequently than biennially</p>
<p><input type="checkbox"/> CUSTOMER COMPLAINTS—number/frequency</p>	
<p><input type="checkbox"/> CUSTOMER SURVEYS</p>	<p>If you use customer surveys, you conduct these surveys:</p> <p><input type="checkbox"/> More than once a year</p> <p><input type="checkbox"/> Annually</p> <p><input type="checkbox"/> Biennially</p> <p><input type="checkbox"/> Less frequently than biennially</p>
<p><input type="checkbox"/> OTHER: _____</p> <p>_____</p>	<p>Frequency of measurement: _____</p> <p>_____</p>

7. What methods are used to collect and analyze information on sign condition? (Check all that apply. If appropriate, please identify specific device or product technology used by your agency.)

- Visual inspections
- Photologging, videologging: _____
- Physical measurement: _____
- Non-destructive testing: _____
- Customer satisfaction surveys
- Customer complaints
- Other: _____
- No information is collected for these assets

8. If you use *service lives* (or *deterioration rates*) in your management of sign components, how are their values determined? (Check all that apply.)

- As part of management system or analytical model development for signs
- As a component of agency life-cycle-performance or -cost analyses comparing sign products
- From agency experience: e.g., database of historical sign service lives
- Obtained from literature
- Agency professional judgment
- Manufacturer's data
- Other (describe briefly): _____
- The agency does not use service life information for signs

9. What is your agency's estimate of service life of signs? Please enter information for the major components and materials used by your agency. Enter data only for components and materials that your agency uses; if there is no estimate of service life for an item used by your agency please enter "None." For components/materials *not* used by your agency, leave the **Service Life** field blank.

Sign Panels		Roadside Sign Posts		Overhead Sign Bridges	
Type or Material or Color (specify)	Service Life, yrs	Type or Material	Service Life, yrs	Type or Material	Service Life, yrs
_____		Steel U-channel		Steel	
_____		Steel square tube		Aluminum	
_____		Aluminum tube		Other: _____	
_____		Fiberglass		Other: _____	
_____		Wood		Other: _____	
_____		Other: _____		Other: _____	

10. How do you determine where a sign is in its service life? (Prioritize responses: 1 = most important or most widely used; 2, 3, ... ≥ declining importance or prevalence of use.)

-
- Compare its age with the maximum age that defines service life
 - Apply deterioration models to estimate where the asset is on “the curve”
 - Monitor condition as described in Item 7 periodically every ____ months
 - Monitor condition as described in Item 7 occasionally
 - Assets are replaced on preventive-maintenance schedule every ____ months without regard to service life
 - Assets are repaired or replaced as soon as they fail without regard to service life
 - Service life is often determined more by functional obsolescence than by wear and tear
 - The agency does not use/does not monitor service life for this type of asset
 - Other: _____
-

11. Has your agency estimated the extension in service life (or improvement in condition) for this asset resulting from maintenance or rehabilitation actions? Yes No

If Yes, please provide examples of these data (or attach or fax a copy of this information):

12. What information technology capabilities exist to help manage your agency's signs? (Check all that apply.)

Inventory/database containing:

- Number/quantity of asset
- Location of these assets (e.g., route-milepost, reference point-offset, intersection)
- GPS coordinates
- Condition of these assets/current performance level
- Photograph
- Usage, traffic volume

- Asset age
- Dates of inspections/condition assessments
- Anticipated service life (lives)
- Deterioration models

Treatment selection/timing using:

- Established maintenance schedule
- Recommendations of inspectors
- Decision rules or "trees" based on forecast condition
- Benefit-cost procedures in life-cycle analyses
- Other optimization procedures for selecting treatments and their timing

- Cost models for maintenance, improvement, and replacement treatments

- Tracking of public comments/concerns/agency responses
- Models predicting impacts of asset condition to the public (e.g., improved safety, environmental impact)

- GIS interface
- GIS-based maps, reports

- Performance measurement/dashboards/accountability reporting
- Historical database for tracking costs, condition, etc., and/or estimating deterioration models

- Other: _____

- NONE OF THE ABOVE (skip next response; go directly to item 13)

Most or all of the capabilities identified above are:

- Organized within a sign management system
- Organized within a broad-based management system (e.g., for maintenance or asset management) that includes signs as well as other assets
- Contained within simple programs that address signs
- Contained within worksheets or spreadsheets that address signs
- Part of other products/procedures (describe briefly): _____

13. Maintaining signs in good condition is important to several transportation objectives below. Please indicate the relative priority you assign to these objectives (1 = most important, then 2, 3, ... n for the number that apply to your agency):

-
- Preservation of the existing road infrastructure; reduced agency life-cycle costs
 - More efficient travel; maintain intended flow and operating speed; reduce travel time costs
 - Public safety; accident and accident risk reduction
 - Comfort and convenience of the traveling public (motorists, pedestrians, cyclists)
 - Road aesthetics and appeal
 - Other: _____
-

14. What are the major gaps in knowledge impeding better asset management for roadway signs?

15. What research needs to be done to improve the validity of service life estimates for roadway signs?

You have completed Part 3. Thank you!

PART 4. PAVEMENT STRIPING AND MARKINGS

1. What are the *key sources of technical guidance* for your management of pavement striping and markings? (Check all that apply as *important drivers* of engineering and management decisions.) If your agency doesn't manage this asset, check this box and skip to Part 5.

For Construction or New Installation	For Maintenance and Rehabilitation
<input type="checkbox"/> Explicit requirements in state or federal law	<input type="checkbox"/> Explicit requirements in state or federal law
<input type="checkbox"/> National standards (e.g., AASHTO, MUTCD)	<input type="checkbox"/> National standards (e.g., AASHTO, MUTCD)
<input type="checkbox"/> Explicit requirements of statewide public policy	<input type="checkbox"/> Explicit requirements of statewide public policy
<input type="checkbox"/> Policies, standards, guidelines, and procedures established by your agency	<input type="checkbox"/> Policies, standards, guidelines, and procedures established by your agency
<input type="checkbox"/> Other: _____	<input type="checkbox"/> Other: _____

2. Understanding the scope of your effort will be helpful.

a. Approximate quantity and units of inventory (e.g., stripe miles, square yards of pavement markings)	Qty: _____ Units: _____
	Qty: _____ Units: _____
	Qty: _____ Units: _____
	Qty: _____ Units: _____
b. Total highway/road/street annual budget	\$ _____
c. Approximate amount spent annually on striping and pavement markings	\$ _____
d. Percent of c. for new construction, new installation, or system expansion	_____ %
e. Percent of c. for MRR	_____ %

3. Which description(s) below best describe(s) your annual budgeting approach for *preservation, operation, and maintenance* of pavement striping and markings?

<input type="checkbox"/> Budget recommendations based upon the cost to achieve a performance target (i.e., target drives budget)
<input type="checkbox"/> Budget recommendations maximize the performance target that can be achieved for the available funding (i.e., budget drives target)
<input type="checkbox"/> Budget recommendations based upon addressing a percentage of the inventory each year
<input type="checkbox"/> Budget recommendations based upon previous year's budget plus inflation and other adjustments
<input type="checkbox"/> Budget recommendations based upon staff judgments, political priorities, and citizen demands
<input type="checkbox"/> Budget recommendations based upon a percentage of the total anticipated budget
<input type="checkbox"/> Other approach (describe briefly): _____

<input type="checkbox"/> No specific approach

4. What descriptions characterize your approach to preserving/maintaining pavement striping and markings? (Check all that apply, adding comments if needed.)

Approach	Comments (optional)
<input type="checkbox"/> Preventive maintenance carried out on a set schedule	
<input type="checkbox"/> Immediate – repairs carried out as soon as possible after damage/failure is reported	
<input type="checkbox"/> Corrective – repairs prioritized and scheduled to meet performance targets subject to resource constraints	
<input type="checkbox"/> “Worst-first” – limited number of repairs each year, but backlog exists	
<input type="checkbox"/> Deferred maintenance – little or no work performed annually	
<input type="checkbox"/> This agency does not maintain pavement striping/markings	
<input type="checkbox"/> Other: _____	

5. Who maintains the pavement striping and markings after they are built or installed? (Check all that apply.)

Organization Conducting Work	Does the Selected Organization Have <i>Management Responsibility</i> for What Work to Perform?	
<input type="checkbox"/> Your agency	<input type="checkbox"/> Yes	<input type="checkbox"/> No
<input type="checkbox"/> Private contractor (outsourced)	<input type="checkbox"/> Yes	<input type="checkbox"/> No
<input type="checkbox"/> Another level of government (e.g., inter-governmental agreement)	<input type="checkbox"/> Yes	<input type="checkbox"/> No
<input type="checkbox"/> Other: _____	<input type="checkbox"/> Yes	<input type="checkbox"/> No

6. How do you measure performance of pavement striping and markings? (Check all that apply.) For selected performance measures, indicate also the frequency of data collection/computation.

<p>PHYSICAL CONDITION:</p> <p><input type="checkbox"/> Abrasion, wear, loss of adhesion</p> <p><input type="checkbox"/> Broken/missing raised pavement markers</p> <p><input type="checkbox"/> Loss of reflectivity</p> <p><input type="checkbox"/> Use-related factors (e.g., debris accumulation, loss of pavement edge)</p> <p><input type="checkbox"/> Other: _____</p>	<p>If you use a measure of physical condition, you gather this information:</p> <p><input type="checkbox"/> More than once a year</p> <p><input type="checkbox"/> Annually</p> <p><input type="checkbox"/> Biennially</p> <p><input type="checkbox"/> Less frequently than biennially</p>
<p><input type="checkbox"/> AGE</p>	
<p><input type="checkbox"/> PERFORMANCE/HEALTH INDEX, which is based on:</p> <p>_____</p> <p>_____</p> <p>_____</p> <p>_____</p>	<p>If you use an index, you compute this index:</p> <p><input type="checkbox"/> More than once a year</p> <p><input type="checkbox"/> Annually</p> <p><input type="checkbox"/> Biennially</p> <p><input type="checkbox"/> Less frequently than biennially</p>
<p>QUALITATIVE RATINGS: e.g., Good-Fair-Poor, based on:</p> <p><input type="checkbox"/> Abrasion, wear, loss of adhesion</p> <p><input type="checkbox"/> Broken/missing raised pavement markers</p> <p><input type="checkbox"/> Loss of reflectivity</p> <p><input type="checkbox"/> Use-related factors (e.g., debris accumulation, loss of pavement edge)</p> <p><input type="checkbox"/> Other: _____</p>	<p>If you use a qualitative rating, you gather information for this rating:</p> <p><input type="checkbox"/> More than once a year</p> <p><input type="checkbox"/> Annually</p> <p><input type="checkbox"/> Biennially</p> <p><input type="checkbox"/> Less frequently than biennially</p>
<p><input type="checkbox"/> ASSET VALUE, in dollars</p>	<p>If you use asset value, you compute this value:</p> <p><input type="checkbox"/> More than once a year</p> <p><input type="checkbox"/> Annually</p> <p><input type="checkbox"/> Biennially</p> <p><input type="checkbox"/> Less frequently than biennially</p>
<p><input type="checkbox"/> CUSTOMER COMPLAINTS—number/frequency</p>	
<p><input type="checkbox"/> CUSTOMER SURVEYS</p>	<p>If you use customer surveys, you conduct these surveys:</p> <p><input type="checkbox"/> More than once a year</p> <p><input type="checkbox"/> Annually</p> <p><input type="checkbox"/> Biennially</p> <p><input type="checkbox"/> Less frequently than biennially</p>
<p><input type="checkbox"/> OTHER: _____</p> <p>_____</p>	<p>Frequency of measurement: _____</p> <p>_____</p>

7. What methods are used to collect and analyze information on pavement striping and marking condition? (Check all that apply. If appropriate, please identify specific device or product technology used by your agency.)

-
- Visual inspections
 - Photologging, videologging: _____
 - Physical measurement: _____
 - Non-destructive testing: _____
 - Customer satisfaction surveys
 - Customer complaints
 - Other: _____
 - No information is collected for these assets
-

8. If you use *service lives* (or *deterioration rates*) in your management of pavement striping and markings, how are their values determined? (Check all that apply.)

-
- As part of management system or analytical model development for pavement striping and markings
 - As a component of agency life-cycle-performance or -cost analyses comparing pavement striping and marking products
 - From agency experience: e.g., database of historical pavement striping and marking service lives
 - Obtained from literature
 - Agency professional judgment
 - Manufacturer's data
 - Other (describe briefly): _____
 - The agency does not use service life information for pavement striping and markings
-

9. What is your agency's estimate of service life of pavement striping and markings? Please enter information for the major components and materials used by your agency. Enter data only for components and materials that your agency uses; if there is no estimate of service life for an item used by your agency please enter "None." For components/materials *not* used by your agency, leave the **Service Life** field blank.

Lane or Edge Striping		Raised Markers – Lane Dividers		Other Pavement Markings	
Type or Material	Service Life, yrs	Type or Material	Service Life, yrs	Type or Material	Service Life, yrs
Paint (non-epoxy)		Ceramic markers		Paint (non-epoxy)	
Epoxy-based paint		Raised markers		Epoxy-based paint	
Paint/epoxy with glass beads		Recessed markers		Paint/epoxy with glass beads	
Thermoplastic		Other: _____		Thermoplastic	
Cold plastic		Other: _____		Cold plastic	
Instant dry thermo powder		Other: _____		Instant dry thermo powder	
Polyester		Other: _____		Polyester	
Other: _____		Other: _____		Other: _____	

10. How do you determine where pavement striping or marking is in its service life? (Prioritize responses: 1 = most important or most widely used; 2, 3, ... ≥ declining importance or prevalence of use.)

-
- Compare its age with the maximum age that defines service life
 - Apply deterioration models to estimate where the asset is on “the curve”
 - Monitor condition as described in Item 7 periodically every ____ months
 - Monitor condition as described in Item 7 occasionally
 - Assets are replaced on preventive-maintenance schedule every ____ months without regard to service life
 - Assets are repaired or replaced as soon as they fail without regard to service life
 - The agency does not use/does not monitor service life for this type of asset
 - Other: _____
-

11. Has your agency estimated the extension in service life (or improvement in condition) for this asset resulting from maintenance or rehabilitation actions? Yes No

If Yes, please provide examples of these data (or attach a copy of this information):

12. What information technology capabilities exist to help manage your agency's pavement striping and markings? (Check all that apply.)

Inventory/database containing:

- Number/quantity of asset
 - Location of these assets (e.g., route-milepost, reference point-offset, intersection)
 - GPS coordinates
 - Condition of these assets/current performance level
 - Photograph
 - Usage, traffic volume
-

- Asset age
 - Dates of inspections/condition assessments
 - Anticipated service life (lives)
 - Deterioration models
-

Treatment selection/timing using:

- Established maintenance schedule
 - Recommendations of inspectors
 - Decision rules or "trees" based on forecast condition
 - Benefit-cost procedures in life-cycle analyses
 - Other optimization procedures for selecting treatments and their timing
-

- Cost models for maintenance, improvement, and replacement treatments
 - Tracking of public comments/concerns/agency responses
 - Models predicting impacts of asset condition to the public (e.g., improved safety, environmental impact)
-

- GIS interface
 - GIS-based maps, reports
-

- Performance measurement/dashboards/accountability reporting
 - Historical database for tracking costs, condition, etc., and/or estimating deterioration models
-

- Other: _____
-

- NONE OF THE ABOVE (skip next response; go directly to item 13)
-

Most or all of the capabilities identified above are:

- Organized within a pavement striping/markings management system
 - Organized within a broad-based management system (e.g., for maintenance or asset management) that includes pavement striping/markings as well as other assets
 - Contained within simple programs that address pavement striping/markings
 - Contained within worksheets or spreadsheets that address pavement striping/markings
 - Part of other products/procedures (describe briefly): _____
-

13. Maintaining pavement striping and markings in good condition is important to several transportation objectives below. Please indicate the relative priority you assign to these objectives (1 = most important, then 2, 3, ... n for the number that apply to your agency):

-
- Preservation of the existing road infrastructure; reduced agency life-cycle costs
 - More efficient travel; maintain intended flow and operating speed; reduce travel time costs
 - Public safety; accident and accident risk reduction
 - Comfort and convenience of the traveling public (motorists, pedestrians, cyclists)
 - Road aesthetics and appeal
 - Other: _____
-

14. What are the major gaps in knowledge impeding better asset management for pavement striping and markings?

15. What research needs to be done to improve the validity of service life estimates for pavement striping and markings?

You have completed Part 4. Thank you!

PART 5. DRAINAGE CULVERTS

1. What are the *key sources of technical guidance* for your management of drainage culverts? (Check all that apply as *important drivers* of engineering and management decisions.) If your agency doesn't manage this asset, check this box and skip to Part 6.

For Construction or New Installation	For Maintenance and Rehabilitation
<input type="checkbox"/> Explicit requirements in state or federal law	<input type="checkbox"/> Explicit requirements in state or federal law
<input type="checkbox"/> National standards (e.g., AASHTO)	<input type="checkbox"/> National standards (e.g., AASHTO)
<input type="checkbox"/> Explicit requirements of statewide public policy	<input type="checkbox"/> Explicit requirements of statewide public policy
<input type="checkbox"/> Policies, standards, guidelines, and procedures established by your agency	<input type="checkbox"/> Policies, standards, guidelines, and procedures established by your agency
<input type="checkbox"/> Other: _____	<input type="checkbox"/> Other: _____

2. Understanding the scope of your effort will be helpful.

a. Approximate quantity and units of inventory (e.g., number of culverts, linear feet of culvert pipe)	Qty: _____	Units: _____
	Qty: _____	Units: _____
	Qty: _____	Units: _____
	Qty: _____	Units: _____
b. Total highway/road/street annual budget	\$ _____	
c. Approximate amount spent annually on culverts	\$ _____	
d. Percent of c. for new construction, new installation, or system expansion	_____	%
e. Percent of c. for MRR	_____	%

3. Which description(s) below best describe(s) your annual budgeting approach for *preservation, operation, and maintenance* of drainage culverts?

<input type="checkbox"/> Budget recommendations based upon the cost to achieve a performance target (i.e., target drives budget)
<input type="checkbox"/> Budget recommendations maximize the performance target that can be achieved for the available funding (i.e., budget drives target)
<input type="checkbox"/> Budget recommendations based upon addressing a percentage of the inventory each year
<input type="checkbox"/> Budget recommendations based upon previous year's budget plus inflation and other adjustments
<input type="checkbox"/> Budget recommendations based upon staff judgments, political priorities, and citizen demands
<input type="checkbox"/> Budget recommendations based upon a percentage of the total anticipated budget
<input type="checkbox"/> Other approach (describe briefly): _____

<input type="checkbox"/> No specific approach

4. What descriptions characterize your approach to preserving/maintaining drainage culverts? (Check all that apply, adding comments if needed.)

Approach	Comments (optional)
<input type="checkbox"/> Preventive maintenance carried out on a set schedule	
<input type="checkbox"/> Immediate – repairs carried out as soon as possible after damage/failure is reported	
<input type="checkbox"/> Corrective – repairs prioritized and scheduled to meet performance targets subject to resource constraints	
<input type="checkbox"/> “Worst-first” – limited number of repairs each year, but backlog exists	
<input type="checkbox"/> Deferred maintenance – little or no work performed annually	
<input type="checkbox"/> This agency does not maintain drainage culverts	
<input type="checkbox"/> Other: _____	

5. Who maintains the drainage culverts after they are built or installed? (Check all that apply.)

Organization Conducting Work	Does the Selected Organization Have <i>Management Responsibility</i> for What Work to Perform?	
<input type="checkbox"/> Your agency	<input type="checkbox"/> Yes	<input type="checkbox"/> No
<input type="checkbox"/> Private contractor (outsourced)	<input type="checkbox"/> Yes	<input type="checkbox"/> No
<input type="checkbox"/> Another level of government (e.g., inter-governmental agreement)	<input type="checkbox"/> Yes	<input type="checkbox"/> No
<input type="checkbox"/> Other: _____	<input type="checkbox"/> Yes	<input type="checkbox"/> No

6. How do you measure performance of drainage culverts? (Check all that apply.) For selected performance measures, indicate also the frequency of data collection/computation.

<p>PHYSICAL CONDITION:</p> <p><input type="checkbox"/> Structural condition</p> <p><input type="checkbox"/> Corrosion</p> <p><input type="checkbox"/> Debris accumulation</p> <p><input type="checkbox"/> Other: _____</p>	<p>If you use a measure of physical condition, you gather this information:</p> <p><input type="checkbox"/> More than once a year</p> <p><input type="checkbox"/> Annually</p> <p><input type="checkbox"/> Biennially</p> <p><input type="checkbox"/> Less frequently than biennially</p>
<p><input type="checkbox"/> AGE</p>	
<p><input type="checkbox"/> PERFORMANCE/HEALTH INDEX, which is based on:</p> <p>_____</p> <p>_____</p> <p>_____</p> <p>_____</p>	<p>If you use an index, you compute this index:</p> <p><input type="checkbox"/> More than once a year</p> <p><input type="checkbox"/> Annually</p> <p><input type="checkbox"/> Biennially</p> <p><input type="checkbox"/> Less frequently than biennially</p>
<p><input type="checkbox"/> SYSTEM RELIABILITY: e.g., number of failures in some time period</p>	
<p>QUALITATIVE RATINGS: e.g., Good-Fair-Poor, based on:</p> <p><input type="checkbox"/> Structural condition</p> <p><input type="checkbox"/> Corrosion</p> <p><input type="checkbox"/> Debris accumulation</p> <p><input type="checkbox"/> Other: _____</p>	<p>If you use a qualitative rating, you gather information for this rating:</p> <p><input type="checkbox"/> More than once a year</p> <p><input type="checkbox"/> Annually</p> <p><input type="checkbox"/> Biennially</p> <p><input type="checkbox"/> Less frequently than biennially</p>
<p><input type="checkbox"/> ASSET VALUE, in dollars</p>	<p>If you use asset value, you compute this value:</p> <p><input type="checkbox"/> More than once a year</p> <p><input type="checkbox"/> Annually</p> <p><input type="checkbox"/> Biennially</p> <p><input type="checkbox"/> Less frequently than biennially</p>
<p><input type="checkbox"/> CUSTOMER COMPLAINTS—number/frequency</p>	
<p><input type="checkbox"/> CUSTOMER SURVEYS</p>	<p>If you use customer surveys, you conduct these surveys:</p> <p><input type="checkbox"/> More than once a year</p> <p><input type="checkbox"/> Annually</p> <p><input type="checkbox"/> Biennially</p> <p><input type="checkbox"/> Less frequently than biennially</p>
<p><input type="checkbox"/> OTHER: _____</p> <p>_____</p>	<p>Frequency of measurement: _____</p> <p>_____</p>

7. What methods are used to collect and analyze information on drainage culvert condition? (Check all that apply. If appropriate, please identify specific device or product technology used by your agency.)

-
- Visual inspections
 - Photologging, videologging: _____
 - Physical measurement: _____
 - Non-destructive testing: _____
 - Customer satisfaction surveys
 - Customer complaints
 - Other: _____
 - No information is collected for these assets
-

8. If you use *service lives* (or *deterioration rates*) in your management of drainage culverts, how are their values determined? (Check all that apply.)

-
- As part of management system or analytical model development for drainage culverts
 - As a component of agency life-cycle-performance or -cost analyses comparing drainage culvert products
 - From agency experience: e.g., database of historical drainage culvert service lives
 - Obtained from literature
 - Agency professional judgment
 - Manufacturer's data
 - Other (describe briefly): _____
 - The agency does not use service life information for drainage culverts
-

9. What is your agency's estimate of service life of drainage culverts? Please enter information for the major components and materials used by your agency. Enter data only for components and materials that your agency uses; if there is no estimate of service life for an item used by your agency please enter "None." For components/materials *not* used by your agency, leave the **Service Life** field blank.

Pipes		Box Culverts	
Type or Material	Service Life, yrs	Type or Material	Service Life, yrs
Concrete		Reinforced concrete	
Corrugated metal, CSCP		Timber	
ACCP		Other: _____	
Small-diameter plastic		Other: _____	
Other: _____		Other: _____	

10. How do you determine where a drainage culvert is in its service life? (Prioritize responses: 1 = most important or most widely used; 2, 3, ... ≥ declining importance or prevalence of use.)

-
- Compare its age with the maximum age that defines service life
 - Apply deterioration models to estimate where the asset is on “the curve”
 - Monitor condition as described in Item 7 periodically every ____ months
 - Monitor condition as described in Item 7 occasionally
 - Assets are replaced on preventive-maintenance schedule every ____ months without regard to service life
 - Assets are repaired or replaced as soon as they fail without regard to service life
 - The agency does not use/does not monitor service life for this type of asset
 - Other: _____
-

11. Has your agency estimated the extension in service life (or improvement in condition) for this asset resulting from maintenance or rehabilitation actions? Yes No

If Yes, please provide examples of these data (or attach or fax a copy of this information):

12. What information technology capabilities exist to help manage your agency's drainage culverts? (Check all that apply.)

Inventory/database containing:

- Number/quantity of asset
- Location of these assets (e.g., route-milepost, reference point-offset, intersection)
- GPS coordinates
- Condition of these assets/current performance level
- Photograph
- Usage, traffic volume

- Asset age
- Dates of inspections/condition assessments
- Anticipated service life (lives)
- Deterioration models

Treatment selection/timing using:

- Established maintenance schedule
- Recommendations of inspectors
- Decision rules or "trees" based on forecast condition
- Benefit-cost procedures in life-cycle analyses
- Other optimization procedures for selecting treatments and their timing

- Cost models for maintenance, improvement, and replacement treatments

- Tracking of public comments/concerns/agency responses
- Models predicting impacts of asset condition to the public (e.g., improved safety, environmental impact)

- GIS interface
- GIS-based maps, reports

- Performance measurement/dashboards/accountability reporting
- Historical database for tracking costs, condition, etc., and/or estimating deterioration models

- Other: _____

- NONE OF THE ABOVE (skip next response; go directly to item 13)

Most or all of the capabilities identified above are:

- Organized within a culvert management system
- Organized within a broad-based management system (e.g., for maintenance or asset management) that includes culverts as well as other assets
- Contained within simple programs that address culverts
- Contained within worksheets or spreadsheets that address culverts
- Part of other products/procedures (describe briefly): _____

13. Maintaining drainage culverts in good condition is important to several transportation objectives below. Please indicate the relative priority you assign to these objectives (1 = most important, then 2, 3, ... *n* for the number that apply to your agency):

-
- Preservation of the existing road infrastructure; reduced agency life-cycle costs
 - More efficient travel; maintain intended flow and operating speed; reduce travel time costs
 - Public safety; accident and accident risk reduction
 - Comfort and convenience of the traveling public (motorists, pedestrians, cyclists)
 - Road aesthetics and appeal
 - Other: _____
-

14. What are the major gaps in knowledge impeding better asset management for drainage culverts?

15. What research needs to be done to improve the validity of service life estimates for drainage culverts?

You have completed Part 5. Thank you!

PART 6. SIDEWALKS

1. What are the *key sources of technical guidance* for your management of sidewalks? (Check all that apply as *important drivers* of engineering and management decisions.) If your agency doesn't manage this asset, check this box and skip to Part 7.

For Construction or New Installation	For Maintenance and Rehabilitation
<input type="checkbox"/> Explicit requirements in state or federal law	<input type="checkbox"/> Explicit requirements in state or federal law
<input type="checkbox"/> National standards (e.g., AASHTO, ADAG)	<input type="checkbox"/> National standards (e.g., AASHTO)
<input type="checkbox"/> Explicit requirements of statewide public policy	<input type="checkbox"/> Explicit requirements of statewide public policy
<input type="checkbox"/> Policies, standards, guidelines, and procedures established by your agency	<input type="checkbox"/> Policies, standards, guidelines, and procedures established by your agency
<input type="checkbox"/> Other: _____	<input type="checkbox"/> Other: _____

2. Understanding the scope of your effort will be helpful.

a. Approximate quantity and units of inventory (e.g., linear feet of sidewalks, sidewalk miles, square yards of sidewalk area)	Qty: _____ Units: _____
	Qty: _____ Units: _____
	Qty: _____ Units: _____
b. Total highway/road/street annual budget	\$ _____
c. Approximate amount spent annually on sidewalks	\$ _____
d. Percent of c. for new construction, new installation, or system expansion	_____ %
e. Percent of c. for MRR	_____ %

3. Which description(s) below best describe(s) your annual budgeting approach for *preservation, operation, and maintenance* of sidewalks?

<input type="checkbox"/> Budget recommendations based upon the cost to achieve a performance target (i.e., target drives budget)
<input type="checkbox"/> Budget recommendations maximize the performance target that can be achieved for the available funding (i.e., budget drives target)
<input type="checkbox"/> Budget recommendations based upon addressing a percentage of the inventory each year
<input type="checkbox"/> Budget recommendations based upon previous year's budget plus inflation and other adjustments
<input type="checkbox"/> Budget recommendations based upon staff judgments, political priorities, and citizen demands
<input type="checkbox"/> Budget recommendations based upon a percentage of the total anticipated budget
<input type="checkbox"/> Other approach (describe briefly): _____

<input type="checkbox"/> No specific approach

4. What descriptions characterize your approach to preserving/maintaining sidewalks? (Check all that apply, adding comments if needed.)

Approach	Comments (optional)
<input type="checkbox"/> Preventive maintenance carried out on a set schedule	
<input type="checkbox"/> Immediate – repairs carried out as soon as possible after damage/failure is reported	
<input type="checkbox"/> Corrective – repairs prioritized and scheduled to meet performance targets subject to resource constraints	
<input type="checkbox"/> “Worst-first” – limited number of repairs each year, but backlog exists	
<input type="checkbox"/> Deferred maintenance – little or no work performed annually	
<input type="checkbox"/> This agency does not maintain sidewalks	
<input type="checkbox"/> Other: _____	

5. Who maintains the sidewalks after they are built or installed? (Check all that apply.)

Organization Conducting Work	Does the Selected Organization Have <i>Management Responsibility</i> for What Work to Perform?	
<input type="checkbox"/> Your agency	<input type="checkbox"/> Yes	<input type="checkbox"/> No
<input type="checkbox"/> Private contractor (outsourced)	<input type="checkbox"/> Yes	<input type="checkbox"/> No
<input type="checkbox"/> Another level of government (e.g., inter-governmental agreement)	<input type="checkbox"/> Yes	<input type="checkbox"/> No
<input type="checkbox"/> Other: _____	<input type="checkbox"/> Yes	<input type="checkbox"/> No

6. How do you measure the performance of sidewalks? (Check all that apply.) For selected performance measures, indicate also the frequency of data collection/computation.

<p>PHYSICAL CONDITION:</p> <p><input type="checkbox"/> Structural condition (e.g., cracks, surface irregularities)</p> <p><input type="checkbox"/> Surface type and width</p> <p><input type="checkbox"/> Compliance with ADA requirements</p> <p><input type="checkbox"/> Vegetation encroachment</p> <p><input type="checkbox"/> Debris accumulation</p> <p><input type="checkbox"/> Quality of painted markings (if any)</p> <p><input type="checkbox"/> Other: _____</p>	<p>If you use a measure of physical condition, you gather this information:</p> <p><input type="checkbox"/> More than once a year</p> <p><input type="checkbox"/> Annually</p> <p><input type="checkbox"/> Biennially</p> <p><input type="checkbox"/> Less frequently than biennially</p>
<p><input type="checkbox"/> AGE</p>	
<p><input type="checkbox"/> PERFORMANCE/HEALTH INDEX, which is based on:</p> <p>_____</p> <p>_____</p> <p>_____</p> <p>_____</p>	<p>If you use an index, you compute this index:</p> <p><input type="checkbox"/> More than once a year</p> <p><input type="checkbox"/> Annually</p> <p><input type="checkbox"/> Biennially</p> <p><input type="checkbox"/> Less frequently than biennially</p>
<p>QUALITATIVE RATINGS: e.g., Good-Fair-Poor, based on:</p> <p><input type="checkbox"/> Structural condition (e.g., cracks, surface irregularities)</p> <p><input type="checkbox"/> Surface type and width</p> <p><input type="checkbox"/> Compliance with ADA requirements</p> <p><input type="checkbox"/> Vegetation encroachment</p> <p><input type="checkbox"/> Debris accumulation</p> <p><input type="checkbox"/> Quality of painted markings (if any)</p> <p><input type="checkbox"/> Other: _____</p>	<p>If you use a qualitative rating, you gather information for this rating:</p> <p><input type="checkbox"/> More than once a year</p> <p><input type="checkbox"/> Annually</p> <p><input type="checkbox"/> Biennially</p> <p><input type="checkbox"/> Less frequently than biennially</p>
<p><input type="checkbox"/> ASSET VALUE, in dollars</p>	<p>If you use asset value, you compute this value:</p> <p><input type="checkbox"/> More than once a year</p> <p><input type="checkbox"/> Annually</p> <p><input type="checkbox"/> Biennially</p> <p><input type="checkbox"/> Less frequently than biennially</p>
<p><input type="checkbox"/> CUSTOMER COMPLAINTS—number/frequency</p>	
<p><input type="checkbox"/> CUSTOMER SURVEYS</p>	<p>If you use customer surveys, you conduct these surveys:</p> <p><input type="checkbox"/> More than once a year</p> <p><input type="checkbox"/> Annually</p> <p><input type="checkbox"/> Biennially</p> <p><input type="checkbox"/> Less frequently than biennially</p>
<p><input type="checkbox"/> OTHER: _____</p> <p>_____</p>	<p>Frequency of measurement: _____</p> <p>_____</p>

7. What methods are used to collect and analyze information on sidewalk condition? (Check all that apply. If appropriate, please identify specific device or product technology used by your agency.)

-
- Visual inspections
 - Photologging, videologging: _____
 - Physical measurement: _____
 - Non-destructive testing: _____
 - Customer satisfaction surveys
 - Customer complaints
 - Other: _____
 - No information is collected for these assets
-

8. If you use *service lives* (or *deterioration rates*) in your management of sidewalks, how are their values determined? (Check all that apply.)

-
- As part of management system or analytical model development for sidewalks
 - As a component of agency life-cycle-performance or -cost analyses comparing sidewalk products
 - From agency experience: e.g., database of historical sidewalk service lives
 - Obtained from literature
 - Agency professional judgment
 - Manufacturer's data
 - Other (describe briefly): _____
 - The agency does not use service life information for sidewalks
-

9. What is your agency's estimate of service life of sidewalks? Please enter information for the major components and materials used by your agency. Enter data only for components and materials that your agency uses; if there is no estimate of service life for an item used by your agency please enter "None." For components/materials *not* used by your agency, leave the **Service Life** field blank.

Sidewalks		Curbs		Corners (Urban Roads)	
Type or Material	Service Life, yrs	Type or Material	Service Life, yrs	Type or Material	Service Life, yrs
Concrete		Concrete		Concrete curbs	
Asphalt		Asphalt		Granite curbs	
Brick or block		Granite block		Curb with concrete ramp	
Gravel, crushed rock		Other:		Curb with stone or brick ramp	
Other:		Other:		Other:	

10. How do you determine where a sidewalk is in its service life? (Prioritize responses: 1 = most important or most widely used; 2, 3, ... ≥ declining importance or prevalence of use.)

-
- Compare its age with the maximum age that defines service life
 - Apply deterioration models to estimate where the asset is on “the curve”
 - Monitor condition as described in Item 7 periodically every ____ months
 - Monitor condition as described in Item 7 occasionally
 - Assets are repaired or replaced as soon as they fail without regard to service life
 - Service life is often determined more by functional obsolescence (e.g., need to meet new ADA requirements) than by wear-and-tear
 - This agency does not use/does not monitor service life for this type of asset
 - Other: _____
-

11. Has your agency estimated the extension in service life (or improvement in condition) for this asset resulting from maintenance or rehabilitation actions? Yes No

If Yes, please provide examples of these data (or attach or fax a copy of this information):

12. What information technology capabilities exist to help manage your agency's sidewalks? (Check all that apply.)

Inventory/database containing:

- Number/quantity of asset
- Location of these assets (e.g., route-milepost, reference point-offset, intersection)
- GPS coordinates
- Condition of these assets/current performance level
- Photograph
- Usage, traffic volume

-
- Asset age
 - Dates of inspections/condition assessments
 - Anticipated service life (lives)
 - Deterioration models
-

Treatment selection/timing using:

- Established maintenance schedule
 - Recommendations of inspectors
 - Decision rules or "trees" based on forecast condition
 - Benefit-cost procedures in life-cycle analyses
 - Other optimization procedures for selecting treatments and their timing
-

- Cost models for maintenance, improvement, and replacement treatments
 - Tracking of public comments/concerns/agency responses
 - Models predicting impacts of asset condition to the public (e.g., improved safety, environmental impact)
-

- GIS interface
 - GIS-based maps, reports
-

- Performance measurement/dashboards/accountability reporting
 - Historical database for tracking costs, condition, etc., and/or estimating deterioration models
-

Other: _____

- NONE OF THE ABOVE (skip next response; go directly to item 13)
-

Most or all of the capabilities identified above are:

- Organized within a sidewalk management system
 - Organized within a broad-based management system (e.g., for maintenance or asset management) that includes sidewalks as well as other assets
 - Contained within simple programs that address sidewalks
 - Contained within worksheets or spreadsheets that address sidewalks
 - Part of other products/procedures (describe briefly): _____
-

13. Maintaining sidewalks in good condition is important to several transportation objectives below. Please indicate the relative priority you assign to these objectives (1 = most important, then 2, 3, ... n for the number that apply to your agency):

-
- More efficient travel; reduced travel time; congestion mitigation
 - Pedestrian and cyclist safety; accident and accident risk reduction
 - Pedestrian and cyclist comfort and convenience
 - Increased accessibility to public transit or commuter bus or rail
 - Increased accessibility to employment, school, shopping, and other social functions
 - Improved air quality
 - Local aesthetics and appeal
 - Other: _____
-

14. What are the major gaps in knowledge impeding better asset management for sidewalks?

15. What research needs to be done to improve the validity of service life estimates for sidewalks?

You have completed Part 6. Thank you!

PART 7. CONCLUDING QUESTIONS

1. Are the assets addressed in this survey included in a comprehensive asset management approach used by your agency?
 Yes No

If Yes, please describe briefly or attach a description of your asset management program, including how programming decisions for the select asset classes are integrated.

2. Beyond the specific gaps in knowledge identified in Question 14 of Parts 1 through 6, are there major overarching gaps in knowledge or organizational and institutional issues that are impeding better asset management for the assets addressed in this survey?

3. Beyond the specific research suggested in your agency’s responses to Question 15 in Parts 1 through 6, are there broader research topics that, if addressed, would help support better asset management for the types of assets addressed in this survey?

4. Are there other assets besides the six in this survey (excluding pavements and bridges) for which your agency has developed management approaches that include service life estimates, prediction of future condition, and prediction of future resource needs?
 Yes No

If Yes, please describe briefly or attach a description of the management techniques used for these other assets.

5. If there are aspects of this survey that you would like to discuss further by e-mail or phone, please indicate so here.

THANK YOU VERY MUCH FOR YOUR PARTICIPATION AND CONTRIBUTIONS TO THIS STUDY!

APPENDIX B

Agencies Responding to Survey

Arkansas State Highway and Transportation Department
P.O. Box 2261
Little Rock, AR 72230

City of Cape Coral
P.O. Box 150027
Cape Coral, FL 33915-0027

Colorado Department of Transportation
4201 E. Arkansas Avenue
Denver, CO 80222

Dakota County Road Department
1863 North Bluff Road
Hubbard, NE 68741

City of Edmonton
9803—102A Avenue
Edmonton, AB T5J 3A3 Canada

Florida Department of Transportation
605 Suwannee Street
Tallahassee, FL 32399-0450

Hawaii Department of Transportation
601 Kamokila Boulevard
Kapolei, HI 96707

Iowa Department of Transportation
800 Lincoln Way
Ames, IA 50010

City of Jacksonville, Streets and Drainage Division
609 St. Johns Bluff Road N
Jacksonville, FL 32225

Kansas Department of Transportation
600 SW Harrison
Topeka, KS 66603-3754

Maryland State Highway Administration
707 N. Calvert Street
Baltimore, MD 21202

Michigan Department of Transportation
P.O. Box 30050
Lansing, MI 48909

Minnesota Department of Transportation
395 John Ireland Boulevard
St. Paul, MN 55155

New Brunswick Department of Transportation
P.O. Box 6000
Fredericton, NB E3B 5H1 Canada

Nevada Department of Transportation
1263 South Stewart Street
Carson City, NV 89712

New Mexico Department of Transportation
P.O. Box 1149
Santa Fe, NM 87504

New York State Department of Transportation
50 Wolf Road
Albany, NY 12205

North Carolina Department of Transportation
1 South Wilmington Street
Raleigh, NC 27601

North Dakota Department of Transportation
608 East Boulevard Avenue
Bismarck, ND 58505-0700

Ohio Department of Transportation
1980 West Broad Street
Columbus, OH 43223

Oklahoma Department of Transportation
200 NE 21st Street
Oklahoma City, OK 73105-3204

Oregon Department of Transportation
355 Capitol Street NE
Salem, OR 97301

Pennsylvania Department of Transportation
400 North Street
Harrisburg, PA 17120

City of Portland, Office of Transportation
2929 N. Kerby Avenue
Portland, OR 97227

Ministry of Transportation of Quebec
700, Rene-Levesque Boulevard
Québec, QC G1R 5H1 Canada

Sarasota County Public Works, Road and Bridge
4551 Englewood Road
Venice, FL 34293

Saskatchewan Highways and Transportation
240 Henderson Drive
Regina, SK S4N 5P7 Canada

South Carolina Department of Transportation
955 Park Street
Columbia, SC 29202

City of Tampa, Department of Public Works
306 East Jackson Street
Tampa, FL 33601

Texas Department of Transportation
125 East 11th Street
Austin, TX 78701

Utah Department of Transportation
2060 South 2760 West
Salt Lake City, UT 84104

Vermont Agency of Transportation
1 National Life Drive
Montpelier, VT 05633

Virginia Department of Transportation
1111 East Broad Street
Richmond, VA 23219

Washington County Public Works
2215 Mud Hill Road
Chipley, FL 32428

West Virginia Department of Transportation
1900 Kanawha Boulevard East
Charleston, WV 25305-3340

Abbreviations used without definitions in TRB publications:

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