Georgia Department of Transportation

COMPREHENSIVE TRANSPORTATION ASSET MANAGEMENT: MAKING A BUSINESS CASE AND PRIORITIZING ASSETS FOR INCLUSION IN FORMAL ASSET MANAGEMENT PROGRAMS

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16. Abstract:

Several agencies are applying asset management principles as a business tool and paradigm to help them define goals and prioritize agency resources in decision making. Previously, transportation asset management (TAM) has focused more on “big ticket” assets such as roadways and bridges, and less on lower-cost assets such as traffic signs and guardrails. This purpose of this study is to assess the state of the practice in managing ancillary transportation assets, and develop a benefit-cost-risk framework and supporting tool that can be used to evaluate and prioritize assets for systematic management. The project focuses on ten main ancillary assets: culverts, earth retaining structures, guardrails, mitigation features, pavement markings, sidewalks (and curbs), street lighting, traffic signals, traffic signs and utilities and manholes, and one information asset: data. A literature review and targeted survey were conducted to determine the state of the practice in ancillary TAM and collect data for the development of the evaluation framework. The results of the literature review indicate that a growing number of agencies are making notable efforts to systematically manage the assets under consideration. Based on the literature, methods and practices vary from agency to agency; however, very little was found on data collection costs. A survey conducted targeting 41 state and municipal agencies with reported activity in the literature (with 44% response rate), showed varied agency practices, with more agencies beginning to manage roadway safety assets. It was difficult to obtain specific estimates of data collection costs and cost savings from the TAM systems implementation. The study findings indicate that making a business case for formal asset management programs is more meaningful when approached as an ongoing activity rather than a snapshot action because asset management programs are evolving and at different levels of maturity. At present, the data available for several programs is not adequate enough to conduct a comprehensive benefit-cost analysis of such programs. Thus, the study recommends collecting the necessary data to periodically evaluate the benefits and costs of asset management programs to ensure that they are becoming more cost effective as they are evolved to higher levels of maturity. A benefit-cost framework is provided and data collection needs are outlined to enable such an analysis to be conducted adequately. With regard to prioritizing assets for inclusion in a formal asset management program, the study recommends that the prioritization must be tied to the strategic goals of the agency, and the objective of the prioritization should be risk reduction relative to agency strategic goals. A risk framework is provided and data needs are outlined for conducting such an analysis adequately. Another caution that results from the study is that ancillary assets cannot properly be considered in isolation and prioritized one against another but must also be considered as complementary units, with synergistic effects, that are part of the overall system.

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Comprehensive Transportation Asset Management: Making a Business Case and Prioritizing Assets for Inclusion in Formal Asset Management Programs

Final Report

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Executive Summary

Several agencies are applying asset management principles as a business tool and paradigm to help them define goals and prioritize agency resources in decision making. Previously, transportation infrastructure management has focused more on "big ticket" assets such as roadways and bridges, and less on lower-cost assets such as traffic signs and guardrails. The purpose of this study is to assess the state of the practice in managing ancillary transportation assets, and develop a benefit-cost-risk framework and supporting tool that can be used to evaluate and prioritize assets for systematic management. The project focuses on ten main ancillary asset classes: culverts, earth retaining structures, guardrails, mitigation features, pavement markings, sidewalks (and curbs), street lighting, traffic signals, traffic signs and utilities and manholes, and one information asset: data. A literature review and targeted survey were conducted to determine the state of the practice in ancillary TAM and collect data for the development of the evaluation framework.

The results of the literature review indicate that a growing number of agencies are making notable efforts to manage the assets under consideration, systematically. The methods and practices found in literature vary from agency to agency; however, very little was found on data collection costs. A survey was conducted targeting 41 state and municipal agencies with reported activity in the literature. The survey, with a 44% response rate, showed varied agency practices, with more agencies beginning to manage roadway safety assets. On the other hand, it was difficult to obtain specific estimates of data collection costs and cost savings from the implementation of TAMS.

The study findings indicate that making a business case for formal asset management programs is more meaningful when approached as an ongoing activity rather than a snapshot

activity because asset management programs are evolving and at different levels of maturity. Thus, the study recommends collecting the necessary data to periodically evaluate the benefits and costs of asset management programs to ensure that they are becoming more cost effective as they are evolved to higher levels of maturity. The study also cautions against using a snapshot evaluation of any asset management program or system to decide conclusively on the fate of such system or program as one can expect the benefit-cost ratios of such programs or systems to change as they are evolved to higher levels of maturity. At present, the data available for several programs is not adequate enough to conduct a comprehensive benefit-cost analysis of such programs. A benefit-cost framework is provided and data collection needs are outlined to enable such an analysis to be conducted adequately.

With regard to prioritizing assets for inclusion in a formal asset management program, the study recommends that the prioritization must be tied to the strategic goals of the agency, and the objective of the prioritization should be risk reduction (relative to agency strategic goals). Thus, an appropriate analysis to prioritize assets for inclusion in a formal management system would be to determine the relative risk reductions that could be afforded by formal management of the different ancillary assets under consideration, considering their roles in the overall highway or transportation system. A risk framework is provided and data needs are outlined for conducting such an analysis adequately. For example, an agency with a strategic goal of safety and a more significant gap between the present level and target value of safety may prioritize including safety hardware assets in their asset management program. Such an agency would also need to conduct studies to determine which safety ancillary assets or combinations of assets would afford the highest improvements in safety. Thus, another caution that results from the study is that all ancillary assets cannot properly be considered in isolation and prioritized one against another but must also be considered as complementary units, with synergistic effects, that are part of the overall system.

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1 Introduction

1.1 Background and Motivation

Transportation Asset Management (TAM) has been embraced by both local and state transportation agencies as a tool to facilitate decision making for capital investment, maintenance, rehabilitation, and replacement of assets. Although the term asset management has been used in different capacities by different agencies, all uses tend to have the same objective of upgrading, preserving and maintaining infrastructure cost-effectively over the lifecycle. The American Association of State Highway and Transportation Officials (AASHTO) Subcommittee on Asset Management defines asset management as "a strategic and systematic process of operating, maintaining, upgrading and expanding physical assets cost-effectively throughout their lifecycle. It focuses on business and engineering practices for resource allocation and utilization, with the objective of better decision-making based on quality information and well-defined objectives" (NCHRP, 2011).

Over the past 50 years, significant capital investment (almost $40B in 2010) has been made in transportation infrastructure; and, the practice of systematically maintaining these massive infrastructure systems has been growing steadily since the late 50s (Highway Statistics, 2010). It became apparent, as these infrastructure systems aged and funds became more limited, that a paradigm of asset management has to be adopted to help allocate these limited resources more effectively and efficiently to keep infrastructure functioning at the highest levels possible. Many Transportation agencies have taken the initiative to establish some form of management system or program to manage their assets. The most widely used systems are Pavement Management Systems (PMS) and Bridge Management Systems (BMS), which help in managing only the “big ticket” transportation infrastructure (Hensing and Rowshan, 2005).

Pavement management began with the AASHO Road Tests in the late 50s in Ottawa, Illinois, where experiments were designed to establish the relationship between structural designs and expected loadings over pavement life (Federal Highway Administration, 2011). The AASHO Road Tests data were also used in developing the first models linking pavement serviceability to distress data (Carey and Irick, 1960), one of the first elements of PMS and the beginning of performance modeling. One of the main drivers for the development of BMS was regulatory requirements imposed to improve stewardship of bridges as a result of the critical nature of bridge failure, as well as the costs of replacement. What seem to have less developed asset management systems thus far are the safety elements of the transportation network such as roadway lighting, traffic signals, earth retaining structures, culverts, guardrails, etc. Safety Management Systems (SMS) seek to incorporate safety assets as a key component in all transportation infrastructure related decision-making processes. Lower activity in SMS within transportation agencies could be attributed in part to the rescinding of the 1991 ISTEA management system mandate through the 1995 National Highway System legislation (Lindquist, 1999). However, a number of DOTs who experienced the effectiveness of their SMS from 1991 through the later part of 1995 have maintained them to date.

Although the costs to build and operate these safety assets may not be as high as that for bridges and pavements, they are critical to the safe operation of the transportation system. In addition, the rate of failure of some of these assets might be low; however, the consequences of their malfunction could be fatal. As asset management systems evolve in maturity, there is a need for formal asset management procedures for these and other ancillary assets, to improve budgeting and project prioritization. Developing ancillary transportation asset management programs however could require making a business case for expending the dollars necessary to collect data and develop analytical capabilities for managing these assets more systematically. Furthermore, when the decision has been made to manage these assets more systematically, the question of which asset to begin with may be important for agencies given the extent of available options and limited funding. Together with other criteria, quantified benefits can be important when prioritizing these ancillary assets for formal management procedures.

1.2 Objectives & Organization

The purpose of this study is to assess the data needs, and develop capabilities for evaluating the benefits, costs and risks of including various ancillary asset classes in a formal asset management program. More explicitly, the objectives of this project are to:

1. Determine the inventory and attribute data requirements and estimate costs of data collection and costs savings from AMS implementation;
2. Develop a risk-based framework for assessing the relative risks of failure associated with different ancillary assets (as a function of the relative benefits of investing in the different asset classes);
3. Apply the framework to assign priorities for incorporating various asset classes into GDOT's existing TAM system, taking into consideration the costs and benefits of asset management, and the risks of not applying systematic asset management procedures to these asset classes.

The study was conducted based on a literature review and targeted survey of selected state and municipal agencies to determine common and effective practices for managing ancillary transportation assets. Subsequently, a risk-based framework was developed to identify asset classes with the highest probability and consequences of failure as an input in prioritizing the assets for inclusion in a formal management program. A benefit-cost approach was outlined for evaluating the marginal benefits per unit cost of including an asset class in a formal management program. These two frameworks were integrated into a benefit-cost-risk framework, and, in the absence of data to populate the framework, data needs assessed and outlined for applying the framework to prioritize assets for inclusion in a formal asset management program.

In the following sections, the results of the literature review and survey are presented, followed by the risk and benefit-cost approaches, and the risk-benefit-cost framework for evaluating candidate asset classes for inclusion in a formal management system, including data requirements. The report concludes with recommendations on making a business case for asset management and prioritizing various asset classes for inclusion in a formal asset management program.

2 Literature Review

The literature review, conducted as the first phase of this project, focused primarily on reviewing transportation agency practices, both domestic and international, to document the state of the practice regarding the management of 10 ancillary asset classes and one information asset class: earth retaining structures (ERS), traffic signals, guardrails, pavement markings, culverts, roadway lighting, traffic signs, sidewalks and curbs, and mitigation features, utilities and manholes (typically managed by local agencies), and data (an information asset). More specifically, the literature review focused on investigating the necessary inventory and attribute data, data collection and data analysis tools, and costs, involved in managing these asset classes.

The literature revealed that at least one agency in the United States is involved in managing each of the eleven categories of assets. However, no single agency was identified as having an asset management program or programs in place for all eleven asset classes. In addition, most agency efforts seemed to be limited to the initial stages of more comprehensive asset management plans. These stages included the development of asset inventories, some condition assessment and information management, and, in some cases, asset valuation (DeMarco, et al., 2009). According to a report prepared for the NCHRP in 2009 (Brutus and Tauber, 2009) there are about 12 transportation agencies in the U.S. currently practicing ERS Asset Management in some capacity. However, only a few of these agencies actually use their inventory and inspection data in more advanced asset management practices such as planning and budgeting. Evaluating such asset management programs could result in a range of results reflecting the relative maturity of the various programs. The AASHTO Transportation Asset Management Guide, Vol. 2, presents a maturity-scale model for asset management practice (Table 2-1), indicating that the relative cost-effectiveness of various asset management programs could be a function of their relative maturity.

TABLE 2-1 AASHTO TAM Maturity Scale

TAM Maturity Scale Level	Generalized Description
Initial	No effective support from strategy, processes, or tools. There can be lack of motivation to improve.
Awakening	Recognition of a need, and basic data collection. There is often reliance on heroic effort of individuals.
Structured	Shared understanding, motivation, and coordination. Development of processes and tools.
Proficient	Expectations and accountability drawn from asset management strategy, processes, and tools.
Best Practice	Asset management strategies, processes, and tools are routinely evaluated and improved.

Source: AASHTO Transportation Asset Management Guide, Vol. 2

Overall, 64 agencies (34 state transportation departments, 11 local county and city agencies and 19 international agencies) were identified as having some activity in ancillary transportation asset management in the literature. A chart showing the specific assets managed by each agency is provided in Appendix A. Figure 2.1 shows the percentages of the agencies identified that manage each asset class. As shown, culverts are the most common assets managed by about 50% of the agencies identified. This is followed by traffic signs and then pavement markings. The management of culverts is a result of some agencies including these and other structures in their National Bridge Inventory System (NBIS); however, according to Davidson and Grimes (2006) culverts are not given the required attention they deserve, even with the introduction of the Federal Highway Administration (FHWA) voluntary Culverts Management System in 2001. The prevalence of signs and pavement marking management systems, on the other hand, could be attributed, at least in part, to FHWA legislative mandates for retro reflectivity (FHWA, 2007). There is an absence of such directives pertaining to the rest of the asset classes, and few agencies have included them in their management systems.

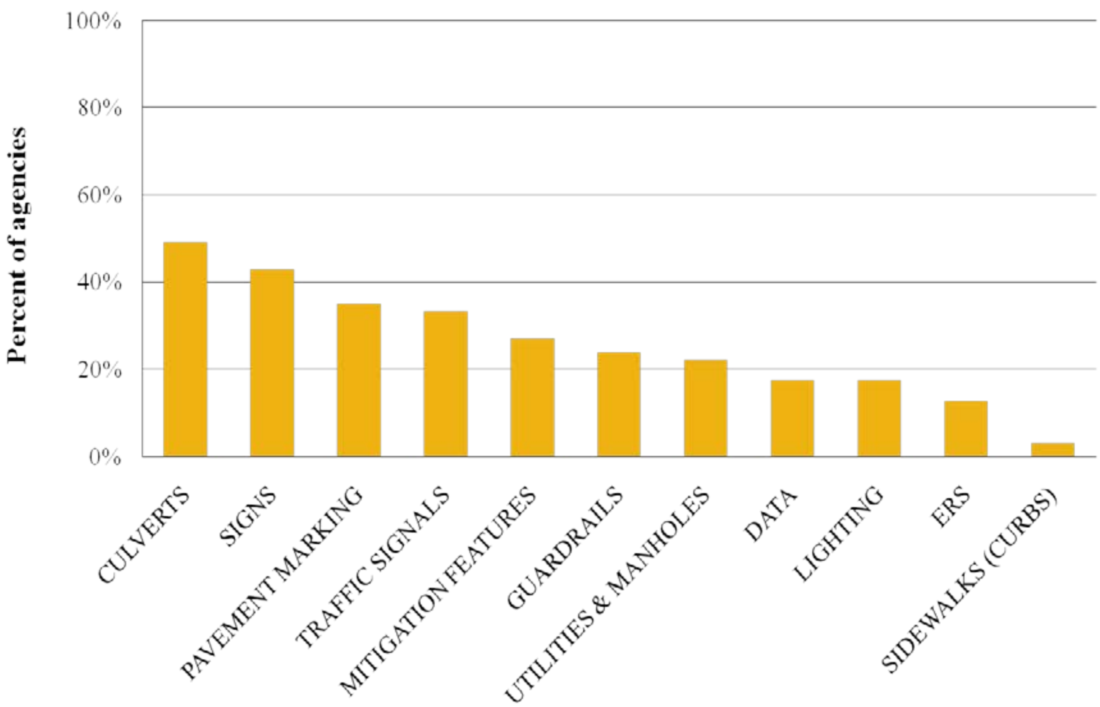

FIGURE 2.1 Assets managed by agencies as identified from literature review.

2.1 Data Needs, Data Collection Costs and Analysis Tools

Effective planning for a transportation asset management program includes an assessment of the data needs, costs and analysis tools that are needed to run a successful program. According to a National Cooperative Highway Research Program (NCHRP) study conducted by Markow, agencies often lack the necessary data to complete their management systems (2007). In addition, a lack of standardized measurement methods of service life has created challenges in data coordination and compilation for asset management. A 2008 study by Li and Madanu further supports this finding of a deficiency in asset service life evaluation methods (2008). Although data collected by agencies with asset management programs varies by agency, it generally includes standard inventory data (location, type, etc.) and attribute data relating to the agency's measure of operational performance for the specific asset.

The analysis tools employed in asset management systems should enable effective decision making and planning. Agencies have employed various analysis tools according to their specific needs. For example, in 2008, the City of Clearwater, FL implemented the Oracle Utilities Work and Asset Management module to "gain a comprehensive view of [their] infrastructure assets to help enhance planning, streamline operations and contain costs" (Oracle, 2008). Oracle database tools are, arguably, the most common advanced asset management analysis tools utilized by many other agencies, such as, the California DOT (Caltrans), which used the Oracle Road Feature Viewer in 2008 (Li and Madanu, 2008). In addition, many states have developed individualized software systems to manage assets based on their needs, as seen in Alaska and Ohio DOTs' efforts to manage their culverts and other drainage infrastructure (Najafi, et al., 2008). Regardless of the existence and use of database and analysis tools (although limited) which can support data-driven decisions, agencies often employ historical data, political input and professional judgment in determining asset service-life estimates and in creating their operating budgets (Markow, 2007). Although these less quantitative approaches may be common, several agencies are considering or investing resources in data collection for more systematic decision making for their assets.

In order to fully develop a business case for any asset management system, it is important to know the costs of running and maintaining the system. However, very little documentation of data collection costs for developing asset management programs was found. Hensing and Rowshan studied several roadway safety hardware asset management systems in 2005 and estimated that the New Mexico Road Feature Inventory (RFI) system had an initial cost of $2 million with an additional $500,000 to complete the acquisition of data that was missing from the initial process (2005). Another study conducted by the United States Environmental Protection Agency (EPA) and the FHWA reports that the City of Calgary, Canada, saved about $30 million in their rehabilitation and replacement decisions by employing asset management practices in their Water Resources sector, and was able to avert a main break repair cost of about $16 million over a period of 10 years (USEPA, 2009). The City of Portland Planning Bureau, on the other hand, does not quantify their benefits but acknowledges that the introduction of business risk assessment in their asset management process has yielded a better decision-making process and has created a common language across all sectors of the city (USEPA, 2009).

2.2 Key Studies

2.2.1 Roadway Safety Hardware Management

A 2008 study by Li highlights the state of practice of roadway safety hardware management across 12 Midwest states and the state of Tennessee (Li and Madanu, 2008). The purpose of this study was twofold: to synthesize state-of-the-practice techniques for managing safety hardware assets and to develop a methodology for integrating these assets into other maintenance management programs. The study develops a risk-based framework for safety improvements focusing on safety indices as a measure of accident reduction or increase at an intersection or over a highway segment. The risk framework, however does not take into consideration other broader impact factors such as economic or environmental impacts of transportation asset failure. Some of the major findings of this study are that data collection is performed by field staff both manually and with the use of automated data collection tools, and that these data are in some cases, maintained by a central office. The study also suggests that most states allocate safety hardware management program budgets using expert knowledge. A few of the states surveyed use a systematic process such as Level of Service (LOS) to determine which assets require maintenance.

2.2.2 Culvert Management Systems

Another study conducted under the NCHRP evaluates the state of practice in culvert assessment, selection of appropriate rehabilitation methods, and the type of asset management systems used by transportation agencies (NCHRP, 2002). The study also looks at the methods used by DOTs to predict the service life of culverts and finally the type of material selected to use in the rehabilitation of pipes. In all, 155 transportation agencies were surveyed, consisting of local and state agencies, public works departments, and county utility departments. Some of the findings from this study are that the minimum and maximum pipe sizes included in various systems vary from one organization to the other; however, the typical range adopted by most agencies is between 12 inches and 12ft. In addition, most of the respondents indicated that the appurtenances around the pipes are also assessed with most emphasis placed on the joints of the pipes. Another important take away from this study is the driving factors for pipe repairs as described by most agencies: hydraulic capacity, traffic volume, height of fill, service life, and risk assessment. A notable finding of this report is that none of the participating agencies were using the Culvert Management System (CMS) developed by FHWA to assist local governments and others to manage their culverts.

2.2.3 ERS Management Systems

DeMarco's study on earth retaining structures (or retaining walls) evaluates the Wall Inventory Program (WIP) implemented by the National Park Services (NPS) in 2004 through the help of the FHWA Office of Federal Lands Highway (FLH) (Anderson et al., 2008). The WIP is similar in scope to the Roadway inventory program (RIP) and the Bridge inventory program

(BIP). The main purpose of the WIP is to assist the NPS in defining and quantifying retaining walls in terms of their location, geometry, construction attributes, condition, failure consequence, cultural value, apparent design criteria, and cost of structure maintenance, repair, or replacement. The take away here is that the NPS WIP, can serve as a template that transportation agencies can use or develop.

2.2.4 Comprehensive Transportation Asset Management

Throughout the extensive literature reviewed, no transportation agency was identified to have a comprehensive asset management system in place for all 10 classes of ancillary assets. Sixty-four local and state transportation departments, county public works departments and international agencies were identified as managing at least one of the eleven classes of assets. Every one of these agencies was found to be at a different stage in the management process but most of them were practicing some form of systematic assessment for large culverts followed by signs and pavement markings. The activity with large culverts is a result of some agencies including qualifying these structures in their National Bridge Inventory System (NBIS); however, culverts are not given the required attention they deserve, even with the introduction of the FHWA voluntary Culverts Management System in 2001 (Davidson and Grimes, 2006). The prevalence of signs and pavement marking management systems, on the other hand, can be attributed in part to the FHWA legislative mandates for retro reflectivity. There is an absence of such mandates pertaining to the rest of the asset classes, and few agencies have included them in their management systems thus far.

The map in Figure 2.2 below shows the U.S. State DOTs identified as having some sort of systematic approach to taking inventory or managing the assets under consideration. The state agencies are classified by the number of assets managed.

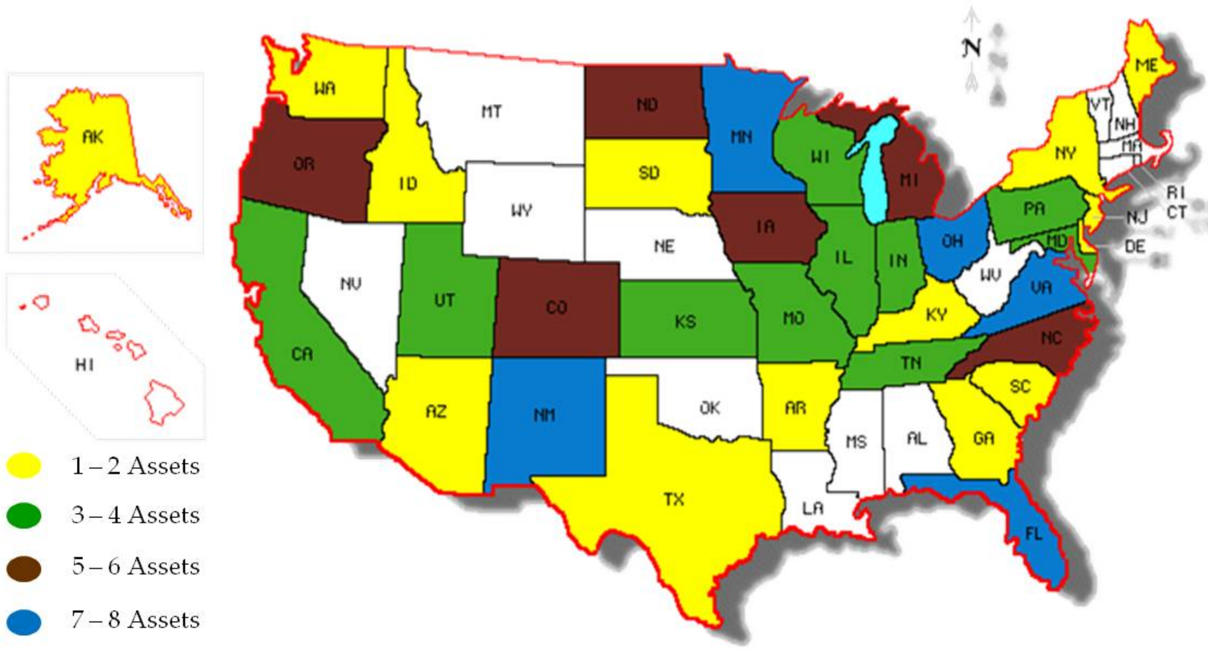

FIGURE 2.2 States identified as having an asset management system from literature review

As shown, five states – New Mexico, Minnesota, Ohio, Virginia and Florida – were found to have a management system for 7 or 8 of the asset classes. This was the maximum number of asset categories determined to be managed by any one agency. This result formed the foundation of the next phase of the project, the targeted surveys. Clearly, the list of state DOTs shown here is not comprehensive as a national survey was not conducted to determine the status of DOTS in ancillary transportation asset management. Instead, the literature was used to determine reported activity in ancillary transportation asset management, and a follow up targeted survey was used to determine that status of ancillary transportation asset management in those agencies that had reported activity in the literature. This way, there was some basis for verifying the information obtained from the literature with that which was obtained from the survey. Where the two pieces of information did not align, follow up surveys were done for clarification. In the cases where the literature information could not be verified with the survey information, the information was left out of the analysis altogether.

2.3 International Practices & Standards

In 2005, the FHWA, AASHTO and NCHRP sponsored an international scan study of transportation asset management experiences, techniques and programs in Australia, Canada, England and New Zealand. The report from this scan provides a comprehensive synthesis of asset management best practices outside the United States. England's Department for Transportation, Gloucestershire County in England, the cities of Edmonton (Canada) and Brisbane (Australia), the New Zealand Transport Agency and the Quebec Ministry of Transportation were all identified as having transportation asset management systems that incorporate at least one of the 11 classes of assets being investigated (Geiger, et al., 2005). Generally, much more documentation, relating to data costs, was found from the international scan report than was found from all the literature on domestic transportation agencies.

For example, in Canada, the City of Edmonton manages a collection of assets that include culverts, sidewalks, street lights, traffic signals and traffic signs, among others. Data collection costs were reported to be at about $400,000 as of 2005 with analysis tools that include an infrastructure report card and a pavement quality index (PQI). The report card gives details on various asset characteristics including replacement value and expected asset life. The PQI is an in-house measure that can be estimated using deterioration curves, based on assumed budgets (Geiger, et al., 2005). Overall, there is much to be extracted from international experiences with asset management of ancillary assets, extending beyond the asset classes considered in this work.

2.4 Consideration of Risk in Infrastructure Decision Making

The literature shows that risk analysis is being developed and employed for making decisions in infrastructure planning and investment. Risk is typically defined as the probability of failure and the consequences of this failure (Kaplan & Garrick, 1981). Several approaches have been reported in the literature for addressing risk in transportation decision making, some with practical applications and others yet to be developed as practical applications. The approaches include probability-based, input-output-based, expert opinion and multi-attribute decision making based methods. Examples are presented below to highlight how risk is being addressed in infrastructure decision making.

An earlier study, (Haimes and Jiang, 2004), developed a Leontief-based infrastructure input-output model to help account for the intra-connectedness within each critical infrastructure as well as the interconnectedness among them. The model considers a system consisting of a number of critical complex intra-connected and interconnected infrastructures (e.g., highway safety appurtenances). The model uses failures due to accidents, natural hazards, or acts of terrorism, as input data, with the outputs being the risks of inoperability that can be triggered by one or more failures. Inoperability of a system is defined as the inability of the system to perform its intended functions. In other words, the expected inoperability is classified as the risk of inoperability that measures the joint effect of the probability (i.e., likelihood) and degree (i.e., percentage) of the inoperability of a system. The researchers used a continuous variable, between zero and one, to assess the inoperable state, with zero corresponding to a flawless operable system state, and one corresponding to the system being completely inoperable. The study generalized the linear input/output model into a generic risk model with the former as the first-order approximation.

Dicdican et al., (2004) developed a systematic risk-based asset management methodology to manage the maintenance of highway infrastructure systems. The decision-making methodology developed could enable harmonization and coordination of actions of different units and levels in a hierarchical organization. The framework uses a multi-objective decision tree for analysis to validate the tradeoffs between long-term and short-term costs, applying the concept of remaining life to distinguish actions in the present from those in the future. The systematic methodology also enables organizations to prioritize assets for maintenance while addressing the potential for extreme events. The costs, benefits, and risks of maintenance and inspection policies are balanced by the methodology and applied to the various types of assets. The methodology presented adopts three objective functions in the options and strategies evaluation process: minimizing short-term cost, minimizing long-term cost, and maximizing the remaining service life of highway assets. The use of a constraint function enables the method to eliminate infeasible options by coordinating the remaining service life across assets. The methodology is not only applicable to highway infrastructure systems, but can also be applied to the management of large-scale dynamic systems that exhibit similar characteristics as those of highway systems.

The literature also presents another study (Cambridge Systematics, Inc., et al., 2009) that proposes an approach to augment transportation agencies' existing risk management activities with a process that helps assess risks resulting from the failure of interstate highway system (IHS) assets. The approach helps owners of the IHS to perform risk assessment for their IHS assets and any other assets determined to be on their highest priority network. This risk assessment approach yields a set of priorities for risk mitigation as well as providing input to the resource allocation process. In this study, scenario-based methods are used in identifying risks. In the identification process, a four quadrant scale, known as the universe of risk, is used to categorize risk in terms of its consequence on human safety, property damage, and system/mission disruption. The approach focuses on the right hand quadrants, which are the quadrants with the greatest consequences. The model uses either an objective or subjective approach depending on data availability. Although the objective-consequence modeling approach requires a larger input data, in return, owners obtain a more quantifiable estimate of consequences for materialized threats/hazards. Therefore, knowing the estimates of mitigation costs, a benefit/cost analysis can be performed as an option in the decision process. On the contrary, a subjective approach uses the consequence threshold technique in which levels of certain transportation assets characteristics are identified. With this approach, no action would be required if the asset condition stays at or above the threshold.

In addition to these studies, Fares & Zayed (2010) used a hierarchical fuzzy expert system to assess the risk of failure of water mains. This paper states that there are 700 water main breaks per day in Canada and the United States, costing more than CAD 6 billion since 2000. It defines risk of failure as the combination of probability and impact severity of a particular circumstance that negatively impacts the ability of infrastructure assets to meet municipal objectives. The study proposes a framework to evaluate the risk associated with the failure of a water main using a hierarchical fuzzy expert system (HFES). The model considers 16 risk-of-failure factors within four main categories which represent both probability and negative consequences of failure. It establishes a strong correlation between pipe age and risk of failure followed by pipe material and breakage rate. The study also shows that the surroundings suffered the most negative consequence of a failure event. Finally, a pilot project was implemented to examine their methodology. This project suggested that a percentage (~8%) of the network's pipelines is risky and requires mitigation actions in the short term.

A practical application of the probability/consequences of failure model is seen in a bridge management application in Queensland, Australia (Geiger et al., 2005). The authors outline how Queensland assesses the risk (product of the probability of failure and the consequence of failure) posed by a bridge, using a program called Whichbridge. The program assigns numerical scores to bridges based on factors such as condition of bridge components, environmental impacts, component materials, design standards and traffic volumes.

Because objective data can be limited, expert opinion is sometimes necessary for characterizing risk. Salgado and Menezes (2010) review some approaches to developing a model based on expert opinion for critical infrastructure risk assessment and vulnerability analysis. The researchers address the challenges (i.e., obtaining estimates for the probabilities of the initiating events as well as obtaining values for the associated consequences) in performing quantitative risk assessment of very rare events by reviewing Dempster-Shafer and Fuzzy approaches to elicit expert opinions.

The literature reveals growing activity to incorporate risk in infrastructure decision making to prioritize alternatives. Several approaches are data intensive indicating that practical implementation may include some combination of objective data with expert opinions. The probability/consequences of failure risk model can be applied to prioritize various asset classes based on their relative risk of catastrophic or performance failure and the consequences of this failure. In cases where there is limited data, expert opinion can be used with what data is available, as agencies make an effort to collect the necessary data to progressively refine their analyses.

2.5 Benefits of Asset Management

Although the practice of asset management has spread throughout Departments of Transportation, Public Works Departments and other infrastructure-related departments throughout the United States and the rest of the world, there are several barriers to implementing asset management programs, especially for ancillary assets, which are seemingly, the "less important" assets. One of the main barriers to the success of these programs is the cost associated with their development and implementation. For some agencies to justify an investment in an ancillary asset management system (or investment in incorporating ancillary assets into existing systems or programs), there needs to be evidence that the benefits outweigh the costs. There are several benefits from the use of asset management programs, either in the short-term or the long-term that have been outlined in various publications (Haas and Hensing, 2005; Kraus, 2004; Mizusawa and McNeil, 2009). Generally, there are more benefits in the long-term than the short-term, which poses a difficulty for advocates of these programs because all the positive effects are not recognized early.

The most prominent benefit from asset management programs is the ability to make rational, data-driven, well-informed decisions when allocating resources or making investment related decisions (Haas and Hensing, 2005), as opposed to ill-informed decisions that cannot be justified. Justifying investment decisions is a critical aspect of agency accountability and transparency especially in relation to the public. For example, in Missouri, since the inclusion of asset data in financial reports resulting from GASB Statement 34, Missouri Department of Transportation's (MoDOT's) functional managers at all levels have begun to understand the effects of investments on the condition of their roadways and bridges (Kraus, 2004). Furthermore, MoDOT reports that the public can "see how the budget drives the outcome on net assets and other services provided" (Kraus, 2004), increasing credibility for the agency to its customers and, by extension, the political decision makers.

Related to data use in decision making, a second important benefit of asset management programs is the support they provide in helping agencies understand the implications of different investment options (Mizusawa and McNeil, 2009). In Missouri, the implementation of asset management provided the tools to determine how available (or constrained) funding can be used to improve asset condition, or assess the funding needs to attain a certain level of asset performance. Essentially, the program created the ability to determine the impact of various funding levels on infrastructure condition over the long-term (Kraus, 2004).

Where a management program is integrated with many different assets, these programs enable consistent evaluation of the infrastructure condition, as well as trade-off of investments across different elements to determine the best investment at the appropriate time (Mizusawa and McNeil, 2009; Haas and Hensing, 2005). Clearly, this integrated approach to decision making, especially pertaining to resource allocation, means agency investment decisions will be more effective and efficient. With this level of informed decision making that integrates all the levels of infrastructure making up a transportation system, agencies will increase their cost-effectiveness in relation to infrastructure maintenance and rehabilitation.

In the long run, successful asset management programs should eventually lead to appropriate maintenance and rehabilitation (M&R) of infrastructure which improves asset performance while simultaneously reducing M&R costs (Mizusawa and McNeil, 2009). Overall, "more timely decisions and other efficiency improvements combine to reduce the costs of acquisition, maintenance, upgrade, and replacement of assets" (Haas and Hensing, 2005). These improvements in asset condition provide a better driving environment for highway transportation system users, thus reducing user costs, vehicle operating costs and other external costs (Mizusawa and McNeil, 2009), which are all important benefit-cost factors.

Evidently, the benefits of ancillary asset management programs and asset management programs in general, are many and varied and can be seen in both the short-term and long-term. Nonetheless, implementing asset management as a standard business tool within transportation agencies still faces obstacles from an investment perspective. Generally, "upperlevel managers are interested in benefits that can be translated into monetary values" (Mizusawa and McNeil, 2009, p. 232) and convince them of the importance of these programs. This comes as no surprise since money is a universal language easily understood by anyone from the common infrastructure user (the general public) to the highly technical engineers who develop these asset management programs. As a result, it can be useful to quantify the benefits of asset management program implementation in order to demonstrate clearly whether and how these benefits exceed the costs associated with program development. In Chapter 4, the opportunities for quantifying the benefits of asset management programs are presented, with a specific focus on ancillary transportation assets.

2.6 Knowledge Gaps

The literature reviewed in this study revealed several gaps regarding ancillary transportation asset management in the United States. First, there is a need to refine data inventory processes and data collection standards in order to make accurate assessments of the data needs for these asset management systems (Li and Madanu, 2008). Additionally, information on estimating and evaluating asset performance and incorporating performance data to enrich decision making and budgeting practices requires improvements (Markow, 2007). As Markow noted, the process of developing ancillary transportation asset management systems is complicated because deterioration models are difficult to build. In relation to the benefits of asset management, it is apparent that there is some significant amount of documentation of the benefits in the literature; however, quantification of these benefits is an area that has not been fully explored, especially for transportation infrastructure. Where some quantification of benefits has been attempted, it is fairly difficult to identify applications of the methodologies to ancillary transportation assets, which is the focus of this study. Details and evaluations of some attempts at benefit quantification are presented in Chapter 4, and the feasibility of applying them to ancillary assets is evaluated.

3 Asset Management Survey of Practice

A targeted survey was conducted to obtain up-to-date information on the status of the ancillary asset management systems of the agencies identified from the literature review. Instead of conducting a national level survey, this targeted survey was used to verify the information gathered in the literature review, working with the assumption that the domestic agencies with reported activity in the literature would be among those that have made substantial progress in managing ancillary transportation assets. Representatives from 41 agencies (33 State DOTs and eight local agencies) were contacted from January to May 2011 and asked to complete a survey either through a written response or telephone interview. Generally, the international agencies were left out due to challenges with the logistics of obtaining contact information, contacting them and following up. Additionally, only 41 of the domestic agencies were surveyed because contact information could not be obtained for the other agencies. Overall, 18 (44%) of the agencies surveyed responded, almost equally between interviews and completed questionnaires. The respondents included 16 state DOTs (shown in Figure 3.1) and two local agencies (Seattle DOT & Hillsborough County Public Works Department, Tampa, FL). Two responding agencies reported that they do not currently operate an asset management program, contrary to what was suggested by the literature. These agencies have therefore been left out of this discussion. A copy of the survey is available in Appendix B and the next few paragraphs examine the survey questions and present the results.

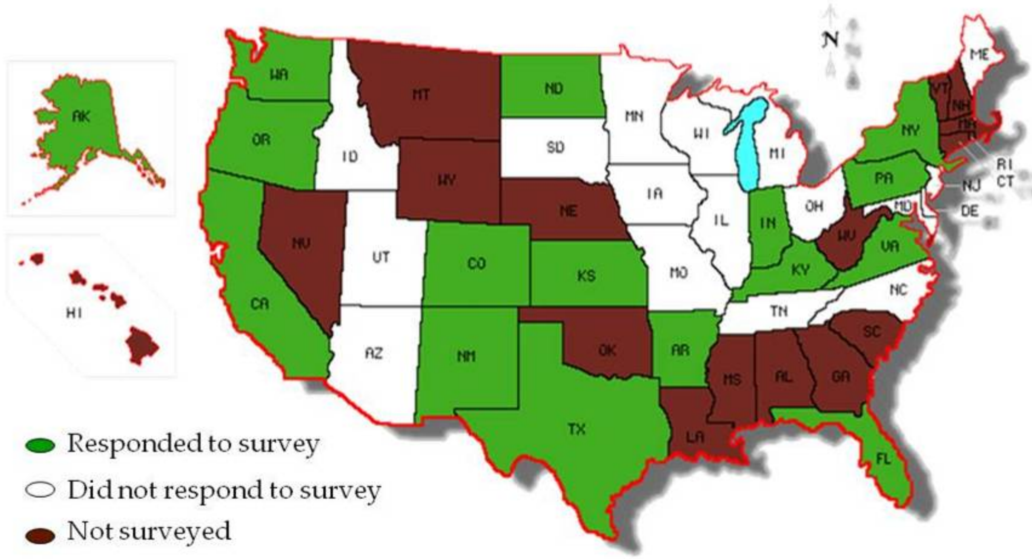

FIGURE 3.1 States responding to asset management survey of practice.

3.1 Findings on the State of Practice

3.1.1 Summary of Findings

Overall, no agency was found to manage all 11 asset classes, consistent with the findings in the literature. Over 50% (9) of the 16 agencies responding to the survey had management systems in place for six or more of the asset classes all including traffic signs and guardrails. Figure 3.2 shows the percentage of the total number of agencies responding to the survey and reporting that they manage each asset class.

From the surveys, traffic signs and signals were found to be the most commonly managed assets, as indicated by 13 (81%) of the 16 responding agencies for both assets. Considering the importance of traffic signals in roadway safety, it seems logical that agencies have taken steps to formalize their management of these assets. Additionally, the 2007 FHWA retro reflectivity mandate gives agencies until January 2012 to implement a management system to maintain minimum levels of retro reflectivity in signs (FHWA, 2007), which is likely an important factor in the increase in management of traffic signs. The next most commonly managed assets are guardrails and culverts, which were reported as managed by 12 (75%) and 11 (69%) of the 16 responding agencies, respectively. Survey responses showed that culverts are typically managed with bridges in the bridge management systems that already exist. On the other hand, the least managed asset according to survey responses, was data, which was reported as managed by only four (25%) of the 16 agencies responding to the survey.

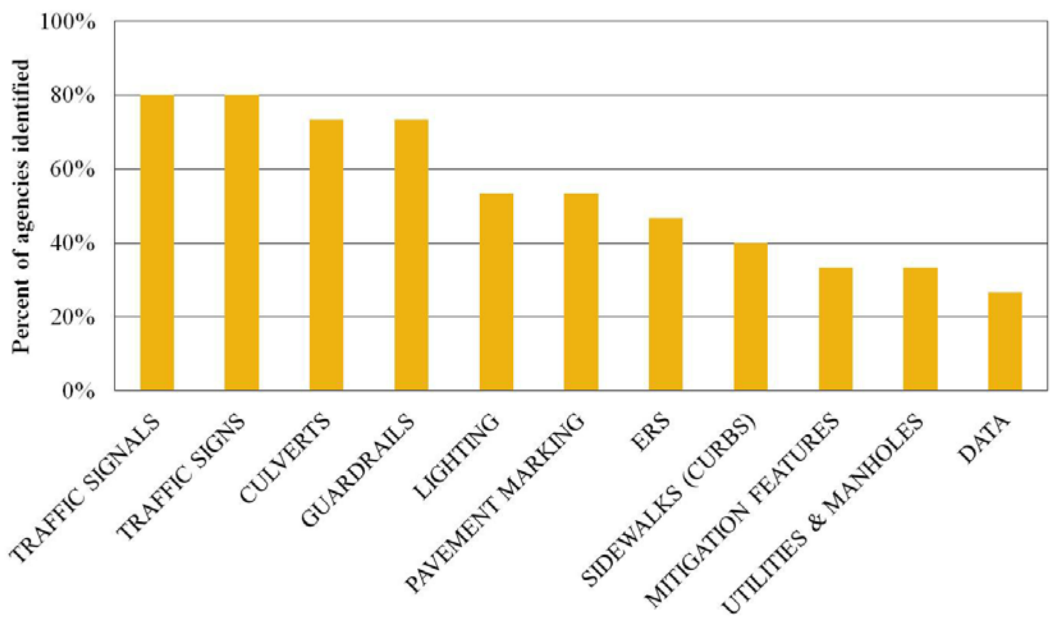

FIGURE 3.2 Assets managed by agencies as identified from targeted survey.

3.1.2 Verification of Literature and Survey Information

One impetus in conducting a targeted survey based on the reported activity in the literature was to have a basis for verifying the results, to some extent. Figure 3.3 shows a comparison between the results of the literature review and the survey of the percentages of agencies managing each asset class.

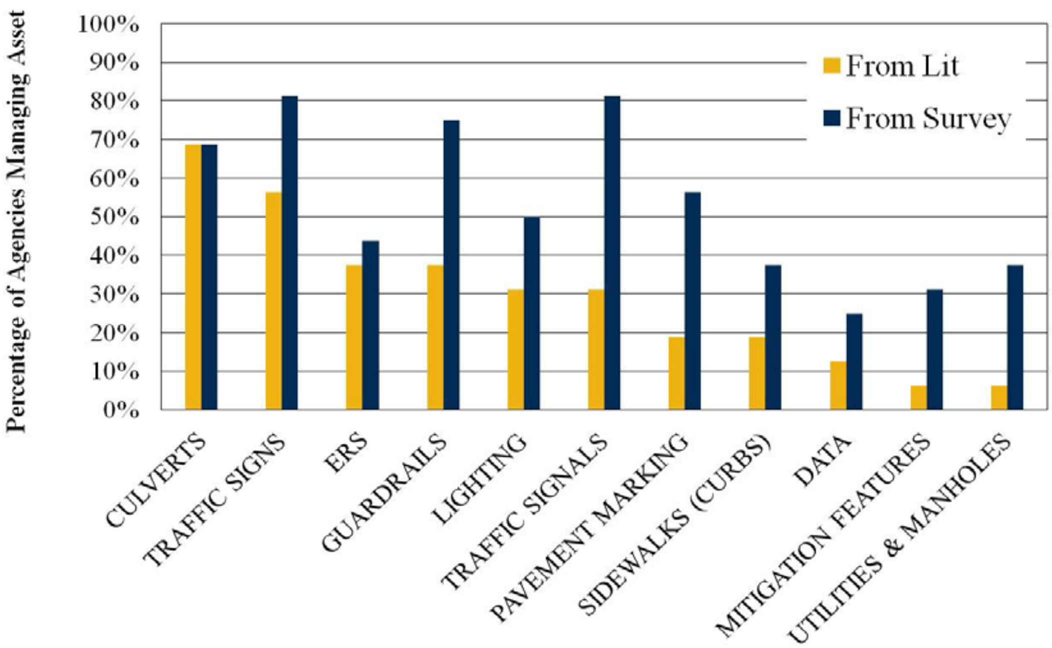

FIGURE 3.3 Comparison between literature and survey for assets managed.

The results seem to reinforce each other as the survey results in each case either equal to or exceed the literature review results, with the exception of the culverts data. This could be interpreted as the surveyed agencies having developed their ancillary and information asset management activities either to the extent reported in the literature or beyond and above what was found in the literature. In instances where what was reported in the literature did not match what was found in the survey, a follow up survey was done to clarify the actual status ancillary asset management in the agency to ensure that what was reported in the survey conformed to the actual programs, procedures and systems within the agency. Where no alignment was found between the literature and survey results, adjustments were made in a follow up interview or the information was not included in the analysis. Information for two agencies was not included as a result of discrepancies between what was reported in the literature and survey.

The number of agencies from the literature review results is different from what was reported in Figure 2.1 because only the 16 agencies responding to the survey are used to calculate the percentages. With the exception of culverts, there were a higher proportion of agencies managing each asset reported in the survey results than in the literature. This indicates that discrepancies exist between the literature and survey results, which could either mean that literature on ancillary transportation asset management is outdated and agencies are managing more assets than they did in the past (which is logical); that the state-of-practice has historically not been comprehensively reported; or that there has been a reduction in the level of agency activities previously reported. Besides the actual numbers being higher, the overall trend of most managed assets also changed from the literature to the survey, making traffic signs and signals the most managed, as opposed to culverts. In the same way, as opposed to mitigation features and utilities and manholes being the least commonly managed assets in the literature, the survey results indicate that data is least commonly managed by the agencies surveyed.

The survey results indicate that agencies are placing more emphasis on formal management of roadway safety assets: traffic signs and signals, guardrails, pavement marking and lighting.

3.1.3 Data Integration

Data integration in asset management systems is important due to the large quantities of data used in these systems. It is "the process of combining or linking two or more data sets from different sources to facilitate data sharing, promote effective data gathering and analysis, and support the overall information management activities in an organization" (Li and Madanu, 2008). Data integration and the integration of other asset management functions allow for effective data sharing across and within agencies, and more holistic decision making in the face of shrinking resources and other constraints (Li and Madanu, 2008). Four (25%) agencies reported that they have fully integrated asset management systems for the assets they manage; however, it was not clear if integration occurs at only the database level or at both database and data analysis levels. Another five (31%) reported that they have some assets integrated into one database, with others still managed independently. Generally, a number of the responding agencies indicated a transition towards integrated systems to be completed within months of the survey.

3.1.4 Population of Data Inventories

In order to identify best practices in managing ancillary transportation infrastructure, it is important to consider the proportion of all the existing assets that are included in management systems. Agency representatives obtained this information by contacting their respective database managers or asset management team leaders. These numbers are generally ballpark estimates of the extent of data collection for the inventory. This information was difficult to obtain from survey contacts; very sparse and incomplete responses were given in most cases. As shown in Table 3-1, the ranges of values vary for each asset class. As shown in the table, all the average values are greater than 50% indicating that the agencies reported that more than half of their asset base has been inventoried, on average. Additionally, all median values are greater than 70% with the exception of pavement markings. For almost all of the asset classes, the most frequently occurring percentage of the assets included in formal management systems is 100% indicating that most agencies reported that they have taken account of all the assets within their jurisdiction.

TABLE 3-1 Percentage of Assets in Management System for Respondents Indicating Asset Inclusion in System

Asset Class	# of Reporting Agencies	Mean	Median
Culverts	8	69.1%	72.5%
Data	1	100%	100%
Earth Retaining Structures	7	70.7%	90%
Guardrails	8	81.6%	100%
Street Lighting	6	95.8%	100%
Mitigation Features	3	96.7%	100%
Pavement Markings	5	66.6%	50%
Sidewalks (& Curbs)	4	97.5%	100%
Traffic Signals	10	96.0%	100%
Traffic Signs	10	83.8%	100%
Utilities & Manholes	4	85.8%	96.5%

3.2 Asset Management Guiding Principles

Agency goals and policies for asset management provide guidelines for consistent evaluation of asset management systems (FHWA, 1999). Furthermore, these goals establish a uniform understanding of the purpose of managing assets for decision makers and the general public. Four (25%) of the agencies responding to the asset management survey of practice indicated the existence of a program statement or some guiding principles. For some agencies, policies exist for some of the asset classes they manage. For others, while no formal statement exists; general goals are apparent and communicated throughout the agency. By and large, agency goals whether documented or not, center around optimizing operational efficiencies, maintaining assets at or above minimum levels of performance for their useful life, and providing a basis for data-driven resource allocation recommendations and decisions considering condition, performance, life-cycle costs, benefits and risk.

3.3 Data Needs & Data Collection Costs

In agreement with the findings from the literature, data collection practices vary from agency to agency; however, in general, agencies collect data on the asset type, location, installation details, components and condition, for use in their systems. Most agencies have employed some form of geographic information system (GIS) or global positioning system (GPS) technology in referencing assets by location. Inventory data collected includes this location information and other general details such as asset type, geometric information and, in some cases, digital photographs. On the other hand, performance data varies by asset and are driven by the measures used to assess performance or predict service life. The frequency of inventory and inspections also varies by asset and by agency as shown in Table 3-2. The table shows ranges of data collection frequency schedules as reported by survey respondents. For a number of assets and agencies, inspections had only been performed only once since the implementation of the management system.

TABLE 3-2 Ranges of Data Collection Frequency as Reported in Survey Responses

Asset Class	Data Collection Frequency
Culverts	1 – 5 years
Data	Weekly – Annually
Earth Retaining Structures	2 – 5 years
Guardrails	1 – 2 years
Street Lighting	1 – 5 years
Mitigation Features	1 – 5 years
Pavement Markings	1 – 5 years
Sidewalks (& Curbs)	Continuous, 5 years
Traffic Signals	1 – 5 years
Traffic Signs	1 – 2 years
Utilities & Manholes	Irregular, 5 years

The tools used in data needs and cost assessment are another important determinant of an effective asset management system. Twenty-eight (28) different data collection methods were reported by agencies with some repetition. Visual inspection is by far the most common inventory and condition assessment technique used by the reporting agencies. This is followed closely by the use of contracted services for collecting data in whichever way the contractor chooses, especially in the case of the utilities and manholes asset class. Other data collection techniques are listed in Table 3-3. As shown, there were variations in some of the methods used; for example, two agencies specified that their data collection involved field collection with verification through GIS and GPS tools as opposed to a simple visual inspection. In another case, some agencies used mapping grade GPS while others used resource grade GPS, which are variations of GPS technology with different levels of precision and accuracy.

TABLE 3-3 Data Collection Techniques for Ancillary Transportation Assets

Aerial Photographs	Microsoft Access Forms
Capture at Installation	Mobile GPS Equipment
Contractor Services	Optical Observation Technology
ESRI ArcCatalog Metadata	Other GIS Metadata
Features Attributes & Conditions (FAC)	Photo/Video logging
Field Collection & Verification	Pontis Data Collection
Field Laptops	Resource-Grade GPS
GeoResults Mobile by Marshall	Retroreflectometer
Google Streetview	Trimble Data Loggers
Handheld Scanner	Troux Software
Information obtained from Utility Providers	Unspecified Metadata
Infrastructure Plan Sheets	Unspecified Mobile Device
Manli System	Visidata
Mapping-Grade GPS	Visual Inspection

In terms of data collection costs, findings revealed that many agencies either do not estimate data collection costs or were not willing to give out that information in their survey responses. Without cost data, it is impossible to quantify the overall and marginal benefits of implementing an asset management system or determine accurate funding needs for implementation. Nonetheless, the limited cost data obtained are summarized in Table 3-4. In all cases, no distinction was made between inventory and condition assessment data collection; however, for culverts, one agency reported spending about \$140 per asset, while another reported about \$200. For guardrails, data collection was estimated at \$40 per mile of roadway. Similarly, for street lighting, two agencies reported spending \$100 and \$280 per structure (or unit) for a condition assessment. One agency reported data collection costs for traffic signs to be at about \$350 per structure or \$500 for dynamic message signs. Finally, another agency estimated pavement marking data collection at \$4 per lane mile. Where contracted services are used for data collection, the contractor determines the cost, as in the case of utilities and manholes. Ultimately, data collection costs will be driven by the technique used to collect the data, the type and amount of data collected, and the frequency of data collection.

TABLE 3-4 Costs of Data Collection

Asset Class	Average Cost Provided
Culverts	$140 - $200 per unit
Guardrails	$40 per mile
Street Lighting	$100 - $280 per unit
Traffic Signs	$350 per structure ($500 per DMS* structure)
Utilities & Manholes	Determined by contractor
Pavement Markings	$4 per lane mile

**DMS – dynamic message sign*

3.4 Data Analysis and Use

Data analysis tools are important for an asset management system because their capabilities determine the extent to which the data collected can be used effectively. For the states surveyed, 36 different database systems and analysis tools were reported, which included variations of the same concepts. For example, various agencies use different modules of Oracle database systems (e.g., Oracle Maintenance Management System vs. Oracle Work & Asset Management). Several agencies indicated the use of GIS, sometimes specified (ESRI ArcGIS) and other times referred to more generally. Other common analysis tools were Microsoft Office programs such as Excel and Access. A number of independent software solutions were noted as well. Table 3-5 shows the different database and analysis tools being employed by the agencies surveyed.

Data use in the decision-making process depends significantly on the data collected and the capabilities of the analysis tools used. Consequently, agencies apply asset management data in a variety of ways. However, the most common application is in the development of either general agency budgets or specific asset replacement budgets. In some cases, in-house tools have the ability to project future asset performance at different funding levels and can predict when an asset is likely to be replaced. When management systems are effectively integrated, geographic information can be used to guide how to be efficient in replacing multiple assets (or asset classes) at the same location, at the same time. Many other agencies use their asset management data in project prioritization and in the selection of rehabilitation candidates. Where age is being used as the performance measure for asset replacement, agencies use this data to inform decisions on asset maintenance and replacement and to estimate costs specific to a defined treatment year. Generally, asset management data is also used in answering specific questions about the transportation system or specific assets, without applying a formal approach.

As agencies consider expanding their existing asset management programs, the question of the best way to phase in different asset classes can be important, given funding limitations. Increasingly, agencies may have to make a business case to justify expenditures of funds to bring different asset classes into formal asset management programs. Agencies that can place priorities on investing in the assets that bring the highest benefits to their customers per unit dollar spent, and reduce customer and agency risks most significantly, would be making superior decisions in comparison with those that go about expanding their systems without systematic thinking about which assets must be prioritized for formal asset management in the face of limited funds. The survey findings indicate that agencies have not made efforts to quantify the benefits achieved from the implementation of a management program for any of the eleven categories of assets. Data on the benefits of managing other transportation assets such as agency vehicles were available for one agency responding to the survey. In many regions, individual agency analyses have shown the benefits of priority programming over a worst-first or need-based approach to asset rehabilitation, as reported in the survey.

TABLE 3-5 Database and Analysis Tools Employed in Ancillary Transportation Asset Management

Adaptable Database System (ADABAS) by Software AG	Maintenance Rating Program
AgileAssets	Microsoft Mobile
Exor Management Software	Microsoft Access
Bridge Management System	Microsoft Excel
Cartegraph	Unspecified Oracle Product
Custom-Built (in-house) System	Oracle Data Warehouse
Deighton	Oracle Maintenance Management System
Demand model to determine maintenance need	Oracle Work & Asset Management (WAM)
ESRI ArcGIS	Paper Forms/Records
FileMaker Pro	Plant Maintenance Module by SAP AG
GeoResults Mobile GIS by Marshall	Pontis
Unspecified GIS Geodatabase	Project Scoring System
Hansen v.8 from Infor	Roadway Characteristics Inventory
IBM DB2 Enterprise Server	Sign Deterioration Curves
IMF Mainframe System	SQL Server/Database
Legacy DB II on Mainframe	Toad for Oracle
Level of Service Analysis	Utility Franchise & Permits: Power Builder
Maintenance Level of Service (MLOS) Module by SAP AG	Utilities Module by SAP AG

Overall, these findings indicate that a framework that quantifies the relative benefits and costs (including risks) of systematic management programs for ancillary roadway and other transportation assets could help agencies prioritize their limited funds to areas that promise the highest returns and risk reductions. Where agencies have limited funds, such efforts can guide the use of limited resources for more effective outcomes, making explicit the existing tradeoffs and opportunity costs associated with investing in asset management capabilities for certain asset classes versus others. This way, a more systematic approach could be taken toward expanding existing asset management capabilities, with more effective outcomes with respect to an agency's strategic objectives.

3.5 Case Studies

From the results of the initial survey and interview process, certain agencies stood out as agencies that were not only responsive to requests for information on their asset management programs, but were making notable gains towards improving their management of ancillary assets. These agencies were contacted for a second round of interviews with more detailed questions on the goals of their respective asset management programs, any measured benefits relating to performance measures identified, and the method used to prioritize asset classes for inclusion in their systems. As expected, answers were not obtained for all three questions from all the agencies; however, the summaries below provide some idea of asset management of ancillary transportation infrastructure as conducted in these agencies. Each case study begins with a description of the vision/mission and values of the agencies in order to provide some context for understanding their progress and performance in ancillary asset management.

3.5.1 Colorado Department of Transportation (CDOT)

According to their website, the vision of the Colorado Department of Transportation (CDOT) is "to enhance the quality of life and the environment of the citizens of Colorado by creating an integrated transportation system that focuses on safely moving people and goods by offering convenient linkages among modal choices" (CDOT, 2011a). Their values include safety, people, integrity, customer service, excellence and respect. The Department is responsible for a 9,146 mile highway system which includes 3,447 bridges. Although this system accounts for only about 10 percent of the total mileage on the state system, it covers about 40 percent of all travel in the state.

CDOT manages its major assets with independent software solutions and staff. Pavements are managed with Deighton dTIMS CT software (dTIMS CT); bridges are managed with Pontis, and maintenance fleet equipment, Intelligent Transportation Systems (ITS) and Maintenance Levels of Service (MLOS) are managed in two different modules developed by SAP AG, a German software corporation. A representative from CDOT responded to the initial survey, indicating that asset management practices are in place for ten out of the eleven classes of assets under consideration, leaving out sidewalks and curbs. CDOT's management of their assets are partially integrated with signs, signals, guardrails and pavement markings in Group 1 (pavement is managed in dTIMS, CTI, others in SAP MLOS module) and earth retaining structures, and culverts in Group 2 (with bridges in Pontis). Data is managed in multiple systems. The dTIMS CT software has the capabilities to manage multiple assets and perform projections and CDOT is looking to use it to cross-manage all five categories of assets that are currently managed in different systems. For now, the ancillary assets are managed in the MLOS system that involves an annual physical rating with nine maintenance program areas that are evaluated on a scale of A+ though F-, similar to an academic grading system (CDOT, 2011b). The ratings assigned are then applied to a modeling system that provides cost matrices to identify budget requirements to achieve the target maintenance level of service. In addition, this system is able to project asset performance for future years at different funding levels. Through a separate system, the maintenance fleet equipment is able to predict when the asset is likely to be replaced or has reached its full useful life.

In terms of goals and objectives of the system, CDOT has four investment categories which provide the framework for resource allocation within the Department. They are safety, system quality, mobility and program delivery. Use of the MLOS system fits under the system quality objective, according to the 2012 fiscal year budget narrative, and the goal is to achieve a B level of service grade (CDOT, 2011b).

Although the total number of each asset was not available during the interview, CDOT reported that each management system contains 50 – 100% of the total inventory of each asset. The only exception was with water quality mitigation features, in which case inventory was in development at the time of the interview. Data collection tools for these assets vary from contractor data acquisition (guardrails) to human observation or optical observation technology. In the case of traffic signs and signals, data collection varies by region but is often done by personal (visual) observation. Similarly, the inventory and attribute data collected varies by asset but generally includes basic inventory data (such as location, features of the asset) and attribute data related to the performance of the asset. The only available estimate of data collection was $128,000 spent on guardrails, pavement markings, traffic signs and traffic signals. Inspection frequency ranges from one to four years, or on a rolling basis, or as required by regulations such as for bridge inspections.

CDOT has made a few attempts at quantifying the benefits of ancillary asset management. For one thing, the operational savings for replacing fleet equipment assets at a certain age as opposed to another have been recognized, as have time savings from managing ITS elements. Specific benefit-cost analysis related to the asset data management has not been attempted for decision makers at CDOT.

3.5.2 Oregon Department of Transportation (ODOT)

The vision of the Oregon Department of Transportation (ODOT) is to "provide a safe, efficient transportation system that supports economic opportunity and livable communities for Oregonians" (ODOT, 2011). Their values include safety, customer focus, efficiency in the use of resources, accountability, problem solving, diversity and sustainability. ODOT uses performance measures with annual targets, which indicate progress towards their goals of safety, mobility, preservation, sustainability and stewardship. Progress is reported on their website, annually.

In 2006, ODOT embarked on a pilot study to determine the state's readiness for an asset management program that included nine of the eleven asset classes of interest in this study. The study was an analysis of four highway segments as a sample to learn what was known and the "level of effort required to gather [and integrate] existing or new information" (Wipper, 2007) in order to make recommendations for broader asset management implementation. In March 2008, an Asset Management Program Plan was created, mapping out initiatives, policies and goals to direct ODOT's steps towards successful asset management (ODOT, 2008).

ODOT currently manages nine out of the eleven asset classes under consideration, with the exception of data and utilities and manholes. At the time of the initial interview, the current mainframe-based highway network information system was being replaced with a new system (Exor) that would allow for better integration and a place for additional data for different asset classes. This new system is also more robust and allows tracking of the network for modeling and a more comprehensive understanding, among other options. It was estimated that the asset databases include about 100% of previously existing and new inventories, with the exception of earth retaining structures (20%), pavement markings (50%) and culverts (10%). Data collection for these systems is achieved with mobile GPS equipment and digital video logs. The data collected is commonly available to ODOT staff through the Features Attributes and Conditions Survey – Statewide Transportation Improvement Program (FACS-STIP Tool), which integrates any possible data in preparation for actual data use in project scoping and decision making.

From the survey/interview results, ODOT's efforts seem to be focused more on building the capacity of their asset management program and less on quantifying the benefits at this stage. Nonetheless, it was reported that asset inventories can be performed about five times faster than before and with greater reliability in the data collected. Data is now easily accessible in five minutes or less from one primary source as compared to previous allowances of eight weeks due to multiple individual requests. On the topic of asset class prioritization, asset values, level of risk, safety and mobility were used to determine priorities for the 2006 pilot. As of the summer of 2011, ODOT was in the process of developing a more extensive prioritization framework which considers the criticality of asset classes for mobility, operations, safety, stewardship and other measures, using a Multiple Attribute Utility framework. Risk factors are also included in this framework. Overall, ODOT has made clear and visible steps towards making asset management of all their linear and non-linear assets a priority and a part of agency culture.

3.5.3 Virginia Department of Transportation (VDOT)

The Virginia Department of Transportation (VDOT) is "responsible for building, maintaining and operating the state's roads, bridges and tunnels" (VDOT, 2011). The mission of this agency is to maintain a transportation system that is safe, enables effective transportation, enhances the economy and improves the quality of life of the citizens of Virginia, with values that include responsiveness to customer needs, commitment to safety, mutual trust and respect, respect of public investment, sound judgment and accountability, professional development and forward thinking.

In 2007, the Commonwealth Acts of Assembly established a framework which required VDOT to report "the condition of and needs for maintaining and operating the existing transportation infrastructure based on an asset management methodology" (VDOT, 2007). This report, to be published every odd year, was to extend beyond pavements and bridges to technology assets, pipes and draining, congestion management and other structures.

Asset management is defined in the *Code of Virginia* and is based on goals which include: (a) managing assets based on a life-cycle cost analysis approach; (b) developing and implementing performance measures as a basis for identifying and prioritizing needs; (c) developing predictive models that link inventory, utilization and environmental conditions to asset condition and system performance, to generate performance-based needs assessments; and (d) employing processes to plan, budget, implement, monitor and measure performance. (VDOT, 2007)

According to the survey responses, VDOT conducts systematic asset management efforts for six of the eleven asset classes: traffic signs, street lighting, guardrails, traffic signals, culverts, and sidewalks and curbs. These are all managed in a system that is used to track work done on these assets; however, it is not considered a full-fledged asset management system. Nonetheless, the overall goal is to preserve and extend the useful life of the assets. At the time of the survey, VDOT was using spreadsheets and an oracle database, which did not have performance modeling, planning, budgeting or inventory management capabilities. However, there were plans to procure a new commercial software application with these capabilities to turn the system into a full-fledged asset management system. Inventory of their assets is mostly collected by contract, but in some cases, by state employees. It includes basic data such as the location and physical description of the assets. Inspections of the assets have been performed once overall in all cases, with the exception of culverts which are collected every two years for the National Bridge Inventory (NBI). Although not a fully functioning asset management system, the data collected have been used in some capacity to influence the budgeting process at VDOT, but the benefits of this use have not been documented or formally quantified.

Although benefits have not been formally measured, VDOT determines the benefits of their program by realizing that better information gives more accurate forecasts with better data quality. The data they would use includes the time to enter data or create work requests, time to find data for analysis and the general effectiveness of data. In prioritizing the asset classes, data were collected on eight assets that the most amount of money is spent on. In order to improve these processes, VDOT acknowledges that goals need to be defined with benchmarked performance measures or measures of effectiveness, which are influenced from the higher level of the purpose of the asset. Previously, the performance measure used was the percent of inventory in a condition requiring repair; however, it is important to know the relationship between output and outcome measures in order to more effectively use condition for decision making.

For VDOT, several steps are being taken to ensure the Department reaches a level of success where decisions are informed by the systematic collection of asset condition and performance data.

3.5.4 New York State Department of Transportation (NYSDOT)

The mission of the New York State Department of Transportation (NYSDOT) is to provide a "safe, efficient, balanced and environmentally sound transportation system" (NYSDOT, 2011) for the roadway users. Their values include integrity, customer service, partnership, teamwork, people and excellence. The Department's inventory includes about 38,000 lane miles of pavement markings, 23 million feet of guardrails, 3000 miles of sidewalks and 45,000 curbs (ADA ramps), 7500 small culverts and 75,000 large culverts, 6000 traffic signals and 750,000 traffic signs.

At the time of the survey, NYSDOT was conducting systematic asset management efforts for seven out of the eleven asset classes: earth retaining structures, traffic signs, guardrails, traffic signals, culverts, mitigation features and sidewalks and curbs (ADA ramps). For the beginning stages of their asset management system, NYSDOT has had statewide inventory data for traffic signals, culverts, and sidewalks and curbs; however, the inventories for the other assets are not statewide. In terms of mitigation features, the agency manages settling ponds, wetlands and outfalls. Each of these systems is loosely connected, but there is no consistent integration. Although no formal policy or program statement exists, some FHWA mandates and regulations, for example for retro reflectivity of signs and pavement markings, drive the asset management effort. In the case of mitigation features, New York State Environmental Conservation regulations mandate their management.

In terms of software, NYSDOT uses a combination of Microsoft Access databases, GIS geodatabases, Cartegraph and Oracle. These databases contain 90 to 100 percent of all traffic signals, sidewalks and curbs and small culverts, about 40 percent of all large culverts, but only about 15% of earth retaining structures, guardrails and traffic signs. The data are collected with field collection techniques using laptops, paper forms, photologging as well as Roadware Visidata. Asset inspections vary from annually to every 4 years, with continuous inspections of sidewalks and curbs.

In terms of data use, individual analysis is performed for some regional maintenance or capital programming, but the main use is in the maintenance and operations plan (MOP). The MOP is a tool that is able to estimate the capital improvements needed to achieve a state of good repair for the assets, based on investment needs.

Although the benefits of NYSDOT's asset management have not been quantified, the agency reports to have shown benefits to this form of programming for maintenance over a worst-first approach. Even though the asset management program is not fully developed for these assets at NYSDOT, a request for proposals for an enterprise asset management system has been developed, with the goal of eventually obtaining a fully integrated asset management program for the Department.

3.5.5 Synthesis of Case Studies

These four case studies show various levels of progress with managing ancillary transportation assets. They also indicate the possibility of a range of different costs and benefits for any particular asset management program as the program evolves in maturity. This finding indicates that there is value in developing the data and analytical capabilities to assess benefits and costs of asset management systems as they evolve on the maturity scale, in particular to determine whether the evolution of these systems is in the right direction. Agencies must however be cautious with using snapshot benefit-cost evaluations to make conclusive decisions on the value of asset management systems or programs as these benefit-cost numbers are bound to change as the systems or programs evolve in maturity.

The four cases also provide evidence that Transportation Asset Management is an evolving practice: not only are the different agencies at different stages in developing asset management systems, these systems are tailored to their particular needs, cultures and constraints and continue to be improved to meet their needs better. From this evolution one could infer that the benefit-cost ratios of asset management systems are likely to be higher as the systems approach a higher level of maturity. Benefit cost analysis could thus be applied more appropriately periodically to asset management systems to determine whether the systems are evolving in the right direction, i.e., such that the marginal benefits outweigh the costs of incremental changes to the systems.

The case studies also indicate that agencies that evaluate the effectiveness of their asset management systems in relation to their strategic goals are more likely to evolve their systems to help them achieve these goals. For agencies with clear strategic goals then, assessing the effectiveness of their asset management systems or programs cannot properly be done outside the framework of their strategic goals. In the case of ODOT, a Multiple Attribute Utility Framework is being used to incorporate strategic goals to prioritize assets for inclusion in a formal management program. Risk can be included as a factor in such a framework.

The case studies also indicate that benefit cost evaluations of asset management systems may be misleading as agencies may collect data but not use such data effectively in decision making, or data may be outdated. In both cases, the results of a benefit cost analysis would not reflect the actual capabilities of the system. To be meaningful, benefit cost evaluations of asset management systems must be coupled with the actual capabilities and effectiveness of use of the systems.

4 Prioritizing Assets for Inclusion

4.1 What it means to Prioritize Ancillary Assets for Formal Asset Management

Adopting risk as a management decision-support tool for transportation infrastructure systems offers several benefits. For one, prioritizing ancillary transportation assets for inclusion into existing asset management systems using risk enables transportation agencies to better balance limited funds to provide adequate levels of service for their customers. In addition, risk management facilitates the efficient allocation of limited transportation resources. Resources are often directed to the highest-risk assets after the agency evaluates their associated risks. That is, within an asset class, risk management can be used to optimize the "return-on-investment" of competing assets for a single objective analysis. However, in the case of multi-objective analysis, it is challenging for agencies to achieve this goal. In situations in which different objectives are under consideration, one may have to perform trade-off analyses and not focus solely on optimizing the "return-on-investment." The effective mitigation of such risk leads to the reduction of the likelihood of risk events. Reduction of event likelihood in turn translates into reduced failures. In addition, effective risk mitigation strategies also lessen the consequences associated with the failure of an asset.

Another benefit of risk management is that it can enable asset managers make a better case to decision makers for resources. By quantifying or assessing the probability of failure and consequence of failure of an asset, that is, estimating the risk of failure, asset managers are able to justify why more resources should be made available to manage failing assets. In addition, responses to situations are made quicker in the event of a failure. Knowing the magnitude of the risks associated with the failure of an asset, agencies are able to put in place strategic response procedures for any envisioned failure. This benefit is much more critical for catastrophic failures. This is because the probabilities of such failures are difficult to quantify, and if such failures do occur, they should be managed proactively as opposed to being addressed reactively.

4.2 Using Risk Factors to Identify Critical Assets

4.2.1 Risk Concepts

To better understand the application of risk in prioritizing ancillary transportation assets for management, a few concepts of risk are discussed. The following concepts would enable the asset manager apply risk with an in-depth understanding of the underlying principles of risk.

4.2.1.1 Risk and Uncertainty

Technological systems can be made more useful in asset management if they incorporate the risk pertaining to the physical assets. The potential for negative events and consequences constitute opportunities for risk. In the context of safety, risk is viewed as a negative consequence. Thus, the focus of risk management is to mitigate the negative consequences. Risk can be defined in various ways depending on context. Despite the variations in all the definitions, they all acknowledge two main characteristics related to uncertainty and consequences. The *Merriam-Webster's Collegiate Dictionary* defines risk as the chance of loss, the degree of probability of loss, the amount of possible loss, or the type of loss that an insurance policy covers (2003). In the literature, the definition of risk usually makes reference to an uncertain cause that results in some sort of damage to an existing entity. This uncertain cause is usually referred to as a risk event. In the context of technical risk event analysis, a numerical value is assigned to the risk (Lofstedt and Boholm, 2008). This value is obtained by multiplying the probability of the risk event by the consequence of the event. However, the formulation of risk in this form for decision making fails to incorporate the societal dimensions of risk (i.e., the political and ethical dimensions of risk are not taken into account) (Lofstedt and Boholm, 2008). In the decision-making process, risk assessment is defined as a systematic process that incorporates the evaluation of uncertainties, the development of policies, and the possible consequences of such policies (Haimes and Jiang, 2004).

Uncertainty rises as a result of sparse data availability and incomplete knowledge in the decision-making process (Piyatrapoomi, et al., 2004). Uncertainty also exists as a result of the inherent randomness associated with systems and events (Helton and Burmaster, 1996). It can be attributed to three different types of errors in risk-based decision making for infrastructure: data errors, modeling errors, and forecasting errors. Amekudzi and McNeil, for example, demonstrate the impact of data and model uncertainties associated with highway investment needs analysis, showing how forecasting and other errors can impact funding and performance estimates (2000). Other studies have also shown how optimal maintenance programs can be impacted significantly with small adjustment to their input parameters (AASHTO, 2001). In fact, the level of confidence in the decisions made from the use of these outputs should depend in part on how accurate the input data is. Although these errors could be reduced through the use of statistical models, the extent of reduction of these errors is limited (Piyatrapoomi, et al., 2004). Reducing uncertainty helps to represent risks with increasing levels of confidence; however there are associated costs. Pate-Cornell discusses when and why a full uncertainty analysis is justified because of the complexity and cost involved (Pate-Cornell, 1996).

4.2.1.2 Likelihoods and Consequences

As mentioned above, risk is measured in terms of likelihoods and consequences. The probability of occurrence of some future event can sometimes be calculated precisely with no uncertainty. Other rare future events, however, are forecasted or predicted with a considerable amount of uncertainty. The level of uncertainty inherent in the forecasting process gives rise to risk. Kaplan and Garrick define risk to be a set of scenarios, s_i, each with probability p_i and consequence x_i. If the scenarios are ordered in terms of the increasing severity of the consequences, then a risk curve can be plotted (Kaplan and Garrick, 1981). Another refined notion of risk by Kaplan and Garrick talks about the frequency with which an event might take place instead of using the probability of occurrence of the event. In this context, they introduce the notion of uncertainty about the frequency with which the event will occur (i.e., the "probability of a frequency") (Kaplan and Garrick, 1981).

One challenging factor in measuring risk is the inability to precisely quantify all resulting consequences. Despite the fact that the cost of replacement or repair, or the maintenance cost of some assets may be easily quantified and incorporated in the consequences quantification process, other costs such as societal costs may be very difficult to estimate**. To help agencies understand the consequences associated with the failures as they occur, agencies need to track asset failures and collect appropriate data. Again, accurate tracking would also enable agencies to quantify the likelihoods/probabilities of failure of these assets in the future. Both of these factors would facilitate the risk categorization process. An agency that tracks the condition of its ancillary assets and implements strategic management actions is likely to benefit from the reduction/elimination of unexpected failure of these assets as well as saving on emergency repairs resulting from the unexpected failures.**

4.2.1.3 Types of Risks

The consequence of a risk occurrence differs depending on the type of failure an asset experiences. Ancillary transportation assets are subject to numerous types of failure that can be grouped under various categories. Two common types of failure are catastrophic and non-catastrophic (performance) failures, which result in two types of risk. One is catastrophic risk, which results when a catastrophic failure occurs. Catastrophic failures are failures that are caused by the occurrence of extreme events, which are defined as having a low likelihood of occurrence but with catastrophic results (AASHTO, 2001). Examples of such events are earthquakes, hurricanes, and floods. The probability of occurrence and the consequences of such failures are termed catastrophic risk. An example of a catastrophic failure is the collapse of a section of the retaining wall in hilly northern Manhattan onto the Henry Hudson Parkway in 2005, sending tons of dirt, rocks, and trees onto the roadway, stopping traffic for miles around, and leading to the evacuation of nearby buildings (Pate-Cornell, 1996). The other type of risk is non-catastrophic risk, which results from the occurrence of non-catastrophic or performance failures. This type of failure is caused by the inability of an asset to properly offer the service for which it was built. Any reduction in operational performance below the minimal level of service is referred to as a performance failure. Thus, the probability of occurrence and the consequence of such failures can be termed non-catastrophic or performance risks.

4.2.2 Risk Assessment and Management Framework

In light of the literature reviewed for this study, this section discusses basic elements of a risk-based framework that can help asset managers and decision makers to rank and prioritize ancillary transportation assets for inclusion in existing asset management programs. The section discusses seven basic risk elements that can form the basis of a conceptual framework to properly make a business case for complementary or competing assets to prioritize them for inclusion in an existing formal asset management program. These elements are common in various risk management processes. Figure 4.1 shows the conceptual framework.

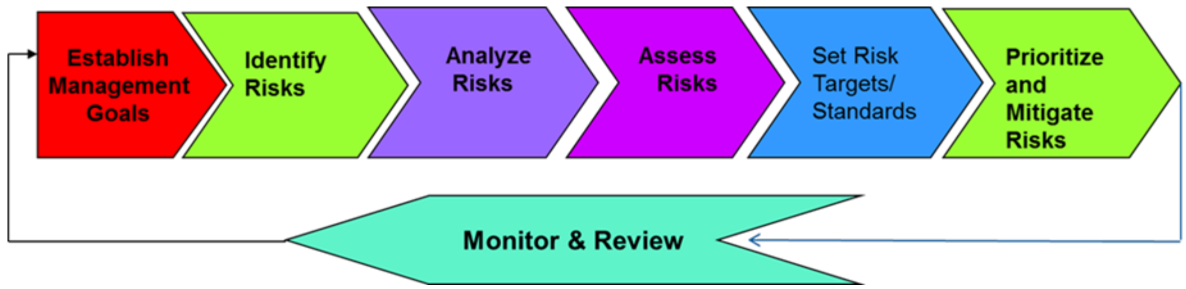

FIGURE 4.1 Conceptual Risk Framework for Decision Making

Identifying management goals is one of the most important steps in the risk management process because objectives must exist before management can identify potential actions to achieve these objectives. Within the context of the agency's established mission or vision, strategic objectives and written policies must be aligned. The focus of the agency then becomes working towards the achievement of these objectives.

The next step after identifying management goals is identifying risks. The objective of the risk identification process is to identify all the assets foreseen to be at risk with respect to the agency's strategic short-term and long-term goals. The identified assets are examined to identify any failure scenarios (i.e., identifying what can happen to the asset of interest). The causes of such scenarios are also identified. The risk identification process exposes and records all foreseeable risks that could affect the agency's achievement of objectives.

After risk identification comes risk analysis. The risk analysis process accomplishes two objectives: determining the likelihood and consequence of failure. That is, the risk analysis process is a comprehensive and systematic process of breaking down risk into its underlying elements. This process presents a few challenges due to the limited availability of condition or historic data for many ancillary assets. This limitation makes the determination of probabilities and consequences of failure very much subjective. However, elicitation of expert knowledge and engineering judgment can aid the decision making process.

After analyzing the risk, likelihoods and consequences are then converted into risk numbers. Depending on the risk modeling approach adopted in the analysis process, the resultant risk of each asset is ascertained. This process basically quantifies and categorizes the risks so that they can be ranked. The ranking identifies which asset is of extreme, high, moderate or low priority. Indeed, the risk assessment process can require as well as provide both qualitative and quantitative data to decision makers for use in risk management. Table 4-1 illustrates four categories of risk zones as identified by Najafi and Salem for culvert management (Najafi, et al., 2008), and Table 4-2 also illustrates different categories of risk effects that result as a consequence of non-maintenance of highway assets (Dicdican, et al., 2004).

TABLE 4-1 Sample Risk Categories (Najafi, Salem, Bhattachar, Salman, Patil, & Calderon, 2008)

General Appraisal	Risk Zone
9,8	Routine maintenance sufficient, no repair required
7,6	Culvert needs repair
5	Culverts needs several repairs or renewal
4,3,2,1,0	Culverts needs to be renewed or replaced

TABLE 4-2 Categories of Risk Effects and Most Likely Consequences Resulting from Non-Maintenance of Assets (Didican et al., 2004)

Risk Effect	Examples
Critical	Multiple fatalities Multiple injuries Complete loss of service Loss of military mobility Total area inaccessibility Major traffic disruption
Moderate	Partial loss of services Partial lane closure Moderate number of fatalities Moderate number of injuries
Minor	Slight increase in maintenance costs Temporary traffic disruption

Once the risk is assessed, the agency will have to define the thresholds for acceptable risk. This is normally dependent on the agency's and public's attitude toward risk. Risk can be perceived differently by the society or different segments of the society. Aktan and Moon explain how society is more willing to tolerate the risk of a traffic accident than the risk of a bridge failure due to natural events. The risk of a traffic accident, however, is far greater than the risk of an earthquake (Aktan and Moon, 2010). Starr also suggests that the degree of voluntariness affects the trade-off between risk and benefit (Starr, 1969).

For a given set of risks and their ranking from the risk assessment step, the next phase of the risk management process is to select a comprehensive strategy for mitigating the risks in a cost-effective manner. In essence, the objective of this step is to make the best use of limited resources to maximize the benefits of investment while minimizing the risks to the general public using the assets under consideration, taking into consideration the risk attitude of the users of the system. Any suggested mitigation activities must take into account cost, time to implement, likelihood of success, and impact over the entire life-cycle of the asset. A risk mitigation strategy must be constrained by management's short-term and long-term goals. The strategy must also directly identify monitoring procedures that can be used to demonstrate that the risks have been properly mitigated.

The risk management process is not a unidirectional process. The process is a continuous feedback loop. Each phase of the risk management process should be reviewed against and aligned with the objectives of the organization. Management objectives/goals are used to monitor the performance of the process. This process answers a fundamental question: did you meet management goals? If not, the whole process starts over again. This check turns the risk management process into a cyclic event to meet management objectives. The cyclic characteristic of the risk management process helps the decision-making process to improve. In order to achieve this process, the risk framework requires interaction or collaboration and exchange of information and opinions among stakeholders (e.g., surveying the road users to determine their level of satisfaction with network performance). It often involves multiple messages about the nature of risk or expressing concerns, opinions, or reactions to risk managers or to legal and institutional stakeholders for risk management. Risk communication is a great way to define the risk acceptance levels of an agency (including the system users' risk acceptance levels) and helps define the acceptance criteria to achieve the agency's transportation network objectives.

4.2.3 Data Collection Needs for Risk Assessment and Management

Availability of quality information is critical for any risk-based asset management system. Data is necessary for setting agency objectives, assisting with the decision-making process and with project delivery, and monitoring progress toward the objectives. Data availability affects every step in the asset management process. That is, the accuracy of a model, and the effectiveness of a final decision are very much contingent on the amount and accuracy of information available to an agency during the decision-making process. In transportation asset management, accurate data is one of the driving forces that make decisions in resource allocation and utilization more effective and efficient. Information about each class of asset—age, condition, historical failure rates, and maintenance activities as well as consequences of failure to the user (user cost), the agency (agency cost), and the environment (external cost) — are very critical to risk modeling. However, information regarding ancillary transportation assets is not always available, or is not always in a suitable format. In fact, depending on the asset class under consideration, most of this data was not found to be available or in the appropriate disaggregate format for the problem at hand. For example, highway fatality statistics exist for various states, but, often, they are not categorized according to the causes of the fatalities -- that is, how many of these fatalities resulted from the collapse or failure of a culvert, guardrail, retaining wall, pavement marking, traffic sign, or highway sign. Because the proposed model does not only address fatality issues, it is also important that the other types of consequences — bodily injuries, extent of property damage, duration of closure of lanes — are also properly documented.

To address this gap in data, ancillary transportation asset management can make use of other databases (e.g., police accident reports) complemented with expert evaluations and estimations; these would be critical in the risk modeling and categorization process. Over the long-term, agencies must find ways to gather and incorporate such data regarding ancillary transportation assets in order to improve data available for risk modeling. Agencies must also establish well-defined processes for gathering and documenting failures within their transportation network. A starting point would be to develop a simple survey that acquires the needed information from other management systems available within various departments, (e.g., culvert management system, safety management system, congestion management system, sign management system, traffic management system, and mobility management system) and integrate this data into a single database for risk modeling. A sample survey is provided in Appendix C.

4.2.4 Proposed Risk Framework with Example

The purpose of the risk-based categorization process is to rank asset classes based on the differences in the risks they pose. A risk matrix modeling approach is used to differentiate the risk level of each asset category. The risk level of each asset category is differentiated based on the strategic objectives of the agency and considering a set of identified performance measures. Table 4-3 illustrates the risk matrix used to analyze a selected performance measure (i.e., safety risk) associated with an asset class, based on the probability of failure/consequence of failure concept.

TABLE 4-3 Risk Matrix

Risk Level of Performanace Measure		Safety		
		CONSEQUENCE		
		LOW	MEDIUM	HIGH
PROBABILITY	LOW	LOW	LOW	MEDIUM
	MEDIUM	LOW	MEDIUM	HIGH
	HIGH	MEDIUM	HIGH	HIGH

This generic risk matrix could be used for all of the performance measures identified by an agency (linked with their strategic objectives). For a specific performance measure and a given asset class, the risk is estimated by mapping the probability of failure with the consequence of failure. The probability of failure could be dependent on several factors such as: asset age, maintenance practices, failure modes, and operating environment. With the experts' understanding of these factors, the likelihood/rate of failure of the asset can be estimated reasonably, though subjectively. In the illustration presented below, the probability of failure is dependent on the average age and the average expected useful life of the asset class as shown in equation 4.1.

Likelihood of Asset Failure (f) = Average Age of Asset Class/Average Expected Useful Life…Eq. 4.1

Tables 4-4 to 4-7 illustrate the definition of the probability and consequence scales used in the risk matrix. The consequence scales were developed using guidelines from the consequences of failure factors identified by the FHWA wall inventory program (DeMarco et al., 2010). These factors are outlined below:

- Low or Minor: No loss of roadway; no to low public risk; no impact to traffic during wall repair/replacement.
- Moderate or Significant: Hourly to short-term closure of roadway; low-to-moderate public risk; multiple alternate routes available.
- High or Severe: Seasonal- to long-term loss of roadway; substantial loss-of-life risk; no alternate routes available.

Each of the identified asset classes is evaluated to estimate how much risk it poses for each of the identified performance measures.

TABLE 4-4 Probability Scale (DeMarco et al., 2010)

Scale	Description	PROBABILITY
3	LOW	If failure rate f < 0.5
2	MEDIUM	If failure rate 0.5 ≤ f < 1
1	HIGH	If failure rate f ≥ 1

TABLE 4-5 Safety Risk Consequences Scale (DeMarco et al., 2010)

Scale	Description	CONSEQUENCES
3	LOW	No injuries or death in 10yrs
2	MEDIUM	Property loss or body injuries in 10yrs
1	HIGH	Body injuries and death in 10yrs

TABLE 4-6 Mobility Risk Consequences Scale (DeMarco et al., 2010)

Scale	Description	CONSEQUENCES
3	LOW	lane(s) closure/delays experienced for a period (within hours, no detour required) in 10yrs
2	MEDIUM	lane(s) closure/delays experienced for a day or more (no detour required) in 10yrs
1	HIGH	Road closure for a day or more (detour required) in 10yrs

TABLE 4-7 Maintenance Risk Consequences Scale (DeMarco et al., 2010)

Scale	Description	CONSEQUENCES
3	LOW	Impacting less than 5000 ADT
2	MEDIUM	Impacting between 5000 and 25000 ADT
1	HIGH	Impacting over 25000 ADT

4.2.5 Evaluation of Asset Classes using Selected Performance Measures/ Hypothetical Data

In the absence of actual data, this section uses hypothetical data to represent fairly new, medium aged assets, and older assets to demonstrate how the proposed risk-based framework may be used in prioritizing assets for inclusion in a formal management system once the appropriate data has been collected or estimated. The risk approach is based on the use of performance measures derived from the strategic goals of the agency, and it may be applied to any number of ancillary assets in an agency's asset base. This example uses three performance measures: safety, mobility and maintenance. Each asset class was evaluated against each performance measure to establish a risk factor by considering the probability and the consequence of failure of the asset. The probability, consequence, and risk factors were all measured on a scale of 1, 2, and 3, representing high, medium, and low, respectively. In the evaluation, the scale measures were used to assess the risk differentials using hypothetical data to represent three categories of assets: fairly new assets, medium aged assets, and fairly old assets. Table 4-8 shows hypothetical data for three categories of assets (culverts, guardrail, and traffic signals) representing the three age categories. The culverts have a low probability of failure, a high safety consequence, a high mobility consequence, and a medium maintenance consequence. The culverts, therefore, possess a medium safety risk (ranked as 2), a medium mobility risk (ranked as 2), and a low maintenance risk (ranked as 3). In addition, guardrail and traffic signals were categorized using the same procedure and the results are shown in Table 4-9.

TABLE 4-8 Evaluation Data

Asset Class	Culverts	Guardrails	Traffic Signals
PROBABILITY			
Average age of asset base	20	15	14
Expected useful life of asset	45	30	20
Likelihood of asset failure	0.4	0.5	0.7
CONSEQUENCES (10yr analysis period) - Yes/No			
Safety			
Bodily injury to involved party	YES	NO	YES
Property loss/damage	YES	YES	YES
Death/fatality	YES	NO	YES
Mobility			
Lane closure/delay resolved in hours	NO	YES	YES
Lane closure/delay resolved in days with no detours	NO	YES	NO
Lane closure/delay resolved in days with detours	YES	NO	NO
Maintenance			
Failure on roadway with ADT <5000	YES	NO	YES
Failure on roadway with ADT 5000 - 25000	YES	YES	YES
Failure on roadway with ADT >25000	NO	YES	NO

TABLE 4-9 Risk Factor Scale

Scale	Risk Description
3	LOW
2	MEDIUM
1	HIGH

4.2.6 Risk-Based Asset Prioritization

The results of the risk categorization of each alternative (asset class) are put into another matrix as shown in Table 4-10. This ranking matrix assumes that all the performance measures being used carry the same weight; however, the matrix can be adjusted to reflect different weights if the agency wishes to place different levels of importance on the strategic objectives from which the performance measures are derived. In this illustration, the risk factors in Table 4-10 for each performance measure were deduced using the same probability and consequence scales above. The linear sum of the risk factors for each performance measure is termed the total score, and used as the alternative selection criterion.

TABLE 4-10 Computational Matrix for Ranking

ALTERNATIVES PRIORITIZATION				
ALTERNATIVES	SAFETY	MOBILITY	EFFICIENT MANAGEMENT	TOTAL SCORE
Culverts	2	2	3	7
Guardrail	2	2	1	5
Traffic Signals	1	3	2	6

Using the total score, Table 4-11, and the agency's risk target/standard, a wish list of qualifying alternatives can be established and used as a point of departure for decision makers.

TABLE 4-11 Alternatives Ranking Matrix

High Risk Alternative	Action Required if Total Score is <=5 (i.e., at least 1 high risk and 2 medium risks)
Medium Risk Alternative	Total Score is Either 6 or 7
Low Risk Alternative	Total Score >7

In this illustration, the computational and the alternative ranking matrices (i.e., Tables 4-10 and Table 4-11, respectively) indicate that traffic signals and culverts are medium risk alternatives, whereas guardrails are a high risk alternative.

Each alternative is ranked using Table 4-7 and Table 4-8, and the highest risk alternatives are short-listed for further evaluation and consideration (i.e., using implementation and other costs, and benefits) and prioritized for inclusion in the existing asset management system. The main objective in using the computational matrix to further evaluate and consider the alternatives is to help decision makers identify second best alternatives, or even third best based on the potential for risk reduction as well as the cost-benefit ratio. These analyses and evaluation procedures are undertaken to select the most critical alternatives for prioritization.

4.3 Quantifying the Benefits of Asset Management

Quantifying the benefits of asset management, particularly when focused on ancillary assets, involves identifying the agency's strategic objectives and performance measures, and assessing how formal management procedures for ancillary assets contribute to achieving these strategic objectives. A report by Amekudzi and Meyer showed the most common performance measures in state DOTs to be preservation, safety, and mobility (2011), indicating that implicitly or explicitly most agencies' strategic objectives include system preservation, safety and mobility. Various agencies may have additional strategic objectives and if they have adopted asset management as an agency-wide business process, apply asset management in their efforts to achieve these objectives. Any evaluation of the benefits of asset management would thus be linked to the agency's strategic goals – some of which can be quantified more readily than others.

It is important that the benefits of any asset management program are expected to be a function of the maturity of the program, and that programs tend to evolve in maturity over time. Table 2-1 shows the maturity scale for asset management programs presented in the AASHTO Transportation Asset Management Guide Volume 2 (NCHRP, 2011). This scale indicates that the results of analyses conducted to determine the benefits and costs of particular asset management programs should be interpreted carefully, because the benefits and costs of an asset management program are likely to vary according to its relative maturity. In particular, an important dynamic measure for the value of asset management systems ought to be how the benefits are changing relative to the costs of the system and whether the benefit/cost ratio is moving in the right direction. Tracking the benefit-cost ratio of an asset management system may provide more valuable information for an agency in the long run as it continues to develop its system to higher levels of maturity.

Arguably, agencies at different levels of maturity are likely to demonstrate different levels of benefit from their programs. This issue presents complications for ex-ante and ex-post facto evaluation of asset management systems. Agencies that are considering implementation of asset management programs for particular ancillary assets may be interested in finding out the relative costs and benefits that other agencies have experienced in implementing asset management programs for similar assets. The caveat here is that analyses conducted for these other agencies would yield results based on their relative levels of maturity and the extent to which asset management decision support information is actually used in decision making. Thus, ex-ante evaluations which may be dependent on the use of data from other agencies (because the conducting agency has not yet developed a formal asset program) ought to be considered carefully in the context of the factors that influence the results of such evaluations. In addition, there should be an understanding that the evaluating agency may realize similar or different benefit-cost results after implementation, depending on what capabilities they implement and the extent to which they actually apply decision-support information in decision making.

Another factor to consider, in determining the benefit of ancillary transportation asset management is the combination of assets that have formal asset management programs implemented. Since these assets work together to improve the performance of the highway system overall, incorporating different combinations of assets in the formal asset management program could produce different results. This issue could be exacerbated when evaluating a particular asset class, for example, traffic signals. Asset Management programs where a wider range of ancillary assets are being formally managed may turn out different benefits and costs for a particular asset class such as signals, because of the synergistic effects of ancillary assets on overall system performance. In particular here, the task of attributing particular benefits to a particular asset class may become a challenging one, where these assets are working to complement one another with synergistic effects. Quantifying the benefits for particular assets may also prove to be difficult, in which case performance outputs or outcomes can be considered as a function of different asset management maturity levels, and evaluated to determine if benefits have accrued with growth in the maturity of the asset management program.

Any benefit-cost evaluation of formal asset management programs must take these important factors and issues into consideration for proper interpretation of the evaluation results. In essence, given the fact that asset management is an evolving practice and asset management programs have different maturity levels, one may view benefits evaluation as maturity-level dependent and any quantified benefit (in the form of a benefit-cost ratio, or otherwise) of an asset management program as a dynamic number which is likely to change over time. This also leads to the question of whether there is an optimum maturity level for an asset management program where the net benefits are maximized. In addition, depending on the types of benefits emphasized (in relation to the strategic objectives of the agency), the resulting benefit-cost ratio may change. In addition to asking the question, which asset classes will likely provide the highest benefits when formally managed, agencies may benefit also from asking the question what types of management functions must we include in a particular asset category to enhance or maximize the benefits of such a program, and then take proactive steps to institute such elements to improve the effectiveness of such a program. With these complicating factors in mind, agencies can still collect appropriate data to monitor the benefit-cost evolution of their asset management programs as they implement and continue to improve their systems, advancing the maturity level and effectiveness of these systems.

4.3.1 Benefit and Cost Factors

Benefit and cost factors are those elements that can be quantified in order to measure improvements in asset performance and condition as a result of the operation of an asset management system. These factors outline the type of data that should be collected when a method for quantifying the benefits has been designed or selected. Cost factors are easier to determine or measure, than benefit factors, because there is some direct cost associated with asset management program development and implementation. Benefits are usually measured in terms of cost reduction, and thus rely on the same cost factors. These factors are typically grouped in three categories: agency costs, user costs and external costs.

Agency costs are those "directly represented by the budget or out-of-pocket costs paid by the owner" (Hudson, et al., 1997, p. 292). Agency costs include the costs of developing and operating the asset management program - data collection costs, software development and maintenance, staffing or department restructuring, and any other costs associated with maintaining the program. User costs are those costs incurred directly by the users of the asset.

This includes occupancy time (travel time costs), vehicle operating costs, crash costs and even the time delay as a result of maintenance and rehabilitation (Mizusawa and McNeil, 2009; Hudson, et al., 1997). External costs are those costs that do not affect infrastructure users directly, but may eventually become significant. Typically, external costs are associated with environmental and social impacts and include emissions, noise and visual pollution, and other neighborhood disruptions (Hudson, et al., 1997). All together, these factors are important for the quantification of the benefits of asset management.

4.3.2 Benefit Quantification Case Studies

The literature reviewed shows that a number of researchers have made attempts to quantify the benefits of asset management programs. Unfortunately, no documented processes for quantifying the benefits of ancillary asset management were found; however, methods have been developed for pavement management systems and even in the utility industry. The following case studies present and evaluate these methods of benefit quantification and examine their applicability to ancillary transportation assets.

4.3.2.1 Generic Methodology for Evaluating Net Benefit

From 2005 to 2008, Mizusawa and McNeil developed a generic methodology for evaluating the net benefit of asset management system implementation (2009). They quantified the benefits of pavement management systems with a special focus on the PMS used by the Vermont Agency of Transportation, VTrans, and the Highway Economic Requirements System – State Version (HERS-ST), created by the FHWA. The generic methodology involved two types of evaluation design – ex post facto and ex ante – and three analysis methods – descriptive analysis, regression analysis and benefit-cost analysis (BCA).

Ex post facto evaluation is retrospective, comparing conditions before and after implementation of an asset management system or conditions with and without. This form of evaluation is useful in situations where an asset management system has already been implemented. Where the asset management system has not been implemented, ex ante evaluation is employed. This prospective evaluation design compares with and without scenarios based on predicted data. Figure 4.2 below shows these concepts graphically. Besides, whether or not the asset management system has been implemented, the selection of evaluation design also depends on the availability of time series data of asset performance/condition.

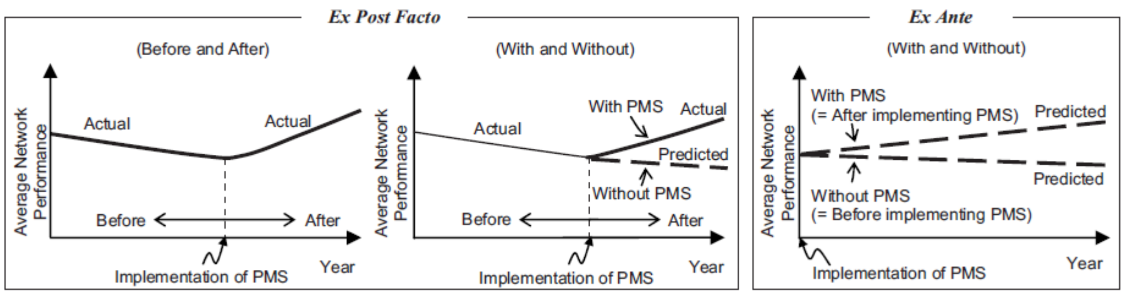

FIGURE 4.2 Concepts of ex post facto and ex ante evaluations (Mizusawa and McNeil, 2009)

When the evaluation design has been selected, the benefits of the asset management system can be quantified by three analysis methods. The first of these is descriptive analysis, a method that captures improvements in asset performance and conditions using common performance measures such as international roughness index (IRI) or present serviceability rating (PSR). The descriptive analysis method is very simple, either comparing actual asset performance or predicted performance. This analysis method cannot consider changes in various performance measures simultaneously, but can identify performance measures to be used in the regression analysis and BCA.

Regression analysis models several independent variables to determine the degree of their influence on a dependent variable, represented by the coefficients of those variables in the final regression equation. With this method, an appropriate dependent variable must be selected, typically related to the performance objectives of the program. This method is much more complicated than the descriptive analysis method and requires time series data for the asset condition and other measures that can influence condition.

The third part of this generic methodology is a BCA, which attempts to show the cost factors described previously, in monetary values. The BCA methodology compares alternatives which in this case are to adopt or not to adopt a management system. Using the cost factors, the net present value (NPV) or benefit-cost ratio (BCR) methods can be used to show the differences in costs and benefits, making sure to use the same analysis periods for both alternatives, or to standardize the costs and benefits by annualizing them for example. The analysis period would depend on the expected life of the investment and a period of time in which the benefits can be reliably predicted. This final analysis method, unlike the previous two, does not require time series data and presents benefits in monetary terms, which is possibly the most applicable for decision makers.

In applying this generic methodology to ancillary transportation assets, the biggest challenge would be the availability of data and the ability to simulate predicted performance with or without the asset management program. As was observed from the literature review and the survey results, cost data for ancillary asset management have been difficult to come by. In addition, determining clear performance measures on which to base analysis may be challenging for some of the assets. Finally, the data required for this methodology is highly aggregated, which works for pavement management systems because pavement performance is directly related to the performance measures being used, and therefore, changes in performance can easily be attributed to the management system. In the case of ancillary assets, however, attributing transportation system outcomes and other benefits to a particular asset is a difficult task because there are no clear and direct relationships between all the assets and all the benefit factors.

4.3.2.2 A Utilities Perspective

Outside the transportation industry, the concept of asset management continues to grow. In a white paper by the UMS Group (UMS Group, 2010), Schipper and Huisma build a framework to measure the effectiveness of asset management by transmission service operators (TSOs). Discussions between groups in the utility and energy industry led to the conclusion that specific benchmarks are necessary to assure the agencies that they are justified in implementing asset management procedures.

In this paper, the authors begin by presenting a hypothesis which states that "developing an Asset Management orientation will always bring you to a higher level of business output and success" (UMS Group, 2010, p. 1). The premise of the hypothesis presented is based on the illustration shown in Figure 4.3 which defines three distinct zones of performance. Agencies found in the "Low Impact Zone" have high asset management service levels, but with low levels of business outcome performance, while agencies in the "No Need for Asset Management" zone have high output performance without clearly expressed asset management values. When data points (representing agencies) are plotted in this framework, the hypothesis holds in the "Asset Management Maturation Zone;" however if any points fall in the "No Need for Asset Management" zone, then the hypothesis will not be valid.

According to the paper, the definition of business outcome performance should be related to the stakeholders of the agency; however, standardized parameters are difficult to obtain since market conditions and stakeholder needs may be different for each agency.

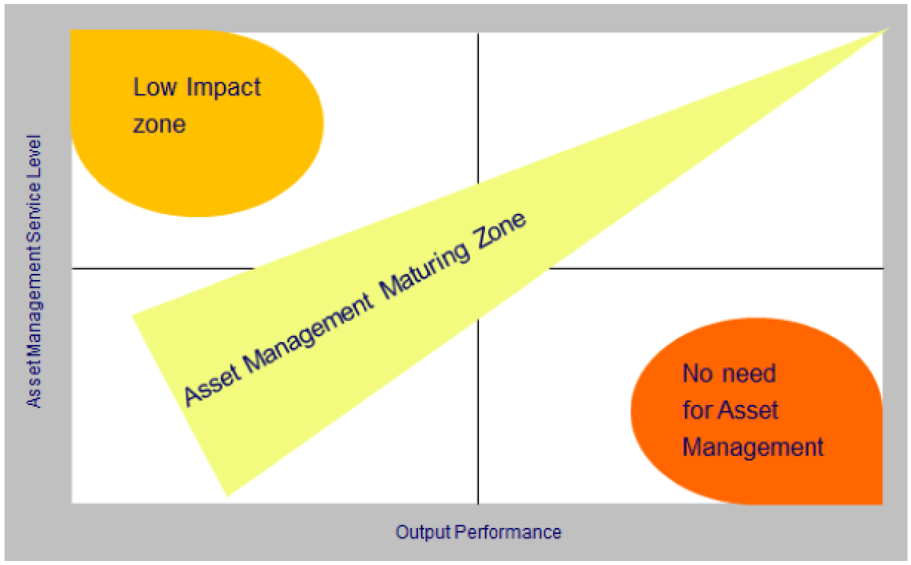

FIGURE 4.3 Asset Management Measurement Framework (UMS Group, 2010)

Nonetheless, the authors define a number of key performance indicators (KPIs) that should be applicable to all utility companies taking into consideration quality, safety, return on assets and transparency in terms of planned operating and capital expenditures. The KPIs selected are summarized into an output performance index that ranges from 0 to 2. In defining the asset management service level, the framework encompasses four areas key to asset management best practices: operating (and accountability) model, processes, competences and culture, and information management and enabling technology. These areas of competency are scored from 1 (lack of awareness) to 5 (excellence in asset management). This KPI framework may be viewed as a kind of maturity-scale model similar in concept to what is defined in the AASHTO Asset Management Guide, Vol. 2 (Table 2-1).

Based on these definitions, agencies were provided with a data pack identifying specific data to be collected which was used to plot points in the framework. As shown in Figure 4.4, the results illustrate some accuracy in the hypothesis. Most of the agencies plotted fall within the Asset Management Maturation Zone with a few outliers falling near the Low Impact Zone. Additionally, the researchers found several correlations between the KPI that suggest a positive value for asset management. To measure actual quantities of the benefits, the paper suggests comparing the difference between best practice and average KPIs.

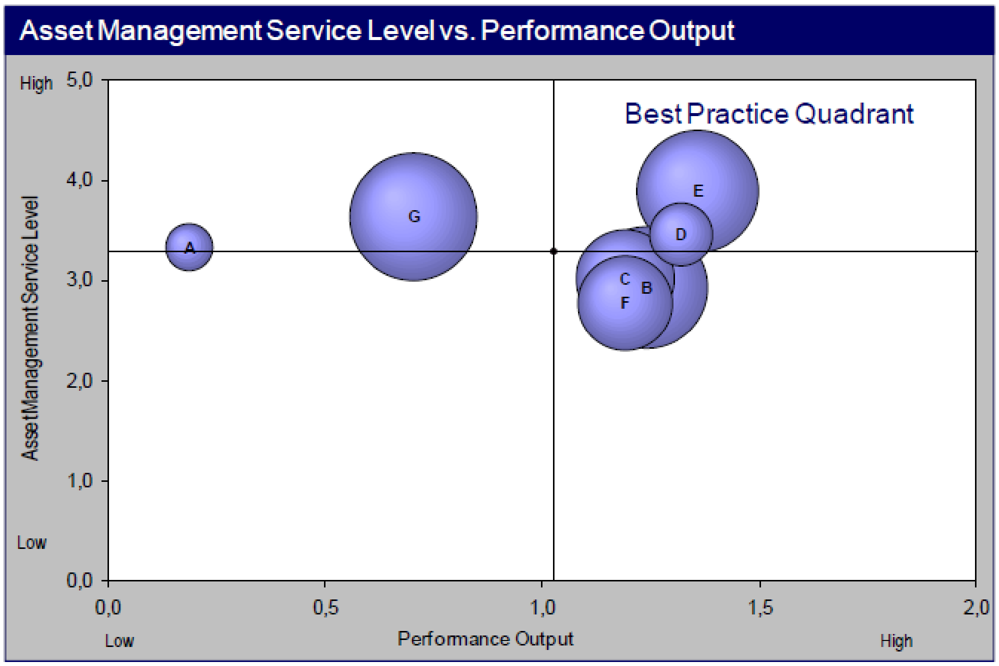

FIGURE 4.4 Agencies plotted on Asset Management framework (UMS Group, 2010)

This framework may be more easily applied to ancillary transportation assets, as compared to the generic methodology because the issue of attributing outcomes to specific assets is alleviated. This is because output performance metrics can be selected based on performance measures for each asset as opposed to an aggregated metric (for example, retro reflectivity for signs as opposed to reductions in crash costs). On the other hand, unlike the generic methodology explained in the first case study, this framework only works retrospectively for asset management programs already implemented. However, since ancillary transportation asset management is still a growing field, collecting the necessary data may pose a challenge because many agencies have not fully developed their systems. However, this finding makes it all the more important for agencies to make efforts to collect data systematically in order to begin to demonstrate gains from maturing asset management programs.

Finally, the framework presented in Figure 4.2 makes the assumption that there is a fairly linear relationship between asset management service level and output performance. Any discrepancies in this assumption would change the shape of the Asset Management Maturing Zone, possibly re-defining the framework and the results obtained. One question of interest to some practitioners is whether there is an optimum level for programmatic asset management beyond which additional expenditures fail to produce marginal benefits. If this is the case, the Asset Management Maturing Zone may be monotonically increasing in the beginning but could flatten out at some point indicating no improvement in output with further program maturation. These issues are worthy of additional research as more data becomes available.

4.3.3 Benefit-Cost Analysis (BCA) Framework

Besides making a business case for asset management programs, quantifying the benefits of ancillary asset management is also useful in prioritizing these assets for inclusion in existing asset management programs. **According to the survey conducted as part of this research, most agencies select assets for inclusion in a formal asset management program based on ease of data collection or the value of the asset, as defined by the amount of money spent on building and maintaining those assets on an annual basis.** In order to improve this asset prioritization process and to ensure that agencies are integrating ancillary assets cost-effectively, the net benefit of managing each ancillary asset could be quantified and included as a factor in a prioritization framework.

Life-cycle cost analysis (LCCA) is an economic analysis tool frequently used in the transportation industry to compare highway investments to identify the least cost alternative. LCCA ensures that an alternative is not selected only based on the initial costs, but also considers the future costs and the lifetime of the investment (FHWA, 2003). According to the FHWA Economic Analysis Primer, LCCA is used most appropriately when selecting from alternatives that yield the same amount of benefits. With the range of transportation assets being considered, each asset serves a distinct purpose and thus management may have different benefits. In this situation, the primer recommends using Benefit-Cost Analysis (BCA).

A standard BCA procedure, using the net present value method, involves six distinct steps: (a) specify the alternatives; (b) set the analysis period; (c) decide the benefit and cost factors; (d) determine the measures quantitatively based on the benefit and cost factors; (e) attach monetary values to the measures and discount to obtain present values; and (f) Compute the net present value of each alternative (FHWA, 2003; Boardman, et al. 2011). In this framework, the alternatives are asset management program implementation for each of the ten asset classes under consideration (leaving the data asset as a separate category); hence, there are ten alternatives. The benefit and cost factors are those described in the Section 4.3.1, with impact categories (measures) shown below:

I. **Cost Factors** – monetary costs associated with program implementation and use

   A. **Data Collection Costs**

      1. Equipment

      2. Labor

3. Other costs

B. Program Implementation Costs

1. Software

2. Organizational changes

3. Other costs

C. System Operation Costs

1. Additional labor

2. System/program maintenance

II. Benefit Factors – cost savings as a result of the asset management program

A. Failure and Replacement Costs

1. Asset value

2. Injuries and fatalities (number of incidents in 5 - 10 yrs related to specific asset failure based on historical data)

3. Traffic delay (Average hours of lane closure/diversion for asset repair/replacement)

4. Labor costs

5. Other costs

B. Administrative Time Savings

1. Administrative tasks (Average time savings for tasks associated with organizing asset data)

2. Work order placement (Average time savings in placing work orders)

C. Maintenance Expenditure Savings

1. Pre-TAM maintenance expenditure

2. Post-TAM maintenance expenditure

These measures were sent to selected agencies, requesting data to be used in estimating the benefits and costs of formal asset management implementation; however, none of the agencies were able to provide sufficient data to test the framework. Of the data that was returned, the benefit measures were the most deficient. Essentially, the most critical problem with attempting to quantify the benefits of ancillary asset management is attributing the benefits (or reductions in costs) to a particular asset class. The asset value may be used as the only benefit; however, this would be an incomplete assessment in most cases, as it would leave out other factors related to the agency's strategic objectives (i.e., factors that could be improved with systematic asset management). In general, the strategic objectives of an agency should determine which factors are used in the benefit-cost function, if the agency is truly interested in achieving these objectives through asset management.

4.3.4 Opportunities and Suggestions for Improvement

The over-arching goal of this research was to develop a simple and easily understood methodology for transportation agencies to apply quickly to estimate the relative benefits and costs of implementing formal asset management procedures for different classes of ancillary assets. Undoubtedly, the framework proposed here is one of many that could be applied to quantify the benefits of ancillary transportation asset management. In order for this framework to be applied either retrospectively (after the management system is in place) or prospectively (in order to help prioritize assets for management), it is essential to be able to identify measures that can be attributed to specific assets. However, the transportation system is made up of components that work together, complementing each other to provide a service. Specific data needs or the specific data that needs to be collected cannot be recommended, because this should depend on the agency's strategic objectives and performance measures, as well as the functional goals of the assets. The measures provided above should simply be a starting point for the use of this framework. Once the necessary data is obtained and the measures are monetized and put in present values, the present value of net benefits of each management system can be calculated by simple subtraction.

As previously stated, interpreting the results of such an analysis should be done in the context of the maturity level of an asset management program. This study has revealed the importance of considering benefits and costs of asset management programs over an extended period of time as the program matures, rather than at a snapshot in time, in order to make sound decisions on the value of such programs. This finding emphasizes the importance of systematic data collection to track the evolution of benefits and costs of asset management programs. Whereas the determination of a benefit-cost ratio less than one for a program at a lower level of maturity should not create concern, a decreasing benefit-cost ratio as funds continue to be expended to increase the level of maturity of any program should raise a red flag. It should cause the agency to ask critical questions about the nature of additional asset management functions that would raise the value of their evolving program.

Another issue that cannot be trivialized is the attribution of benefits to different aspects of a comprehensive asset management program, especially as far as ancillary assets are concerned. As ancillary assets work together to support the overall functioning of a highway or transportation system, it may be difficult to attribute benefits accurately to one particular category or other of the assets. Sometimes, strategic consideration of how multiple ancillary assets can be phased into formal management to achieve progress toward agency strategic goals could be a more valuable exercise than expending similar efforts to evaluate the relative benefits and costs of formally managing "independent" categories of ancillary assets (particularly where such assets work in a complementary way to help achieve system objectives, e.g., traffic signals, traffic signs and guardrails for safety).

5 Summary, Recommendations and Conclusions

5.1 Summary

This project report presents findings on the practice of ancillary transportation asset management in the United States. The literature review and survey revealed several important aspects of agency implementation of asset management practices over the past few years. Although some actions are driven by Federal mandates, most depend on the priorities and goals of state and municipal agencies. As a result, ancillary transportation asset management practices vary by agency, with some exceptions. No specific trends were observed relative to agencies in the United States that seem to be making the most progress in the management of ancillary transportation assets. Findings also showed no trends in terms of jurisdictional size or the sizes of the inventories of assets that different agencies maintain. However, more agencies were noted to be managing safety assets, the agencies that manage a significant number (greater than 6) of the asset classes presented also seem to be further ahead in terms of data analysis and the use of data in informed decision making. These agencies and several others investigated seem to be developed past the general inventory stage, which is usually the first step in the creation of an asset management program. Overall, many agencies are working towards improved asset management programs for their ancillary assets and greater data and system integration to reduce redundancies and increase data sharing. The practices presented in this report are by no means exhaustive; however the results are indicative of growth in the field of transportation asset management towards informed, efficient capital investment and effective MR&R decisions based on limited resources, with increasing attention being paid to ancillary transportation assets.

In comparison to the results of the literature review, findings from the survey present a more comprehensive and up-to-date synthesis of the data and data collection tools required in asset management systems. The only exception is in the case of cost data, which was not readily available. In the long run, one of the ways an asset management system can be judged to be successful is in the cost savings associated with higher levels of performance for the same expenditures. The availability of the life-cycle costs and benefit data (including risk reduction data) for asset management systems are important inputs for assessing the relative effectiveness and efficiency of such systems. Because most ancillary transportation asset management systems are relatively new, data collection costs may be more easily estimated than the life cycle costs of these systems at their present stage of development, indicating that the results of such analyses should be interpreted as a function of the maturity level of the programs, and that the evolution of the benefits and costs of a particular asset management program would be a better indicator of its value than a snapshot benefit-cost number (particularly at an earlier stage of maturity). The evaluated benefits of asset management systems are also a function of the extent to which decision-support information is actually used in decision making.

This study identifies a number of common elements and approaches to risk assessment and management and discusses basic elements for a risk framework to assess and prioritize ancillary transportation assets for inclusion in formal transportation asset management programs. It discusses seven risk elements commonly present in recognized risk approaches to asset management. These framework elements are used to develop a risk model that provides a means for identifying the highest-risk assets for management and evaluating tradeoffs across different asset classes. The approach covers the functional objectives and lifecycle of the asset while linking these to the wider strategic objectives of the transportation agency and its stakeholders.

The proposed framework draws from and builds on a number of established risk-based management systems that have been developed over several years. Although this provision exists, there is little evidence that agencies have actually employed risk-based benefit-cost approaches to prioritize their ancillary assets for inclusion into existing asset management systems. Additionally, the majority of risk methods that are in use, currently, by transportation agencies have considerable elements of subjectivity. A framework that includes risk profiles for different asset classes, developed by combining engineering judgment with quantitative data, can be tailored to capture the local knowledge in agencies while making the best use of the quantitative data that is available. Furthermore, the study illustrates with a hypothetical example how the proposed model could be implemented if the appropriate data were made available, and makes recommendations for data collection to support such analyses.

Finally, this work has evaluated the feasibility of quantifying the benefits of ancillary transportation asset management based on a review of previously proposed methods of quantification and a proposed quantification framework based on a simple benefit-cost analysis procedure. As noted, the almost secondary nature of ancillary assets within the transportation system makes it difficult to attribute benefits to particular assets. In order to use the proposed benefit-cost framework, agencies need to select cost-benefit factors and metrics related to their strategic objectives and for which data can be obtained (or adequately predicted).

In order to prioritize ancillary assets for systematic and strategic management, this study recommends combining the two frameworks (risk and benefit-cost) proposed in the previous chapter. Establishing the effectiveness of these models for risk and benefit-cost analyses requires a more complete dataset, which would require extra time and funding to collect. On the other hand, some existing management systems (e.g., safety management systems, culvert management systems, and pavement management systems) already contain some valuable data that can be used in the frameworks.

5.2 Recommendations and Caveats

The literature reviewed shows that there has been very little effort made by agencies to gather data that would support a prioritization framework for ancillary transportation assets. The information that does exist may be found in decentralized databases, which are not readily available to decision makers. In the absence of such a system, it would be challenging for decision makers to determine the relative priorities of asset classes objectively. On the other hand, establishing such capabilities would provide valuable information that would help agencies understand the trends and consequences of failure of these ancillary transportation assets, as well as the relative benefits of management, enabling the application of a well-informed prioritization method. As agencies pursue this solution, some caveats and recommendations are offered below.

1. ***Be Wary of the Dynamic Nature of Benefits and Costs of Asset Management Programs as a Function of Maturity Level.***

The results of this study indicate the dynamic nature of the benefits and costs of formal asset management programs. The results indicate that benefits-costs estimation of formal asset management programs is influenced by the following: (I) the level of maturity of the particular program; (II) the synergistic effects of the other asset categories included in the asset management program; (III) the strategic objectives of the agency and hence performance measures used in evaluating the program; (IV) the availability of data influencing whether ex-ante or ex-post facto analysis must occur; (V) the extent to which output and outcome measures exist that can capture benefits which are not readily evaluated monetarily; and (VI) the extent to which the agency is actually applying asset management decision support information in decision making. As such, the evaluation of the benefits and costs of asset management programs cannot properly be a one-time event but must be considered an ongoing or periodic task that, if pursued, can help agencies make more prudent decisions on how to implement and continue to mature their asset management systems. This finding indicates that it is quite possible to get an infeasible benefit-cost ratio for an asset management system or program at a lower level of maturity that will mature to become a cost-beneficial enterprise at a higher level of maturity. Making a decision not to invest or to delay investment using the benefit-cost results of a low-in-maturity asset may deny an agency the benefits of a formal asset management program in the longer term. An agency may thus be better off using risks (in conjunction with net benefits) to prioritize asset classes for inclusion in a formalized asset management program, while using benefits and costs as long term measures to guide the evolution of asset management programs to be more effective and efficient as they mature. In taking a long-term approach to asset management, the more important issue may be to identify asset management functions that have the highest potential to lead to significant net benefits as asset management programs mature; collect data on benefits and costs to assess these programs and help guide their further evolution; while using risk reduction as a parameter to allocate funds in the shorter term. Benefits-costs-risks data collected on an ongoing basis as asset management systems are progressively developed can help agencies make more strategic decisions about how to expand and improve upon these systems rather than assuming that benefit-cost estimates at any particular point in time will remain static.

2. *Be Wary of the Limitations of Ex-ante and Ex-post facto Analysis*

Ex-ante and Ex-post facto analyses of formal asset management programs must be interpreted with care as ex-ante analyses involve forecasting which may be valid to various degrees, and ex-post facto analyses will be dependent on the use of other agencies asset management systems which may be at different levels of maturity. For decisions to be made most appropriately about various asset management classes, a long-term perspective must be taken. However, the nature of various asset management systems is such that they are in a lower rather than higher stage of maturity based on their longevity and the functions of the asset management program. For example, several systems have data collection with few analytic capabilities. Evaluating the benefits and costs of such systems and using them as a basis for decision making for another low-maturity and yet evolving system may result in decisions not to invest further or prioritize such assets for inclusion in a formal management system. However, it is likely that if management systems are implemented for those same assets and carefully and strategically managed to achieve high net benefits in the long term, they will be more effective and efficient than was predicted using a lower-maturity asset. Using ex-post facto data is also subject to the limitation that several asset management programs have not reached the stage where they are actually incorporating the majority of the decision support information generated in their actual decision making (see Pei et al., 2010). Estimating the benefits and costs of such asset management systems from program outputs or outcomes may be misleading and not provide appropriate decision support information for other agencies.

3. *Be Wary of the Difficulties of Attributing Benefits to Different Ancillary Asset Classes*

Because ancillary assets work together to support an effective system, and may have synergistic effects, attributing system gains to a particular ancillary asset may be very difficult, and this may be one of the reasons why several agencies managing ancillary assets have not been able to define the benefits for particular classes of assets. If a longer term approach is taken to asset management, agencies may decide to prioritize assets for inclusion in a formal program based on their strategic objectives, as well as the performance and catastrophic risks to system users of such assets, obviating the need to attribute particular benefits to particular ancillary assets in a system of interrelated ancillary assets. This stance will come with an understanding that the agency is committed to progressively determining superior investments to mature the asset management system into one that helps produce more and more effective and efficient outcomes.

4. Ask the Right Question(s) to Lead to Better Outcomes

The question: "How can we develop and evolve this asset management system to be more effective?" may be more appropriate than asking whether the benefits of a particular asset management system exceed the costs, particularly for programs at a lower level of maturity. Ex-post facto studies of other agencies can be used to identify more effective programs as agencies evolve their programs to become more mature. Efforts to identify cost-effective improvements to existing asset management systems arguably demonstrates a longer-term commitment to asset management and recognizes that, just as an individual as a child is capable of generating a different set and level of benefits than as an adult, so an asset management system must be evolved to more mature levels to generate higher levels of benefits. Another question that arises using this construct is: "Are there stages of the asset management system where there are optimal net benefits obviating the need for further expenditures to mature the system further?" Agencies that are dedicated to collecting the appropriate data to periodically assess the benefits and costs of their asset management programs can begin to address this question: as plots of outcome measures against expenditures begin to flatten, this may indicate that a local (or global) optimum has been reached, or that the agency needs to think more creatively about additional functions that can continue to add value to the system.

5. ***Take Leadership in Advocating for a Peer-to-Peer Evidence-Based Database of Asset Management Benefits and Costs for State Departments of Transportation***

An evidence-based database of asset management benefits and costs will provide information to agencies on the maturity level (i.e., asset management functions), costs and benefits of various asset management systems. Such information can be used to make decisions on investment priorities to improve existing systems, benchmark progress against peer agencies, and identify the most promising developments from the standpoint of generating high returns (in performance outcomes) on investment.

6. ***Use Proposed Tools with Caution***

The tools provided in this study are to be used with caution, understanding the caveats associated with determining benefits-costs for ancillary transportation assets. Risk assessment of ancillary assets will lead to identification of assets with severe risks. These assets can then be prioritized using benefits-costs data available. The asset classes with the highest risks and highest net benefits would surface as priorities for investment in formal management.

7. ***Data Collection on Benefits-Costs of Asset Programs is a Must for More Effective Evolution of Asset Management Programs***

A common feature of most asset management systems or programs is that they continue to evolve and become more mature in their capabilities. Data collection on the benefits and costs of asset management programs must therefore be viewed as critical to continue to make effective decisions for maturing existing asset management systems. Whereas several have asked whether a business case can be made for asset management programs, what is probably more pertinent is understanding how the benefits and costs of asset management programs evolve as they mature and whether more effective pathways for evolving these systems can be identified based on actual data that depicts how performance outcomes have changed as a function of expenditures (as these systems have matured). A one-time assessment of a low-level maturity program that yields a benefit-cost ratio less than one is no assurance that the same program will not yield a higher benefit-cost ratio that makes a business case when it is at a higher level of maturity. Therefore, tracking the benefits and costs of asset management programs becomes a critical component of developing effective asset management systems in the long term. Over time, if agencies can demonstrate increasing cost-effectiveness as they evolve their systems to higher levels of maturity, this would be an indication that asset management does and is making a positive difference. If, on the other hand, a particular agency starts out with a positive benefit-cost ratio and finds out that this ratio hardly changes as expenditures in the system continue or increase, this data trend can be used to assess why the additional asset management functions are not yielding any measurable results, and drawing from the evidence-based database, to explore other functions, approaches or techniques that have shown more promise among peer agencies.

5.3 Concluding Remarks

This study has outlined procedures for estimating the benefits, costs and risks of including ancillary assets in formal asset management programs; and the factors influencing the outcomes of quantifying the benefits of asset management programs, in particular the level of maturity of the programs, the combination of assets included in the programs, and the extent to which decision-support information is actually used in decision making. As agencies face decisions on where to best invest their limited resources, candidate asset classes for more systematic management can be prioritized in reference to their risks, benefits and costs of failure relative to agencies meeting their strategic objectives, understanding the caveats presented. The ability to determine these priorities is linked with willingness on the part of agencies to estimate data collection costs, and invest resources in determining how asset management systems have benefited and continue to benefit them and their customers, as they continue to evolve these systems in maturity.

With respect to risk analysis, the proposed model is limited in one capacity: the inability of the model to incorporate the effect of asset failures resulting from external conditions, e.g., random human events such as failures resulting from a driver running into traffic signal or sign, or failures resulting from natural phenomena such as storm damage or earthquakes. No matter what an agency does to reduce risk, these events will always exist. This limitation must be addressed by future research.

The study also reveals that a single benefit-cost number at any point in time in the maturity evolution of an asset cannot be used properly to make a business case for formal asset management nor prioritize effectively candidate assets for an asset management program. Instead, the evolution of the benefits and costs of an asset management program, as the program matures, is a better indicator of the changing value of the program to the agency and system users.

Overall, the results of this research study emphasize the importance of ongoing, systematic data collection on the benefits and costs of ancillary transportation asset management systems, and the risk of failure of these assets, in order to effectively prioritize them for systematic, strategic management, and continue to improve them systematically to higher levels of maturity in their functions and outcomes.

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7 Appendices

Appendix A. Assets Managed from Literature Review

Agency	CULVERTS	SIGNS	PAVEMENT MARKING	TRAFFIC SIGNALS	MITIGATION FEATURES	GUARDRAILS	UTILITIES & MANHOLES	DATA	LIGHTING	ERS	SIDEWALKS (CURBS)	Total
DEPARTMENTS OF TRANSPORTATION												
Alaska DOT	1				1							2
Arizona DOT			1									1
Arkansas DOT	1	1										2
California DOT	1			1	1				1			4
Colorado DOT	1	1	1	1					1	1		6
Delware DOT	1							1				2
Florida DOT	1	1	1	1	1	1		1	1			8
Idaho DOT	1					1						2
Illinois DOT		1	1			1						3
Indiana DOT	1	1		1	1	1			1			6
Iowa DOT	1	1	1			1			1			5
Kansas State DOT		1	1		1	1				1		5
Kentucky DOT						1						1
Maine DOT					1			1				2
Maryland Highways Agency	1		1	1	1					1		5
Michigan DOT	1	1		1		1		1				5
Minnesota DOT	1	1	1	1	1			1	1	1		8
Missouri DOT		1	1							1		3
New Jersey DOT	1				1							2
New Mexico	1	1	1	1	1	1		1				7
New York State DOT	1				1							2
North Carolina DOT	1	1	1	1	1							5
North Dakota DOT		1	1	1		1			1			5
Ohio DOT	1	1	1	1	1	1		1	1			8
Oregon DOT	1	1		1	1				1			5
Pennsylvania DOT	1	1						1		1		4
South Carolina DOT		1										1
South Dakota DOT		1										1
Tennessee DOT		1	1			1		1				4
Texas DOT	1		1									2
Utah DOT	1	1	1		1							4
Virginia DOT	1	1	1	1	1	1		1				7
Washington State	1				1							2
Wisconsin DOT		1	1	1						1		4
LOCAL/COUNTY AGENCIES												
Alameda County, CA	1											1
Anne Arundel County, MD						1						1
City of Saco, Maine							1					1

Agency	CULVERTS	SIGNS	PAVEMENT MARKING	TRAFFIC SIGNALS	MITIGATION FEATURES	GUARDRAILS	UTILITIES & MANHOLES	DATA	LIGHTING	ERS	SIDEWALKS (CURBS)	Total
Clearwater, Fl							1					1
Dakota County Road Department, NE	1	1	1									3
Fairfax County Waste Water Collection Division							1					1
Greenwood County Metro Authority, SC							1					1
Harford County Public Works Department, MD	1											1
Hillsborough County, FL							1					1
Oklahoma City Water & Waste Utilities Division, OK							1					1
INTERNATIONAL AGENCIES												
Alberta Infrastructure and Transportation, Canada							1					1
Australia							1					1
Brisbane, Australia	1			1								2
British Columbia Ministry of Transportation Canada										1		1
Calgary, Alberta Canada							1					1
Edmonton, Alberta, Canada	1	1		1							1	4
Finland							1					1
Gloucestershire County, England		1	1	1		1		1	1		1	7
Greece							1					1
Hamilton, Ontario Canada							1					1
London, England				1								1
New South Wales Roads & Traffic Authority (RTA), Australia				1								1
New Zealand Transport Agency	1	1							1			3
Oslo, Norway							1					1
Quebec Ministry of Transportation			1	1								2
Queensland Main Roads, Australia	1											1
Saskatchewan Highways & Transportation		1	1									2
Victoria VicRoads, Australia	1			1								2
Wellington, New Zealand							1					1
Total	31	27	22	21	17	15	14	11	11	8	2	

Appendix B. Asset Management Survey of Practice

GEORGIA INSTITUTE OF TECHNOLOGY UNIVERSITY TRANSPORTATION CENTER

COMPREHENSIVE TRANSPORTATION ASSET MANAGEMENT SURVEY OF PRACTICE

JANUARY 2011

Georgia Institute of Technology is conducting a research project titled *Comprehensive Transportation Asset Management: Risk-Based Inventory Expansion & Data Needs*, sponsored by the Georgia Department of Transportation. The purpose is to develop a risk-based framework for integrating high-quantity, lower-cost transportation assets into existing transportation asset management (TAM) systems. This project focuses on eleven main asset groups: traffic signs, traffic signals, roadway lighting, guardrails, culverts, pavement markings, sidewalks & curbs, utilities & manholes, earth retaining structures, mitigation features and data. Your agency has been identified as one that is currently managing one or more of these assets. Please complete the questions below on your management process for TAM. The survey should take about 15-20 minutes to complete. The research results will be made available to participants and made widely available through Transportation Research Board and other practitioner-oriented publications. Thank you for participating in this survey.

Agency: ____

Survey Contact: ____

Position/Title: ____

Department/Division: ____

Address: ____

____

City: ____________________ State: __________ Zip: __________

Tel: ______________ Fax: ______________ Email: ______________

School of Civil and Environmental Engineering
Atlanta, Georgia 30332-0355 U.S.A.
Phone 404/894-2201
FAX 404/894-2278
http://www.ce.gatech.edu

1. (a) For which of the following assets does your agency conduct a systematic asset management effort?

☐ Earth retaining structures ☐ Guardrails ☐ Pavement Markings
☐ Traffic Signs ☐ Traffic Signals ☐ Sidewalks & Curbs
☐ Street Lighting ☐ Culverts ☐ Utilities & Manholes
☐ Mitigation Features ☐ Data

(b) Are the assets managed independently or within an integrated asset management system?

☐ Independently ☐ Integrated

Comments:………
……
……

2. Is there a written policy or program statement that describes the objectives of this effort?

☐ Yes ☐ No

If yes, please send to the contact email provided at the end of the survey. If not, in your own words, what are the main objectives of managing the above assets?

……
……
……
……

3. For the asset(s) included in your asset management effort, what is the approximate quantity of each asset (e.g. number of assets per linear foot/per mile of roadway)?

Earth Retaining structures	………………	Lighting	………………
Guardrails	………………	Culverts	………………
Pavement Markings	………………	Utilities and Manholes	………………
Traffic signs	………………	Data	………………
Traffic signals	………………	Mitigation Features	………………
Sidewalks and Curbs	………………		

4. What type of database system does your agency use to manage the assets?

Earth Retaining Structures…………………………………………………………………………………
Guardrails………………………………………………………………………………………………………
Pavement Markings…………………………………………………………………………………………
Traffic Signs……………………………………………………………………………………………………
Traffic Signals…………………………………………………………………………………………………
Sidewalks and Curbs…………………………………………………………………………………………
Lighting ……
Culverts……

Utilities and Manholes………………………………………………………………………………………….

Data………

Mitigation Features……………………………………………………………………………………………

5. **What is the estimate of the amount of your asset base that is included in your asset management system? Please indicate the percentage population of the system by asset.**

Earth Retaining structures	………………	Lighting	………………
Guardrails	………………	Culverts	………………
Pavement Markings	………………	Utilities and Manholes	………………
Traffic signs	………………	Data	………………
Traffic signals	………………	Mitigation Features	………………
Sidewalks and Curbs	………………		

6. **What specific data collection tools are used for each of these assets?**

Earth Retaining Structures……………………………………………………………………………………

Guardrails………………………………………………………………………………………………………

Pavement Markings……………………………………………………………………………………………

Traffic Signs……………………………………………………………………………………………………

Traffic Signals…………………………………………………………………………………………………

Sidewalks and Curbs…………………………………………………………………………………………

Lighting ……

Culverts……

Utilities and Manholes…………………………………………………………………………………………

Data………

Mitigation Features……………………………………………………………………………………………

7. **What other data analysis tools are used for each of these assets?**

Earth Retaining Structures……………………………………………………………………………………

Guardrails………………………………………………………………………………………………………

Pavement Markings……………………………………………………………………………………………

Traffic Signs……………………………………………………………………………………………………

Traffic Signals…………………………………………………………………………………………………

Sidewalks and Curbs…………………………………………………………………………………………

Lighting ……

Culverts……

Utilities and Manholes…………………………………………………………………………………………

Data………

Mitigation Features……………………………………………………………………………………………

8. For each asset in your asset management system, what *inventory* data are collected?

Earth Retaining Structures…………………………………………………………………………………....
Guardrails………………………………………...……………………………………………………………
Pavement Markings………………………………….………………………………………………………
Traffic Signs……………………………………………..……………………………………………………
Traffic Signals………………………………………………………...………………………………………
Sidewalks and Curbs……………………………………………………………………...…………………..
Lighting ……………………………………………………………..………………………………………..
Culverts……………………………………………………………..…………………………………………...
Utilities and Manholes……………………………………………………………………………………..…
Data………………………………………………………………….………………………………….……
Mitigation Features………………………………………………………………...…………………………

9. For each asset in your asset management system, what *performance* (i.e., attribute) data are collected?

Earth Retaining Structures…………………………………………………………………………………....
Guardrails………………………………………...……………………………………………………………
Pavement Markings………………………………….………………………………………………………
Traffic Signs……………………………………………..……………………………………………………
Traffic Signals………………………………………………………...………………………………………
Sidewalks and Curbs……………………………………………………………………...…………………..
Lighting ……………………………………………………………..………………………………………..
Culverts……………………………………………………………..…………………………………………...
Utilities and Manholes……………………………………………………………………………………..…
Data………………………………………………………………….………………………………….……
Mitigation Features………………………………………………………………...…………………………

10. Does your agency estimate the cost of collecting data on these assets? If so, on what basis (i.e. per mile, per linear feet or per number of assets)? What is the approximate cost of data collection for each of the assets managed?

Earth Retaining Structures…………………………………………………………………………………....
Guardrails………………………………………...……………………………………………………………
Pavement Markings………………………………….………………………………………………………
Traffic Signs……………………………………………..……………………………………………………
Traffic Signals………………………………………………………...………………………………………
Sidewalks and Curbs……………………………………………………………………...…………………..
Lighting ……………………………………………………………..………………………………………..
Culverts……………………………………………………………..…………………………………………...

Utilities and Manholes………………………………………………………………………………………

Data………

Mitigation Features……………………………………………………………………………………………

11. How frequently are inspections or inventories performed?

Earth Retaining structures	………………	Lighting	………………
Guardrails	………………	Culverts	………………
Pavement Markings	………………	Utilities and Manholes	………………
Traffic signs	………………	Data	………………
Traffic signals	………………	Mitigation Features	………………
Sidewalks and Curbs	………………		

12. How are the inventory and performance data used in decision making (e.g., budget setting, project prioritization and selection, etc.)?

Earth Retaining Structures…………………………………………………………………………………

Guardrails……………………………………………………………………………………………………

Pavement Markings…………………………………………………………………………………………

Traffic Signs…………………………………………………………………………………………………

Traffic Signals………………………………………………………………………………………………

Sidewalks and Curbs…………………………………………………………………………………………

Lighting ………………………………………………………………………………………………………

Culverts………………………………………………………………………………………………………

Utilities and Manholes………………………………………………………………………………………

Data………

Mitigation Features……………………………………………………………………………………………

13. Has your agency quantified the benefits resulting from the asset management system or the general maintenance or rehabilitation of any of these assets? For example, has your agency estimated cost savings of prolonging the useful life of such assets?

☐ Yes ☐ No

If yes, please send examples of these data to the contact email provided at the end of the survey.

14. Are there any other aspects of your asset management systems that you consider unique or that you would like us to know about? Please indicate here.

………

………

………

………

Thank you for your participation.

Direct all questions and additional information to:

Margaret-Avis Akofio-Sowah, E.I.T.
Graduate Research Assistant
Department of Civil & Environmental Engineering
Georgia Institute of Technology
Atlanta, GA
manas3@gatech.edu

Appendix C. Sample Survey to Track Failure Data

Department Contact: ________________

Type of Asset: ______________________

Location(s) of Asset Failure - Road: _________ Milepost: __________

Asset Identification Number: ______________________

Date of Asset Failure: ______________________

Number of Lanes Damaged/Closed: _____________

Date of Initial Re-opening: ___________

Number of Lanes Temporarily Opened: ________

Date of Final Repair: ___________

Length of Detour: ___________________

Average Daily Traffic (ADT) on Highway Impacted by Asset Failure: _______________

Percentage Heavy Vehicles on Highway Impacted by Asset Failure: __________________

Average Time to Travel Detour (while asset was down and traffic was congested):________

Average Truck Time to Travel Detour (if different than for normal traffic): _____________

Detour Route (Describe and attach a map if possible): __________________________

Describe Likely Cause of Failure: _______________________________________

Average Age of Asset: ____________________________________

Failure Costs

Initial Cost of Asset Installation: ____________________

Cost of Traffic Control: ____________________

Number of Accidents Caused by Failure: Property Damage: _______ Injury: _____ Fatality: _____

Other Indirect Costs (Business Loss, etc.,):____________________________

Total Cost: _______________________