Asset Management Data Collection

for Supporting Decision Processes

U.S. Department of Transportation
Federal Highway Administration

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Preface

Asset Management is a strategic approach to the optimal allocation of resources for the management, operation, maintenance, and preservation of transportation infrastructure (FHWA 1999). The concept of Asset Management combines engineering and economic principles with sound business practices to support decisionmaking at the strategic, network, and project levels.

One of the key aspects of the development of Asset Management is data collection. The way in which transportation agencies collect, store, and analyze data has evolved along with advances in technology, such as mobile computing, advanced sensors, distributed databases, and spatial technologies. These technologies have enabled data collection and integration procedures necessary to support the comprehensive analyses and evaluation processes needed for Asset Management. However, in many cases, the data collection activities have not been designed specifically to support the decision processes inherent in Asset Management. As a result, the use of the aforementioned technologies has led agencies to collect very large amounts of data and create vast databases that have not always been useful or necessary for supporting decisionmaking processes.

Although agencies have placed a large emphasis on collecting and integrating data, little effort has been placed on linking the data collection to the agencies' decisionmaking processes. The objective of the investigation discussed in this report was to investigate how State departments of transportation are linking their data collection policies, standards, and practices to their Asset Management decisionmaking processes, especially for project selection.

A literature review showed that the majority of the transportation agencies in the United States and the rest of the world have endorsed the concept of Asset Management. Many agencies in different regions of the world are working on the implementation of individual management systems, integrated infrastructure management systems, or Asset Management initiatives. The number of transportation agencies that are beginning to adopt, support, and implement the concepts and methodologies of Asset Management is rapidly increasing; however, Asset Management implementation is still in its initial stages, and there are many hurdles to overcome.

Asset Management implementation efforts have focused mainly on the overarching strategic and network (program) levels. Data needs for this type of decision comprise aggregated overall network performance indexes and overall network characteristics (i.e., overall interstate mileage, total number of bridges, etc.). Similarly, there have been advances in the project level of decisionmaking with the implementation of one or more individual management systems. Data needs for these types of decisions are project specific and require detailed inventory, condition, and performance data. The information gathered at this level is usually collected for only a reduced number of assets identified as the ones needing work, usually from the network-level analysis.

Last, the utmost implementation efforts have created common databases to minimize data storage and enhance interoperability between different management systems. These efforts do not usually address any particular decisionmaking level per se but contribute to the enhancement of the underlying foundations of all of them, which are the data and their corresponding issues of storage, analysis, etc. No efforts in practice, however, have been reported that aim at an overall system or network optimization. The optimization focus has been restricted to the various individual systems, although the notion of overall system integration can be found profusely in the literature.

The literature review also revealed that the level that has received the least attention, in terms of its data needs, is the project selection level. This level, however, is of vital importance to the overall success of the management as it links the overall network with the individual, specific projects. Furthermore, project selection traditionally has been made between projects belonging to the same asset class. Asset Management encourages cross-asset comparisons between the candidate projects for selection. This obviously has increased the data needs and also has created the need for the identification and use of effective and unbiased selection methodologies that can be applied to all different asset classes.

To complement the literature review, a survey was developed and distributed to capture the current level of Asset Management endorsement and implementation, as well as specific aspects of their data collection practices and their relationship with the project selection level of decisionmaking. The survey confirmed that transportation Asset Management implementation in the United States and around the world is still in its initial steps but that most transportation agencies are planning the integration of their individual management systems' roadway inventories and databases.

Transportation agencies have explicitly defined decisionmaking levels and are moving forward to a rationalization of their data collection activities. Data collection decisions are still predominantly based on past agency practices and personnel experience. There is, however, a significant trend toward use of data collection standards and input needs of management systems or processes behind the rationalization of data collection. In the particular area of project selection, there also seems to be a formally established relationship between the data collected and the decisions supported. However, Asset Management practitioners in general agree that project selection criteria cannot or should not be uniform and consistent for all asset types considered.

By using the collected information, the research team identified four States for indepth case studies. The research team then met with these agencies to explore in detail the linkages between data collection and decision processes and to document their practices. The agencies selected have used different data collection approaches and represent different degrees of Asset Management implementation.

The case studies indicated that there is no one-size-fits-all approach for Asset Management data collection. The most appropriate approach will depend on the agency's needs and culture, as well as the availability of economic, technological, and human resources. A gradual implementation of the data collection efforts appears to be the most appropriate approach. Most of the data collected are currently being collected separately for individual asset types that support decisions within their corresponding silos. However, as the agencies embrace the Asset Management philosophy, there is an increased need for more consistent data collection among asset types and locations.

All agencies reviewed have a decentralized approach to project selection in which the field offices of the agencies decide which projects to execute. These agencies also have defined desired levels of service for the various assets and use those levels to enhance both the service provided to the user of the managed assets and the accountability of the decisionmakers. However, except for the Maryland State Highway Administration, the agencies do not have specific software tools for supporting project selection decisions at the field offices.

Finally, a data collection framework for project selection is recommended to optimize the data collection activities for project selection. The process provides clear, logical steps toward the complete rationalization of the data needs for these decisions. This framework can function as a starting point for transportation agencies that wish to handle project selection in a more systematic way and reduce costs by optimizing their data collection to support project selection decisionmaking. However, the proposed framework would only lead to partial optimization of an agency's data collection activities. It only addresses project selection decisions without considering the needs of the other levels of decisionmaking that might require overlapping or complementary data and hence necessitate new or extended data collection activities. A similar rationale can be defined for other levels of Asset Management decisionmaking.

Further research in the area of project selection data collection should be undertaken to determine the factors that render project selection criteria incapable of handling cross-asset comparisons. Additional effort also is needed to generalize the proposed data collection framework for an overall data collection optimization, taking into account all agency decision levels.

This research can help transportation agencies tailor their data collection activities according to their real decisionmaking needs. In this way, the research contributes both to the reduction of data collection costs and to a more effective and efficient implementation of Asset Management in its everyday practice. By focusing on the use of the data, the needs of the decision levels, and the processes to be supported, transportation agencies could define which assets and which data about these assets are most important for decisionmaking and tailor their data collection accordingly.

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Introduction

Background

Asset Management is a strategic approach to the optimal allocation of resources for the management, operation, maintenance, and preservation of transportation infrastructure (FHWA 1999). Asset Management combines engineering and economic principles with sound business practices to support decisionmaking at the strategic, network, and project levels.

One of the key aspects of the development of Asset Management is data collection. The way in which transportation agencies collect, store, and analyze data has evolved along with advances in technology, such as mobile computing (e.g., handheld computers, laptops, tablet notebooks, etc.), sensing (e.g., laser and digital cameras), and spatial technologies (e.g., global positioning systems [GPS], geographic information systems [GIS], and spatially enabled database management systems). These technologies have enhanced the data collection and integration procedures necessary to support the comprehensive analyses and evaluation processes needed for Asset Management (Flintsch et al. 2004).

In many cases, however, the data collection activities have not been designed specifically to support the decision processes inherent in Asset Management. As a result, the use of the aforementioned technologies has led agencies to collect huge amounts of data and create vast databases that have not always been useful or necessary for supporting decision processes.

Objective

In order to support Asset Management, agencies must collect, store, manage, and analyze large amounts of data in an effective and efficient manner. Although agencies have strongly emphasized collecting and integrating data, little effort has gone into linking the data collection to the agencies' decision-making processes. By focusing on the use of the data and the needs of the decision levels and processes to be supported, transportation agencies could define which assets and which data about these assets are more important for decisionmaking and tailor their data collection accordingly.

The objective of the investigation discussed in this report was to investigate how State departments of transportation (DOTs) are linking their data collection policies, standards, and practices to their Asset Management decision-making processes, especially for project selection. This decisionmaking level functions as an intermediate stage between high-level strategic decisions and low-level, project-specific decisions.

Methodology

The investigation started with a comprehensive and thorough literature review in order to retrieve related experience from academic and industrial sources throughout the world. Several reports have documented current and past practices in the United States and Canada as well as Europe and Australia. The literature review summarizes the state-of-the-art and corresponding state-of-the-practice implementation efforts in Asset Management, decision-making, and data collection.

To complement the literature review, a Web survey was developed to capture the current level of Asset Management endorsement and implementation, as well as specific aspects of data collection practices and their relationship with the project selection level of decisionmaking. A link to the survey was distributed to the DOTs in all 50 States and Puerto Rico, and the responses were tabulated and analyzed.

By using the collected information, the research team identified four candidate States for indepth case studies. The research team then met with these agencies to document best practices and to explore in detail the linkages between data collection and the decision process.

The knowledge gained from these activities was used to develop a framework for effective and efficient data collection, particularly for project selection and the identification of major criteria and data attributes to this decisionmaking level. This research can help transportation agencies tailor their data collection activities according to their real decision-making needs. In this way the research contributes both to the reduction of data collection costs and a more effective and efficient implementation of Asset Management.

Acknowledgments

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The authors would like to acknowledge the contribution of the many Asset Management experts that responded to the survey; their knowledge and expertise provided the foundation for this investigation. In addition, the following individuals shared their experiences and insights during the development of the case studies: Charles Larson, Virginia Department of Transportation; Jeff Smith, Peter Stephanos, Dana Havlik, and Michael Wetzel, Maryland State Highway Administration; Mesfin Lakew, District of Colombia Department of Transportation; and Lonnie Watkins and Thomas Goebel, North Carolina Department of Transportation.

Finally, the authors would also like to acknowledge the contribution of the other members of the Virginia team that worked in this project. Aristeidis Pantelias and Chen Chen worked on this project while pursuing graduate studies at Virginia Tech. The survey of practice comprised the main body of Mr. Pantelias' Master Thesis. Mr. Chen prepared the Web-based survey form and assisted with the documentation of the case studies. Susan M. Willis-Walton, Associate Director of the Virginia Tech Center for Survey Research, and Susanne Aref, Ph.D., Director of the Statistical Consulting Center at Virginia Tech, contributed to the development and analysis of the survey.

CHAPTER 1

Literature Review

This chapter reviews available literature to document the state-of-the-art and state-of-the-practice implementation efforts in Asset Management and data collection. The chapter covers general background on Asset Management, decision levels supported, required information, data collection, management and storage methods, and domestic and international implementation efforts.

Asset Management

The concept of infrastructure management, particularly of transportation infrastructure management, is not new to the United States or to the rest of the world. In the second half of the 20th century, these efforts and approaches focused on managing individual transportation infrastructure asset types. Pavement, bridge, tunnel, traffic equipment, congestion, public transportation, and various other types of management systems have emerged during the last decades. Ongoing research in these areas is producing important findings and is continually progressing. Pavement management systems are the oldest and most abundant of these engineering management systems because pavements constitute almost 60 percent of the total infrastructure assets managed by transportation agencies (Haas et al. 1994).

During the last decade of the 20th century, there was a slow but consistent movement toward a more holistic approach to the management of these assets. Transportation agencies in the United States and around the world began to acknowledge the merits of a more comprehensive methodology for managing their infrastructure. This holistic way of dealing with the management of transportation assets, coupled with more business-like objectives, has led to what is today commonly known as Asset Management.

The FHWA defines Asset Management as follows:

> *Asset Management is a systematic approach of maintaining, upgrading, and operating physical assets cost effectively. It combines engineering principles with sound business practices and economic theory, and it provides tools to facilitate a more organized, logical approach to decisionmaking. Thus, asset management provides a framework for handling both short- and long-range planning. (FHWA 1999)*

However, there have been many other definitions that consider different aspects of the business strategies pertaining to Asset Management and also widen its scope beyond solely physical assets (McNeil 2000), such as the following:

> *Asset Management is a comprehensive business strategy employing people, information and technology to effectively and efficiently allocate available funds amongst valued and competing asset needs. (TAC 1999)*
>
> *Asset Management is a methodology to efficiently and equitably allocate resources amongst valid and competing goals and objectives. (Danylo and Lemer 1998)*

Finally, the Organization of Economic Cooperation and Development (OECD) emphasizes the service to the public, which is the end customer of the road agencies and administrations:

> *[Asset Management is] a systematic process of maintaining, upgrading and operating assets, combining engineering principles with sound business practice and economic rationale, and providing tools to facilitate a more organized and flexible approach to making the decisions necessary to achieve the public's expectations. (OECD 2000)*

The genesis of the movement toward Asset Management in the United States has been an understanding of the need for it. Highway agencies in the United States have moved their primary focus many times during the last 50 years. There was a shift from expansion to preservation from the 1960s to the mid-1980s, then the focus changed to reinventing government from the mid-1980s to the beginning of the new century. From that point of time until now, the focus has been on employing sound business practices. This new focus has many implications, including embracing quality, emphasizing the need to address strategic rather than tactical issues, integrating economics and engineering, and taking advantage of the progress made in information technology (AASHTO 1999).

The reasons for this new approach to infrastructure management are many and include limited funds leading to scarce budgets, technological advancements, lack of expert personnel, and public demand for better quality of service and accountability from the people in charge (AASHTO 1999). Taking into account that the estimated value of U.S. transportation infrastructure sums up to more than $1 trillion (estimated by the FHWA in 1999), the need to effectively and efficiently manage this infrastructure with the best and most cost-effective approach has become paramount.

Meanwhile, Asset Management has already been widely accepted by the private sector worldwide and has been practiced since the mid-1990s by transportation agencies in the United Kingdom, Australia, and New Zealand (Stalebrink and Gifford 2002). Hence, transportation agencies in North America had one more reason to investigate whether this was an approach that they wanted to endorse and apply (McNeil 2000).

GASB 34

Another milestone in the development of Asset Management has been the Statement No. 34, "Basic Financial Statements—and Management's Discussion and Analysis—for State and Local Governments" (GASB 34), issued by the Governmental Accounting Standards Board (GASB 1999). This statement established a new financial reporting model for both State and local governments and has been regarded by many as the biggest change in history to public sector accounting (Wilson 2004).

GASB 34 intends to make financial reports more useful to legislators, investors, and creditors and "establishes methods for governments to be more accountable to bond market analysts and underwriters, citizens, and other financial users" (GASB 1999). Furthermore, "the potential impact of GASB 34 extends beyond financial reporting statements and may influence the manner in which infrastructure is thought of by citizens, legislators, and others interested in public finance and infrastructure performance" (FHWA 2000).

GASB 34 requires government financial managers to provide a section on Management's Discussion and Analysis on their financial reports. This section consists of a nontechnical narrative that summarizes the financial performance of the agency and compares it with the previous year's performance (Kadlec and McNeil 2001).

Furthermore, public transportation agencies have to record in their books all their capital and infrastructure assets and all corresponding investments and account for their value by reporting it on a regular annual basis. Because most of the infrastructure assets deteriorate with time due to usage, environmental effects, and aging, agencies can choose to report their value either by depreciating it or by using a modified approach. In the first case the asset value is reported as a historical cost minus depreciation, usually determined by using a straight line depreciation method. In the modified approach:

> *Infrastructure assets are not required to be depreciated if 1) the government manages those assets using an asset management system that has certain characteristics and 2) the government can document that the assets are being preserved approximately at (or above) a condition level established and disclosed by the government. Qualifying governments will make disclosures about infrastructure assets in required supplementary information (RSI), including the physical condition of the assets and the amounts spent to maintain and preserve them over time. (GASB 1999)*

The described Asset Management systems must comply with certain specifications in order to be acceptable by the GASB 34 standards. The systems must have a regularly updated inventory, clearly established condition assessment criteria, and accurate reporting capabilities of the annual expenses dedicated to the infrastructure preservation (Kadlec and McNeil 2001; FHWA 2000).

Although GASB 34 was introduced separately and for different reasons than Asset Management, the two have evolved to be complementary and beneficial for both the accounting and engineering departments of transportation agencies (Wilson 2004). In reality, there is still some impeding hesitation from the accounting profession in choosing the modified over the straight line depreciation approach (Koechling 2004), and there are several other implementation hurdles to overcome (Nemmers 2004). However, transportation agencies that choose to apply Asset Management principles and tools are one step closer to managing their infrastructure more efficiently, complying with the financial reporting mandates of Statement No. 34, and producing other benefits for the agency managers and employees and for the general public (Kraus 2004).

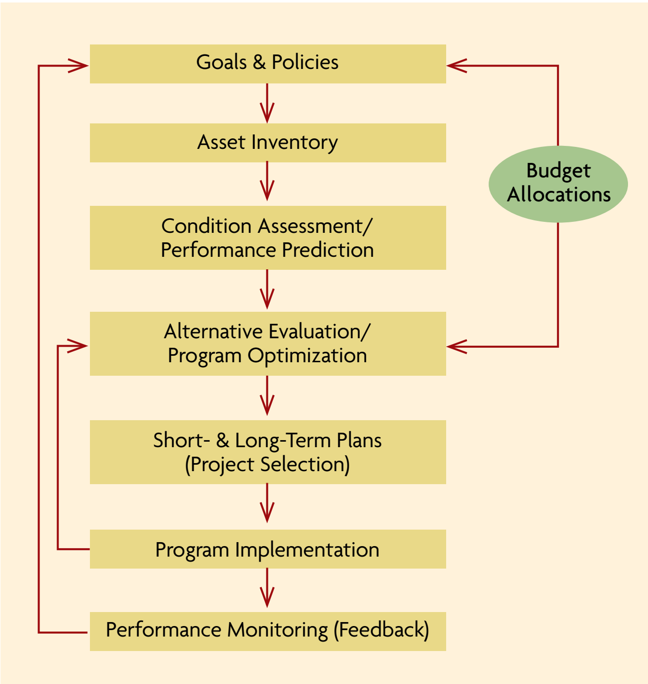
Asset Management Characteristics

Asset Management is a generic framework of tools and methodologies aimed at enhancing infrastructure management by emphasizing good business practices and asserting the holistic approach. It incorporates elements of various diverse disciplines such as accounting, value engineering, life-cycle cost analysis, economics, risk management, and user satisfaction (Danylo 1998). It also differs from the traditional management practices in the following ways:

- Applies strategic, rather than tactical, measures, goals, and policies.
- Addresses decisions in a network, system-wide fashion rather than at a project level.
- Integrates existing individual infrastructure systems and databases in a common interoperable environment.
- Introduces and incorporates financial and economic performance measures, ideas, and theories and treats the infrastructure management process as a business, which requires efficiency and effectiveness.
- Models internal processes after the private sector.
- Establishes efficient documentation and communication of the decision-making process, which yields two significant benefits: (1) making management decisions transparent to all kinds of shareholders and (2) rendering decisionmakers accountable for their choices.

As presented by FHWA (1999) and illustrated in figure 1, an Asset Management system has the following major elements, which are constrained by available budgets and resource allocations: establishment of goals and policies, data collection and development of asset inventory, establishment of performance measures leading to condition assessment and performance modeling, development of management systems to evaluate alternatives and control optimization, decisionmaking regarding short- and long-term project selection, implementation of designed programs and evaluation processes, and use of evaluation results for overall process feedback, redevelopment, or refinement.

Figure 1. Generic Asset Management system components (after FHWA 1999).



Many transportation agencies, educational and academic institutions, and governmental and industrial organizations have rigorously investigated the theoretical concepts behind Asset Management. Research is still ongoing, and the worldwide literature on the subject is annually enlarging. Few results, however, have been reported so far from the implementation of Asset Management in practice. Although several States and countries around the world have welcomed and incorporated the new concepts in their state-of-the-art, the corresponding state-of-the-practice has yet to catch up, and actual implementation has proven more difficult than initially anticipated.

Many of the reasons for lag between the theory and practice have been acknowledged and documented in previous studies (AASHTO 1996). The most commonly mentioned hurdles to overcome include no unique way to establish an Asset Management system and the large number of alternatives from which to choose, difficulties integrating existing databases, and individual infrastructure management systems in spite of the advances in information technology and its applications.

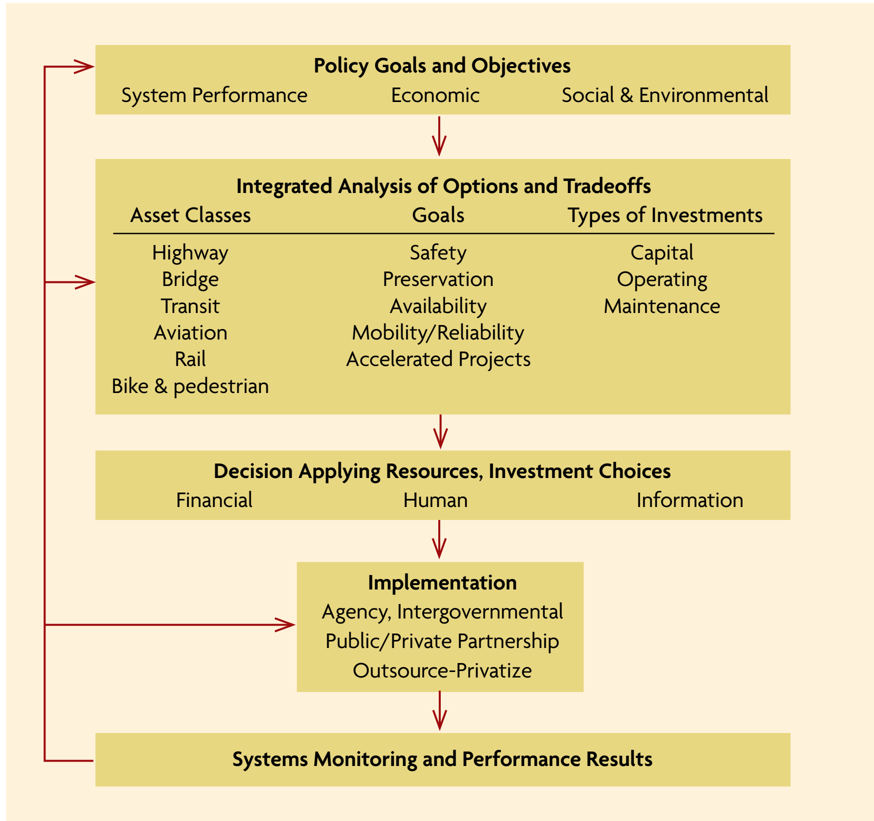
In that context, there have been several domestic and international reports on the progress and challenges faced by private and government transportation agencies on their way to implementing Asset Management. These efforts and milestone examples that are of interest to this research are presented in more detail later in the report.

The American Association of State Highway and Transportation Officials' "Transportation Asset Management Guide" represents a milestone domestic reference (AASHTO 2002). This guide was prepared to assist State DOTs in tailoring a generic Asset Management framework to their individual needs and characteristics. It was developed in the context of the National Cooperative Highway Research Program (NCHRP) and based on up-to-date experience and research findings. This guide describes Asset Management as a strategic approach to managing infrastructure assets and identifies two major clusters of decisionmaking: resource allocation and utilization. Figure 2 illustrates a schematic representation of the overall Asset Management process with emphasis on resource allocation and utilization. The described process is oriented to the actual implementation of the Asset Management concepts and methodologies.

One of the key building blocks of any Asset Management system is a comprehensive inventory of highway infrastructure assets and their respective conditions. Most transportation agencies have basic bridge and pavement data for their transportation network; several of them have also made a great effort over the years to collect, store, manage, and analyze comprehensive inventory data for their other highway infrastructure assets. For example, the Virginia Department of Transportation (VDOT) is developing an Asset Management database and inventory information system. VDOT conducted a pilot for a comprehensive Statewide highway inventory system by utilizing state-of-the-art procedures and cutting-edge technology (Larson and Skrypczuk 2004a, 2004b). The cost of the venture and the size of the resulting database led to the conclusion that such a practice was not necessarily the best one and created skepticism of the real value and usefulness of the collected data.

An important result of this effort—in addition to the creation of the database—was an Asset Management data collection dictionary that encompassed detailed descriptions of roadway asset data and their condition-specification needs (Larson and Skrypczuk 2004b). Furthermore, and in continuation of its previous efforts, the agency has also created an Asset Management data collection guide in order to identify, facilitate, and enhance Asset Management–related data collection (VDOT 2004).

Figure 2. Framework for transportation Asset Management as a resource allocation and utilization process (after ASHTO 2002).



Asset Management Decision Levels

All forms of management have an internal hierarchy of decisionmaking levels. The structured process inherent in most corporate systems aggregates information and generalizes the scope of decisions to be made higher in this hierarchy. Infrastructure management and Asset Management are not exceptions. There are various decisionmaking levels that represent different perspectives on the system, ranging from very specific, detailed, project-oriented views to generalized, comprehensive, strategic ones. The decision levels pertaining to Asset Management as identified in literature are the strategic level, network level, and project level (Haas et al. 1994; Hudson et al. 1997; AASHTO 2001). Although Asset Management is mostly perceived as a strategic level tool, it nevertheless affects—and can be equally successful as—lower levels of decisionmaking within a transportation agency.

The various decisionmaking levels are strongly interconnected. In many cases, they significantly overlap because of the need for permeable and flex-

ible boundaries in an organization's decisionmaking and because communication between the various levels is paramount for the overall success of the management process. The decisionmaking levels do have, however, different scopes and require different data and information inputs in order for the decisionmaking to be carried out effectively and efficiently.

The **strategic** decisionmaking level is the broadest and most comprehensive. It pertains to strategic decisions concerning all types of assets and systems within the civil engineering environment, one of them being the transportation sector. Within transportation, it may consider all different modes and all assets pertaining to these modes. The strategic level of decisionmaking is concerned with generic and strategic resource allocation and utilization decisions within the constructed environment.

The **network** decisionmaking level pertains to determining the overall agency-wide maintenance, rehabilitation, construction strategies, and works programs. This decision level considers system-wide decisions, but its scope is narrower than the strategic level's. Overall budget allocation and transportation planning are the key focus areas. This decision level is often broken down into program and project selection levels (Haas et al. 1994).

The **program** decisionmaking level is concerned with the overall, network-wide programming of actions and allocations. It is involved in policy decisions, and the aim is the system-wide optimization of funds allocated to rehabilitation, maintenance, or new construction of infrastructure assets.

The **project selection** level is concerned with decisions on funding for projects or groups of projects. This level generates decisions at a higher level of aggregation than the project level, but it requires more detailed information than the program and network levels. It serves as a link between the network level and the subsequent project level of analysis.

The **project level** of decisionmaking and analysis pertains to the specific, mode-wise, asset-wise, and geographically determined projects. It addresses the design of the projects included in the overall work plan needed to meet the agencies' performance measures. It is also called "field level" or "operational level" and refers to how the actual work is going to be done.

Although all the above hierarchical levels of decisionmaking are clearly defined, there exists significant overlap in what the management needs to do at every level. The identification of the actual data needed in every decisionmaking level is a very challenging task. This is partly due to that significant overlap between the various decision levels, as well as the lack of relevant research initiatives in this field.

Asset Management Decision Processes

Asset Management decision processes are the individual decisions that need to be made in every level of decisionmaking, be it strategic, network, or project focused. Decision processes can therefore be concerned with budget allocations, network optimization, works programming, and selection of alternative implementation methods, among other things. Decisions made at the different levels of Asset Management are heterogeneous, and the supporting data needs are bound to be quite different.

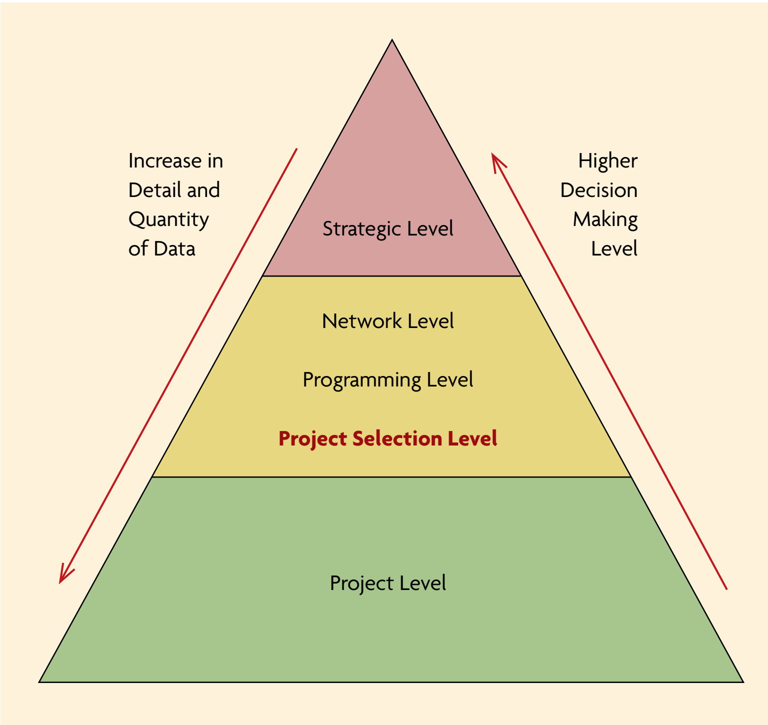
To systematically approach and identify the data needed to support Asset Management decision processes, it is necessary to first define the level of decisionmaking these processes support. The analyst can then assess the level of aggregation of the data needed and identify the data needs for those specific decisionmaking processes and problems.

According to Haas et al. (1994), the specificity of information required, network size considered, and the complexity of the analytical models used have a specific relation to the different levels of decisionmaking. Different levels of decisionmaking have different foci: Higher levels are mostly concerned with overall budget allocations and system utilization, whereas lower levels tend to focus more on the administration, funding, and engineering of specific functions and processes. In addition, decisionmakers have different backgrounds and different interests. As a result, the decisions at each level are different in scope, as are the data aggregation level and the corresponding detail and quantity of the collected data. Higher levels require more generalized information whereas lower ones tend to need more detailed and specific data. This is illustrated in figure 3.

Project Selection and Related Tools

Project selection is a level of decisionmaking that entails the evaluation of the attributes of different candidate projects for the purpose of funding and implementation. As a decisionmaking level, it addresses decisions pertaining to network-level analysis and functions as a bridge between high-level network

Figure 3. Relation between the different decisionmaking levels and the corresponding detail and amount of required data.



decisions and site-specific, detailed project-level decisionmaking. The project selection analysis is based on information that is aggregate enough to show the big picture of the competitive projects and, therefore, identify and assess their usefulness and overall impact. However, it is also detailed enough to capture the individuality of each project, provide accurate cost estimates, and identify implementation implications for the agencies and the users.

Within the framework of Asset Management, the nature of project selection is unique because in many cases the candidate projects concern different assets and treatments. As an example, tradeoffs may consider the rehabilitation of an existing flexible pavement through milling and repaving versus the maintenance of a concrete pavement through crack sealing. As another example, tradeoffs may consider the maintenance of the roadside drainage system of a particular segment of a highway versus the rehabilitation of a bridge's concrete deck or the replacement of its steel railings.

The different types of work that may be encountered by an agency responsible for the management of roadway assets are rehabilitation, maintenance, and new construction. Furthermore, typical roadway assets that are part of an agency's roadway transportation network are pavements, bridges, tunnels, signs, culverts, drainage systems, markings, medians, etc. Table 1 presents a list of roadway assets identified by the VDOT with their corresponding definitions.

According to Hudson et al. (1997), the project selection follows the overall network programming decisions regarding the general funds to be allocated in the different types of agency works. After the agency has decided on the amount of funds to be spent in maintenance, rehabilitation, or new construction (or reconstruction), then the candidate projects that fall into each of these work programs need to be determined.

The selection of the different projects or different groups of projects to be included in a work program is heavily constrained by available budgets and usually resorts to some type of prioritization model. These models usually employ optimization, near-optimization, or other techniques to obtain results that can be used by the transportation officials to support decisionmaking (Haas et al. 1994). The most used prioritization methods have been summarized by Hudson et al. (1997) and are presented in table 2 along with their advantages and disadvantages.

Table 1. Roadway asset types and definitions.

Roadway Assets	Definition
Pavements	Flexible pavements hot-mix asphalt, portland cement concrete pavements, unpaved roads, paved shoulders, and unpaved shoulders.
Roadsides	Vegetation and aesthetics, trees, shrubs and brush, historic markers, and right-of-way fence.
Drainage Structures	Cross pipes and box culverts, entrance pipes, curb and gutter, paved ditches, unpaved ditches, edge drains and underdrains, storm water ponds, and drop inlets.
Traffic	Attenuators, guardrail, pavement striping, pavement markings, raised pavement markers, delineators, signs, and highway lighting.
Structures and Bridges	Overhead sign structures, structural culverts, overall bridges, sound barriers, and retaining walls.
Special Facilities	Movable bridges, rest areas, river and mountain tunnels, weigh stations, and traffic monitoring systems.

Table 2. Classes of methods that can be used in priority analysis.

Class of Method	Advantages/Disadvantages
Simple subjective ranking of projects based on judgment.	Quick and simple; subject to bias and inconsistency; may be far from optimal.
Ranking based on parameters, such as level of service and condition.	Simple and easy to use; may be far from optimal.
Ranking based on parameters with economic analysis.	Reasonably simple; should be closer to optimal.
Optimization by mathematical programming model for year-by-year basis.	Less simple; may be close to optimal; effects of timing not considered.
Near-optimization using a marginal cost-effectiveness approach.	Reasonably simple; close to optimal results.
Comprehensive optimization by mathematical programming model, taking into account the effects of "which," "what," and "when."	Most complex; can give optimal program (maximization of benefits, minimization of costs).

Worldwide practice in the area of project prioritization has shown that in order for the analysis to be comprehensive and as accurate as possible, the effects of economic and timing parameters should be considered. Recent research in this area has focused in proposing models that include economic analysis and multiyear prioritization in the optimization process. Some of these models also take into account the effects of certainty, risk, and uncertainty in the outcome of the prioritization results (Li and Sinha 2004).

Asset management implementation has focused attention on the economic parameters of infrastructure management and their effects on the project selection. There has been extensive research on economic evaluation methods and techniques, most of which are not new and have been used by transportation agencies in the past. The most commonly used techniques include the following: benefit/cost ratio, internal rate of return, present worth method or net present value, equivalent uniform annual costs (EUAC), and cost-effectiveness (Haas et al. 2004).

The development of tools for engineering economic analysis and the development of specified software have advanced rapidly. Flintsch and Kuttesch (2004) identified various pavement engineering economic analysis software tools and listed their area of application as well as their advantages and disadvantages. The reviewed software tools constitute valid approaches for supporting project selection decisionmaking, provided that they are used in full recognition of their capabilities and limitations.

Because the way project selection is carried out by most agencies involves tools similar to the ones described above, it is reasonable to assume that the data needs of this particular level of decisionmaking should include the type and amount of data that form the inputs of these models and techniques. In other words, project selection data needs should be focused on the particular inputs that the project evaluation models require. As different agencies employ different models and techniques, the particular data needed for each agency are also bound to be different.

Data Collection, Management, and Integration

Data collection, data management, and data integration are essential parts of the Asset Management framework that are critical to its success. Timely and accurate data lead to information and form the basis for effective and efficient decisionmaking. Besides, the goal of Asset Management is the development of decision-support systems that provide "access to quantitative data on an organization's resources and its facilities' current and future performance" (Nemmers 1997).

Data collection is very much dependent on the intended use of the data. It is obvious that the level of detail and the depth needed for the collected data vary according to the hierarchical level of the decisions to be made. Although all decisionmaking levels are undisputedly part of the overall Asset Management process, data collection requirements have to specifically consider how the collected information is going to be used at the various management decision levels. Data needs for supporting the strategic, network, or project level are significantly different in terms of degree of detail and required accuracy. Broadly speaking, the data collection requirements can be categorized in the following three groups:

- Location: actual location of the asset as denoted using a linear referencing system or geographic coordinates.
- Physical attributes: description of the considered assets, which can include material type, size, length, etc.
- Condition: condition assessment data can be different from one asset category to another according to the set performance criteria. The data can be qualitative and generic (e.g., good, bad, etc.), or detailed and quantitative in accordance to establish practices and standards (e.g., pavement condition index, bridge health indices, etc.).

Information Quality Levels

Researchers have defined information quality levels (IQL) to link the amount of information detail with the level of decision supported. According to the World Bank (2004), there are five information quality levels in road management (IQL 1–5). These levels relate the different types of road management information, their corresponding degree of sophistication, and the required methods for data collection and processing to the type of decisions supported, as illustrated in figure 4 and table 3. The IQL requires different levels of detail and quality in the collected data to support the corresponding decisionmaking processes, which translate into different methods and frequencies of data collection. Therefore, it is imperative for the determination of data needs to prespecify the decision level of interest. The tailoring of the data collected for effective decisionmaking within the decision level can lead to more specific and focused data collection efforts. This is investigated in the following section for the project selection decision level.

Data Collection Methods

The various methods and technologies used for infrastructure data collection have shown a trend toward automation and computerization. Methods used for the collection of Asset Management data include (1) manual, (2) automated,

Figure 4. Information quality level concept.

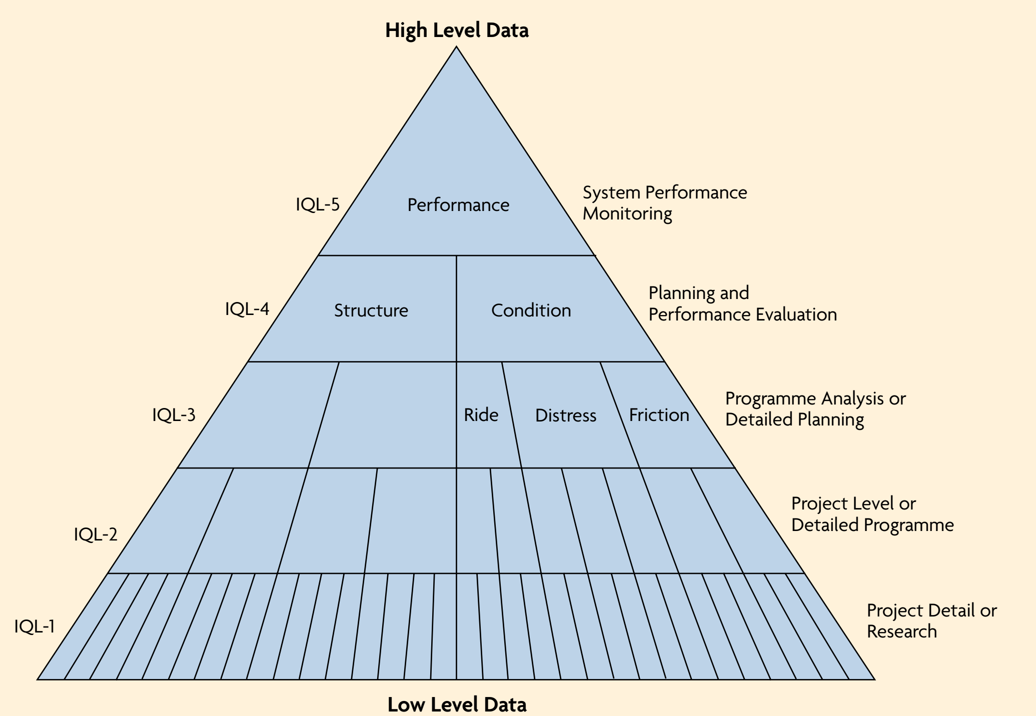


Table 3. Classification of information by quality and detail.

IQL	Amount of Detail
1	Most comprehensive level of detail, such as that which would be used as a reference benchmark for other measurement methods or in fundamental research. Would also be used in detailed field investigations for an indepth diagnosis of problems and for high-class project design. Normally used at project level in special cases; unlikely to be used for network monitoring. Requires high-level skill and institutional resources to support and utilize collection methods.
2	A level of detail sufficient for comprehensive programming models and for standard design methods. For planning, would be used only on sample coverage. Sufficient to distinguish the performance and economic returns of different technical options with practical differences in dimensions or materials. Standard acquisition methods for project level data collection. Would usually require automated acquisition methods for network surveys and use for network level programming. Requires reliable institutional support and resources.
3	Sufficient detail for planning models and standard programming models for full network coverage. For project design, it would suit elementary methods such as catalog type with meager data needs and low-volume road/bridge design methods. Can be collected in network surveys by semiautomated methods or combined automated and manual methods.
4	The basic summary statistics of inventory, performance, and utilization that are of interest to providers and users. Suitable for the simplest planning and programming models, but for projects is suitable only for standardized designs of very low-volume roads. The simplest, most basic collection methods, either entirely manual or entirely semiautomated, provide direct but approximate measures and suit small or resource–poor agencies. Alternatively, the statistics may be computed from more detailed data.

(3) semiautomated, and (4) remote collection. Regardless of the method used, the existence of an effective quality control and quality assurance (QC/QA) program is vital for the success and reliability of the collection. A brief description of each method follows (VDOT 2004).

Manual Collection

This method employs two or more data collectors and a distance-measuring device. The collected data are documented either with pen and paper, or in more recent cases, with handheld computers equipped with GPS (Larson and Skrypczuk 2004a). At a particular location, the data collectors walk from one site to the other and inspect and record the condition of the considered assets. A variation of this method, the windshield survey, uses a vehicle to perform the inspection while driving; the recording is still done manually. Manual surveys allow for very detailed data collection but are very labor intensive and require more time per asset than automated or semiautomated methods.

Automated Collection

This method involves the use of a multipurpose vehicle equipped with a distance-measuring device as well as combinations of video cameras (downward- or forward-looking), gyroscopes, laser sensors, computer hardware, and GPS antennas in order to capture, store, and process the collected data. The gyroscope and GPS are used to capture location data. The laser sensors are used to acquire pavement surface properties, and the downward-looking cameras are used to assess pavement surface properties (usually distresses).

The forward-looking cameras are used to determine the location of roadside assets and assess performance measures. Specifically developed software is generally used to visualize in three dimensions the location of the transportation assets from the digital two-dimension frames. The newest data collection equipment has achieved high automation and accuracy and is capable of very fast, comprehensive data collection (Peggar et al. 2004; Rada et al. 2004). In most cases, however, even with the use of automated methods, some post processing of the data is required.

Semiautomated Collection

This method involves similar equipment as the completely automated method but with a lesser degree of automation. It is very popular within transportation agencies and yields comprehensive and accurate data collection when properly implemented.

Remote Collection

This last method pertains to the use of satellite imagery and remote sensing applications. These methods involve high-resolution images acquired through satellites or other types of images and scans obtained by remote sensing technologies (e.g., lasers, aerial photos, etc.). The images are used in conjunction with ground information in order to reference the location of the transportation assets and to assess asset condition or capture various asset attributes and characteristics (NASA 2000; NCRST 2001).

The general progression of automatic transportation Asset Management data collection is as follows (VDOT 2004):

- Photolog: This was the original data collection method and was used from the 1960s to the 1980s. Data had to be viewed through sequential image access or film (VDOT 2004).
- Videolog: This was mainly used during the 1980s, but in some cases it is still in use today. Data could be randomly accessed if they were placed on a laser disk. Today's practice uses mostly digital video.
- Regular resolution digital images (i.e., 640 by 480 dpi): This has been mainly used from the mid 1990s to present. Images are placed on various storage media (magnetic tapes, CDs, DVDs, etc.) and on network servers.
- High-resolution digital images (i.e., 1,300 by 1,000 dpi or Linescan cameras with up to 4,000 pixels per line): This has been mainly used from the end of the 1990s until present. Images also can be placed on magnetic disks but are mainly on network servers and databases for network sharing.

The collection of data for transportation assets can have various purposes, such as inventory, inspection, tort reliability, and performance monitoring. The frequency of data collection may vary accordingly to its purpose. Data collection frequency usually depends on asset type, asset condition, and other factors. More information on data collection frequency can be found elsewhere in VDOT (2004).

Data Characteristics and Properties

The literature review of how agencies worldwide deal with decisionmaking has brought to light particular attributes and characteristics that the collected data should possess in order to be useful for this purpose. Regardless of the particular type or category that the collected data fall into, it is of paramount importance that, when incorporated in a database, they exhibit the following characteristics (Deighton 1991):

- Integrity: Whenever two data elements represent the same piece of information, they should be equal.
- Accuracy: The data values represent as closely as possible the considered piece of information.
- Validity: The given data values are correct in terms of their possible and potential ranges of values.
- Security: Restricting access and properly ensuring systematic and frequent backups in other storage media protect sensitive, confidential, and important data.

It is also recommended that the data elements be rigorously defined in a data dictionary and that—in the most ideal of all cases—these definitions be common between all agencies and parties involved in this area of practice (Deighton 1991).

In addition, the Western European Road Directors (WERD 2003) highlighted the importance of the following criteria when selecting data required by an agency or organization:

- Relevance: Every data item collected and stored should support an explicitly defined decision need.
- Appropriateness: The amount of collected and stored data and the frequency of their updating should be based on the needs and resources of the agency or organization.
- Reliability: The data should exhibit the required accuracy, spatial coverage, completeness, and currency.
- Affordability: The collected data are in accordance with the agency's financial and staff resources.

According to the same source (WERD 2003), agencies planning to engage in data collection should consider and determine the following parameters:

- Specification of the data to be collected.
- Frequency of collection.
- Accuracy and quality that the data should exhibit.
- Completeness and currency.

As a general recommendation, it is noted that the accuracy, quality, and currency of the data should be decided based on the cost of the data collection and the value and benefit associated with the data in question, "Data should only be collected if the benefits that they provide outweigh the cost of their collection and maintenance" (WERD 2003). Data collection costs can and should be minimized by collecting only the needed data and only when needed. The data collection activities and methods used should be based on and produce results that match the levels of accuracy, precision, and resolution required by the decision processes to be supported (Smith and Lytton 1992).

Data Management

The data acquired by one or more of the above described methods and technologies are stored in various formats and storage media. Data formats include paper, electronic databases, and geo-referenced database systems (such as GIS). The storage media employed can be paper forms (still in use in many agencies), hard disks, magnetic tapes, CDs, DVDs, and combinations of these. Electronic data are the easiest to share and can exist in various forms such as text, graphics, photos, and videos. They can be stored either in flat files or in structured database files (relational, object-oriented), which can be standalone or part of a database system.

Organizational culture has traditionally prompted agencies to create database and information management systems that support specific applications such as pavement, bridge, sign, equipment, finance, and other management systems. These independent, legacy, stovepipe systems have to be linked in order to efficiently support Asset Management. The realization of this goal has proved to be extremely challenging because the aforementioned systems often use different data management technologies and information system environments (e.g., database design, software, hardware, etc.; FHWA 2001f). This is the focus of the next section.

Data Integration

As transportation asset data have been collected at different times by different units using different methods stored in varying formats and media, there is naturally a need for data integration. Data integration is essential to transform the data into information that is able to support decisionmaking at the various management levels. Transportation agencies must organize the available data into suitable forms for applications at the different organizational levels of decisionmaking. This venture presents a significant challenge because of the difficulty of data integration.

According to FHWA (2001b, 2001e, 2001f), data integration alternatives include two main approaches: (1) a fused database and (2) many interoperable databases. In the first case, the integration strategy leads to the creation of one database that contains all integrated data; in the second case existing or newly created databases are linked together, and the integration of the data is achieved with the use of queries that provide a view of the linked data.

The choice between the two integration strategies depends on many factors and is clearly a judgment call for the agency officials. The factors to be considered include the following:

- Intended use of the integrated data (by whom and for what purpose).
- Characteristics of the existing databases or information systems.
- Type and volume of the data to be integrated.
- Currently available information technology.
- Level of staff and resource allocation that will be dedicated to the process.
- Structure of the agency or organization itself (business units and their roles, data needs, people, and information systems).

Because location is an important property of all transportation assets, it has served in many cases as the common platform used for data integration. For example, various State DOTs have used GIS and other geospatial tools for data integration (Flintsch et al. 2004). GIS software and related functionalities can alternatively be incorporated in the databases as external software that enhances the analytical and reporting capabilities of the system (FHWA 2001f).

Another aid for the integration and interoperability of databases is the use of commonly accepted data definitions and consistent formats across systems. A standard data dictionary or global standard for data definition, representation, storage, and communication could be vital to data integration regardless of the integration strategy implemented. However, agencies have identified many challenges in developing and implementing data standards and converting existing legacy data to these new standards. These challenges include agreeing on suitable data formats, models, and protocols when the existing databases present extreme diversity; achieving support from the agency staff and getting people to conform to the new standards; and reducing the effort and resources needed as much as possible and implementing the standards (FHWA 2001f).

Decision Processes and Data Collection

Independent of the data integration strategy chosen and the level of integration achieved, there are many dimensions inherent in the analytical and decisionmaking processes concerning transportation assets that need be taken into account. Decision processes can (1) be at an operational level (i.e., how to repair a bridge component) or at a more generalized strategic level (i.e., how often to resurface a road), (2) address a specific project that is geographically restricted and has a narrow scope (i.e., a route or a highway section) or a complete network of roadways (i.e., all State rural arterials), and (3) refer to resource allocation and analysis of alternatives across different assets (i.e., pavements, bridges, tunnels, signs, etc.) or different governmental jurisdictions (i.e., counties, districts, etc.). Therefore, large diverse data are needed to fully support the decision processes in all their possible dimensions and in all levels of decisionmaking within the agencies.

In addition, the resulting system's complexity is high enough to intimidate even carefully designed strategies and high levels of data integration (FHWA 2001f). A carefully conceptualized thought process of rationalizing which data is needed to support which type or level of decision processes needs to be developed. This process can lead to more effective and efficient data integration within the intended scope of the data and the decision systems they support.

The data needed to populate a complete database and inventory for the assets managed by a State transportation agency are enormous and costly. Data should be collected according to their intended use and therefore data collection should be carefully planned according to these needs. This is a notion that has been identified early in the development of Asset Management (Nemmers 1997), but occasionally seems to be forgotten. In that context, transportation agencies and organizations need a cost effective and rational approach to data collection. For this purpose, the existence of specific links between the collected data and the actual decisions they are intended to support have to be investigated.

Asset Management Implementation Efforts

This section presents a brief review of the state-of-the-practice in the United States and the world regarding Asset Management, individual management systems, and issues revolving around data collection. Although significant advances have been made in the implementation of Asset Management or individual management systems, the literature has very little information about the data needs of the various transportation agencies' decisionmaking processes. This is partly due to this issue's relative newness for most agencies (private or public) and because it affects only agencies that have already taken the initial step of developing Asset Management inventories and databases. Because the concept of Asset Management is relatively new and because there have been many hurdles in its implementation process to begin with, it is not surprising that formal links between decisionmaking processes and data collection have not been identified.

Domestic Experience

Most States have implemented some sort of management system for at least some of their individual assets, and many have reportedly been moving toward the integration of these systems. Asset Management efforts are underway, but as mentioned previously, with many implementation hurdles yet to overcome.

There have been several efforts to capture the U.S. state-of-the-practice and to document the degree of development of Asset Management systems. For example, Flintsch et al. (2004) investigated the number of States that use and collect major pavement management system (PMS) data types (table 4). In this investigation, State DOTs were asked to report whether their PMS was using specifically identified data items, whether these items were collected by the PMS's data collection activities, and what the data collection methods were. Furthermore, in order to get more specific about the U.S. practice, one has to recognize all the stakeholders that influence the development, endorsement, and implementation of Asset Management in the United States. Stalebrink and Gifford (2002) identified the main stakeholders, including three levels of government (Federal, State, and local), various organizations, academia, and consulting firms. In addition, the private sector contribution to Asset Management know-how should also be acknowledged (Nemmers 1997).

Concerning the various levels of U.S. Government, there have been several reports coming from State DOTs and municipal departments that present and analyze their current state-of-the-practice. These reports refer to implementation efforts, general methodologies adopted and implemented, and breakthrough initiatives undertaken, among others. They indicate that many State and municipal transportation agencies have been moving toward an integration of individual management systems and databases to support Asset Management. There have been efforts to integrate GIS in their information systems (Flintsch et al. 2004), to enhance data collection methods and procedures (Larson and Skrypczuk 2004a), and to develop models that link strategic goals and resource allocation to elements of an Asset Management system (Ogard et al. 2004).

Organizations, such as the Transportation Research Board (TRB) and the Governmental Accounting Standards Board (GASB), have made significant efforts to enhance the level of knowledge of Asset Management and to support its implementation by the creation of relevant committees and task forces and by linking Asset Management with accounting reporting governmental mandates such as GASB 34 (GASB 1999).

Within academia, various universities and university clusters, (e.g., the Midwest Regional University Transportation Center [MRUTC]), have made significant efforts to promote knowledge exchange and research concerning Asset Management principles and methodologies (MRUTC 2002a, 2002b). Some of these universities have even created courses addressing Asset Management in their graduate degree programs (Stalebrink and Gifford 2002).

Table 4. Number of DOTs that use and collect each major pavement management system (PMS) data type.

Item	PMS Uses Data Item?		Collected By PMS?		Data Collection Method			
					Manual	Auto	Both	Total
Road Inventory	44	85%	13	25%	14	5	20	39
Pavement Condition	52	100%	43	83%	9	14	28	51
Traffic Volume	41	79%	2	4%	2	14	21	37
Equivalent Single Axle Loads	31	60%	3	6%	6	11	12	29
Maintenance and Rehabilitation History	44	85%	26	50%	34	1	8	43

Finally, private sector firms have participated in several peer-exchanging conferences and symposia to bridge the gap between themselves and the public sector regarding Asset Management implementation efforts and challenges (AASHTO 1999). The American Public Works Association has also dedicated resources to developing guides and promoting research in this subject area (Danylo and Lemer 1998; Stalebrink and Gifford 2002).

Canada

Canada has been moving in the same direction as the United States. Canadian transportation agencies, universities, and public and private organizations have been promoting Asset Management and funding-associated research since the late 1990s (Vanier 2000). These efforts, complemented by the extensive Canadian experience in individual management systems (Haas et al. 2001), have resulted in a thorough development of the Asset Management state-of-the-art and has led to the publication of a variety of research reports (Cowe Falls et al. 2001; Haas et al. 2004).

Besides the various official publications on Asset Management issued by the Transportation Association of Canada (TAC 1999), Asset Management has been of interest to Canadian municipalities in charge of municipal infrastructure assets. Therefore, significant effort has been made in providing guidelines and creating a framework for the implementation of Asset Management in this area (NGSMI 2003). Reports produced in the past few years suggest that Canadian authorities and other stakeholders are very much interested in the concepts and methodologies of Asset Management and look forward to its gradual implementation.

However, significant implementation of Asset Management in Canada has yet to be seen because there are various hurdles to overcome and little related experience. Canadian provinces have possessed individual management systems (pavement, bridge, and maintenance) for a long time. In recent years, there have been efforts to draw on the experience of utilizing these systems for the promotion of Asset Management implementation. The focus mainly has been on the integration of such individual management systems under the umbrella of Asset Management (Cowe Falls et al. 2001).

Australia and New Zealand

Australia and New Zealand have been among the pioneers of Asset Management. The first related efforts and reports date back to the late 1980s, and since then there has been much research in this subject (Sheldon 2004). Australian transportation agencies conducted early studies toward the state-of-the-art of Asset Management (Burns et al. 1999) and in 1990 were the first in the world to capitalize and record their road and bridge infrastructure in their annual reports (Sheldon 2004). One of the first comprehensive guides to Asset Management, "Total Asset Management," was issued in 1996. The Australian Procurement and Construction Council recently published a revised version, "Asset Management 2001" (APCC 2001).

Australian transportation organizations and authorities have repeatedly reported their progress toward Asset Management implementation and have produced significant results in all related fields, including data collection and related methods and equipment (Pratt and Ferguson 2004; Sheldon 2004), decisionmaking systems and their implementation and evaluation (Robertson 2004), and refinements of their state-of-the-art through new methodologies (Paine 2004), policy updates (APCC 2001), and implementation recommendations for efforts concerning partnerships with the private sector (Jordan 2004).

Similar efforts have taken place in New Zealand. Significant progress has been made in the implementation of Asset Management concepts by the public transportation authorities (Robinson 2000) as well as by the private sector (Pidwerbesky and Hunt 2004).

Finally, both Australian and New Zealand transportation authorities have been moving lately toward the issuing of performance-oriented maintenance contracts for their road networks, creating another milestone in their implementation of Asset Management concepts and methodologies (Robinson 2000; World Highways 2004).

Europe

European transportation agencies present a very diverse picture in terms of their endorsement of Asset Management methodologies and principles and their consequent implementation efforts. Many European countries are still in the phase of developing or investigating the potential advantages of individual management systems, and implementation in this respect is still very premature. Other countries, however, are much more advanced and have been considering integrating their existing management systems within an overall Asset Management framework.

The United Kingdom has been among the pioneers in Europe, reporting on related efforts starting in the 1980s. The British Highways Agency has reportedly been using individual management systems for pavements and maintenance and is currently moving forward in introducing new, more effective data management schemes to accommodate its new business functions (Hawker 2003; Hawker et al. 2003a, 2003b; Hawker and Spong 2004; Spong and Pickett 2003; WERD 2003).

In the Nordic countries (Norway, Sweden, Finland, and Denmark) the use of individual management systems has been abundant for many years. These countries are now beginning to investigate the merits resulting from the integration of these systems under an Asset Management framework, and research projects are being conducted in most of them (Kristiansen 2003; Männistö 2003; Männistö and Inkala 2003; Potucek and Lang 2004; Sund 2003; Sund et al. 2004; WERD 2003). In these countries, there is also ongoing research in the area of data collection and its related topics (Offrell and Sjögren 2003; Ruotoistenmäki et al. 2003; WERD 2003).

Germany has also been promoting the use of individual management systems for its road network (Krause and Maerschalk 2003; Woltereck 2003). Significant work has taken place in the area of data collection and integration (Bock and Heller 2003; WERD 2003) as well as in the creation of a common road data catalog for all German road administrations (WERD 2003; Socina 2004).

Similar efforts in the development and initial implementation of individual management systems coupled with research and development in the area of data collection and management can be found in many other European countries, such as Austria (Petschacher 2003; Weninger-Vycudil et al. 2003), Croatia (Keller et al. 2003; Srsen 2003), the Czech Republic (WERD 2003; Fencl 2004), France (WERD 2003), Italy (Crispino et al. 2003), Portugal (Picado-Santos et al. 2003a, 2003b), Slovakia (WERD 2003), Spain (Gascón Varón and Vázquez de Diego 2003), Switzerland (Scazziga 2003), and Ukraine (Vincent et al. 2003). Furthermore, in many of these countries, there is already a trend toward Asset Management with various efforts focusing on integration of databases and management systems.

Finally, in some other European countries, such as Greece, the adaptability of individual management systems in local conditions is still under investigation, and implementation efforts in this area are still in the initial stages (Roberts and Loizos 2004; Loizos and Papanikolaou 2005).

Summary of the Literature Review

Many agencies in different regions of the world are working on the implementation of individual management systems, integrated infrastructure management systems, or Asset Management initiatives. The number of transportation agencies that are beginning to adopt, support, and implement the concepts and methodologies of Asset Management is rapidly increasing.

Asset Management implementation efforts have focused mainly on the overarching strategic and network (program) levels. For example, there have been efforts to link Asset Management systems with strategic planning and with overall network improvements. Data needs for this type of decision comprise aggregated overall network performance indices and overall network characteristics, (e.g., overall interstate mileage, total number of bridges, etc.).

In a similar vein, there have been advances in the project level of decision-making with the implementation of one or more individual management systems; in other words, pavement management systems (PMS), bridge management systems (BMS), etc. Data needs for these types of decisions are project-specific and require detailed inventory, condition, and performance data. However, it should be noted that the information gathered at this level is usually on an as-needed basis. It is collected only for a reduced number of assets that have been identified as the ones needing work, usually from the network-level analysis. Strong emphasis has traditionally been placed on the data needs of project-level decisionmaking and will continue to be so, although these needs depend on and are most usually defined by the individual management systems and process employed at this decision level.

Last, the utmost of implementation efforts have been cases in which common databases have been or are being created to minimize data storage and enhance interoperability between different management systems. These efforts do not usually address any particular decisionmaking level per se, but they contribute to the enhancement of the underlying foundations of all levels, which are the data and their corresponding issues of storage, analysis, etc. No efforts, however, have been reported in practice aiming at an overall system or network optimization. The optimization focus has been restricted to the various individual systems, although the notion of an overall systems integration can be found profusely in the literature.

The literature review has revealed that although there has been progress and research in almost all levels of decisionmaking, the level that has received the least attention in terms of its data needs is project selection. This level, however, is of vital importance to the overall success of the management because it links the overall network with the individual, specific projects. Project selection has unique data needs: The data must be detailed enough to effectively assist the understanding and rationalization of project selection, and at the same time they must be aggregate enough to allow projects of different nature and scope within the entire network to be addressed. Therefore, this decisionmaking level requires data that are between being too general and too specific. General data would not help in the selection project because they would ignore vital project details, but it is usually not cost-effective to collect very detailed (i.e., project-level) data for the project selection process. Furthermore, project selection has traditionally been made between projects that belong to the same asset class. Asset Management encourages the broadening of this traditional practice by encouraging cross-asset comparisons between the candidate projects for selection. This has obviously increased the data needs and has also created the need for the identification and use of effective selection methodologies that are equitable and unbiased in their application to all different asset classes.

CHAPTER 2

Survey of Practice

A two-part Web-based survey was formulated and posted on the Internet to capture the state-of-the-practice in the United States. A link to the survey was sent to 103 transportation officials, and their responses were stored in a specially designed database. Various sources were utilized in order to retrieve similar past experiences and facilitate the formulation of the survey, the database, and the subsequent Web-based program. The questions were as specific as possible in order to gain insight on current practices and also to avoid confusion in terms used and the actual information requested from the survey recipients.

The first part of the survey, "General Agency Information on Asset Management," contained questions on the following:

- Asset Management endorsement and implementation by the State DOTs.
- Existing or planned individual management systems.
- Existing levels of decisionmaking within State DOTs.
- Identification and rating of existing Asset Management decision processes and functions within State DOTs.
- Identification and rating of existing criteria used by the agencies for project selection.

The second part of the survey, "Roadway Asset Management," required more specialized and detailed input on current agency practices of data collection and project selection and contained questions on the following:

- Data management, collection methods, and integration.
- Rationale behind existing or future planned data collection.
- Evaluation of roadway asset data used for project selection.
- Identification of formally documented links between data collection and project selection or Asset Management decision processes in general.

The questions were prepared by using various formats, such as radio buttons, check-all-that-apply boxes, and short essay question fields. Some questions asked recipients to elaborate on their selections in essay fields or to provide supplementary information on answers of "other." Furthermore, a prompt and email link were included to encourage participants to send the survey team helpful documents.

The Web page of the survey was developed using Macromedia Dreamweaver MX 2004 and was uploaded to the server. Access to it could only be granted by entering a valid email address at the survey's home page. The email addresses of all the survey recipients and administrators were used as a security control, so that only invited participants could login. An email was then sent to provide the recipients with the survey's Web page address link and also to explain the purpose of the research and its anticipated importance. The survey was open to responses for 3 weeks. All responses were stored in a project-specific database. The database was created using the MySQL tool.

The contents of the survey were refined several times by the research team for suitability of the contents, wording of the questions, and suitability of the format used for the various questions. In complementary form, the research team also sent the survey to the Statistics and Survey Departments of Virginia Tech for review and comment, and the team made various changes based on their feedback.

Finally, as an ultimate quality control effort, the survey was sent to the American Association of State Highway and Transportation Officials (AASHTO) expert task group, who supervised the project, to receive comments on the content of the questions and to provide feedback on the usefulness of the survey and its anticipated importance. The feedback validated the structure and contents of the questions, and further refinements were completed.

Results

A total of 48 completed surveys from 40 States were received. Therefore, the response percentage was 78 percent in terms of individual States and 47 percent of individual respondents. The obtained responses were downloaded from the database and stored in Microsoft Excel spreadsheets.

Seven States received responses from more than one transportation official. Furthermore, whereas some questions were State-specific and required only one valid answer per responding State, others inquired about the personal opinions of the responding State transportation officials. Because of this difference, two approaches were followed for processing the responses from the States that provided more than one response:

1. In the first case, the various answers within the same State were compared and discrepancies were resolved so that only one answer, as complete as possible, would be kept based on the following criteria:
   - Priority was given to the most complete responses. For example, in a case in which one transportation official reported that the State agency possessed two individual management systems and another official reported the possession of these two and an additional system, the final response would contain all three individual management systems from the second response.
   - Priority was given to the responses of transportation officials whose areas of expertise most closely coincided with that of the survey's questions

and input fields (according to the above criteria, the State response ultimately considered consisted of excerpts from responses provided by different officials).

2. In the remaining cases, in which the survey questions asked for individual opinions, all 48 answers were considered valid and were utilized in the analysis.

Answers to essay questions were not considered in the statistical analysis but were used as a guide for the resolution of discrepancies and also as a compass for the overall status of the responding State in relation to the researched topics. Information from the essay questions utilized to identify candidates for the second phase of the investigation.

Asset Management Implementation

The responses to the first question concerning the implementation stage of an Asset Management system revealed that most of the responding States (24) are still in the planning phase. Only one quarter (11) of the respondents indicated that they have already implemented an Asset Management system.

The responses also revealed that most of the responding States have been utilizing individual management systems, the most predominant among them being pavement (39), bridge (39), and maintenance (34) management systems. Other systems include safety (SMS), congestion (CMS), public transportation (PTMS), and intermodal transportation (ITMS) management.

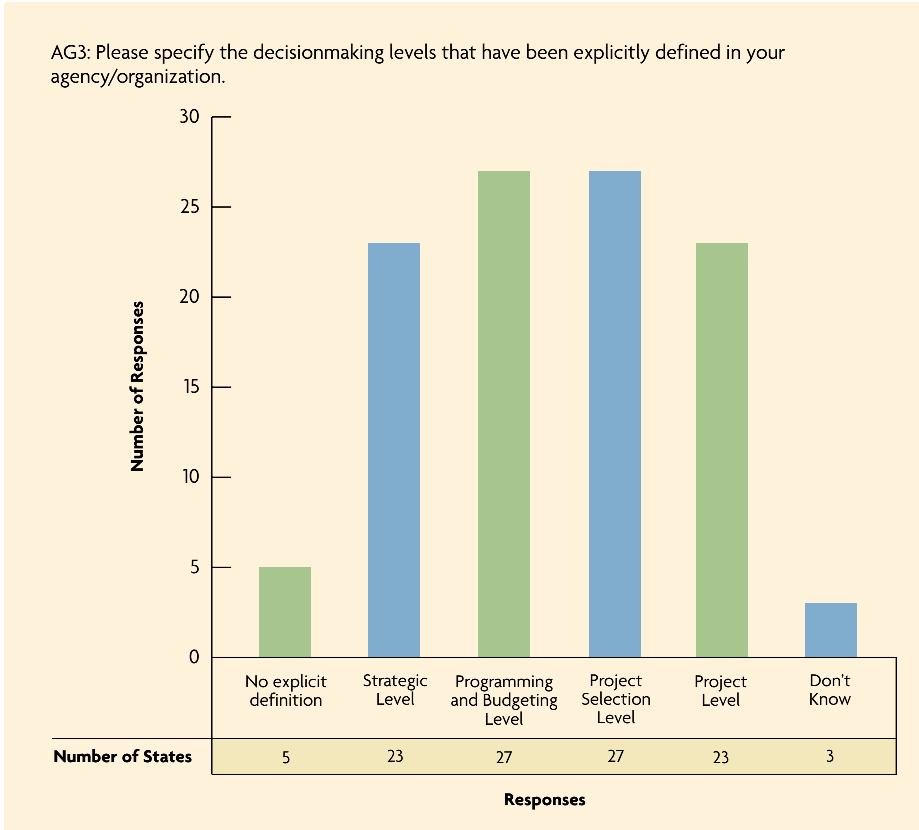
However, for most of these States, the level of integration of these individual systems within an overall Asset Management framework is still in the planning phase. Pavement and bridge management systems seem to be one step ahead of the remaining systems in terms of integration.

Decision Levels and Processes

When asked to report on their defined decisionmaking levels, most of the responding transportation agencies indicated that they have explicitly defined levels that coincide with the ones found in the literature (figure 5). The main levels identified were programming, budgeting, and project selection. This confirms that the correct transportation officials were selected because they were familiar with these levels of decisionmaking. It also confirms that the agencies had focused their attention to these intermediate levels connecting the generic strategic decisions of the strategic level to the actual project implementation at the project level.

Further in the survey, the State transportation officials were asked to rank a list of identified Asset Management decision processes in terms of relative importance. As mentioned, all 48 responses for this question were considered in the analysis. Figure 6 summarizes the responses and shows that most of the listed decision processes fall in the "very important" and "somewhat important" categories.

Figure 5. Defined decisionmaking levels.



The relative importance of the decision processes was determined by computing the average importance rating for each decision process using a score from 1 (not very important at all) to 4 (very important). Table 5 shows that the most important decision process turned out to be performance evaluation and monitoring with fiscal planning following closely behind. Project selection, which is the main interest of this investigation, ranked third, along with resource allocations, which denotes the anticipated significance of this business decision process to the responding transportation officials.

Figure 7 summarizes the relative importance assigned by the State transportation officials to a list of specific project selection criteria. As expected, the variability of opinions is more significant in this question. However, the criterion of available budgets/earmarked funds stands out as the most important criterion, followed closely by engineering parameters and public demands/user opinions. Table 6 shows the average rankings for all the listed criteria.

Figure 6. Asset Management decision processes and their relative importance.

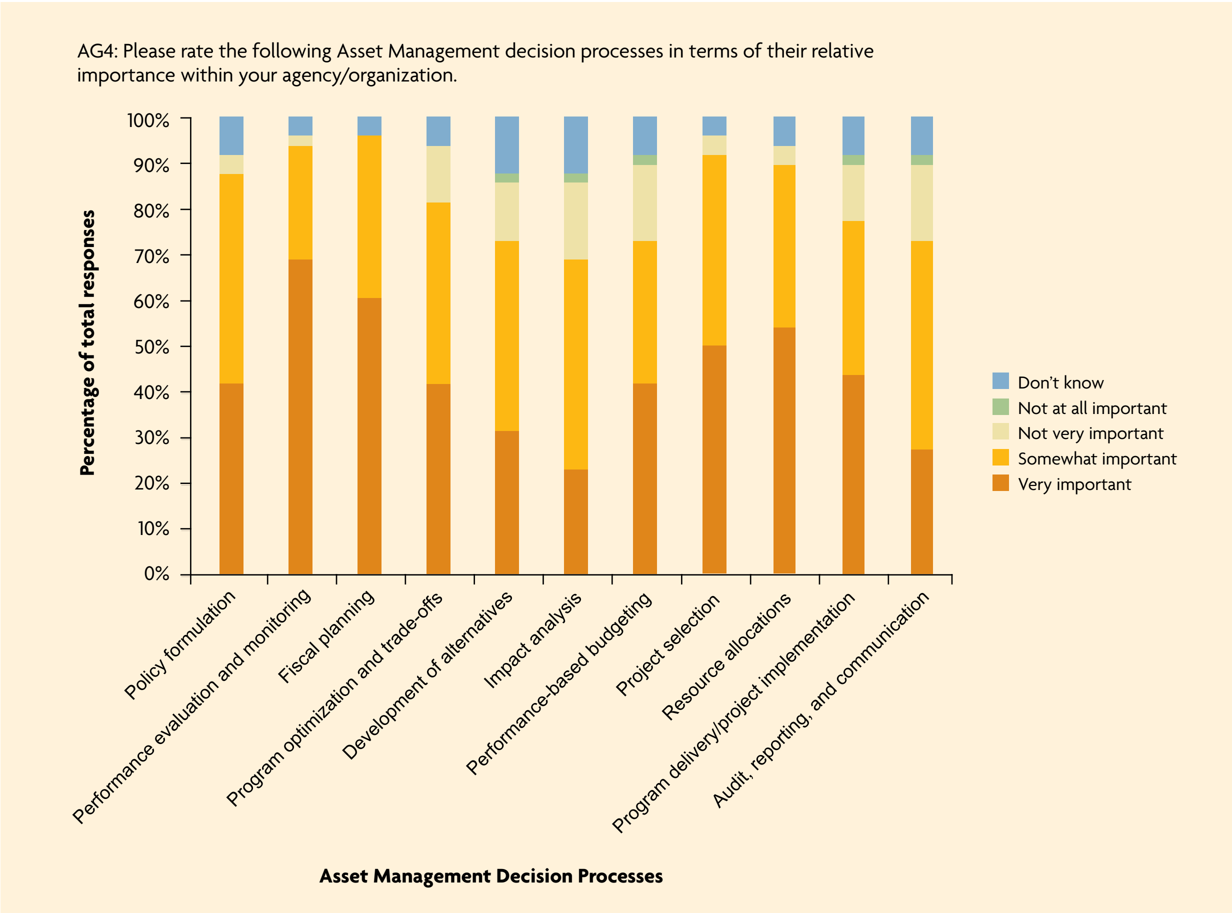


Table 5. Ranking of Asset Management decision processes.

Asset Management Decision Processes	Average Ranking
Performance evaluation and monitoring	3.54
Fiscal planning	3.48
Project selection	3.33
Resource allocations	3.31
Policy formulation	3.13
Program optimization and tradeoffs	3.10
Program delivery/project implementation	3.02
Performance-based budgeting	2.96
Audit, reporting, and communication	2.81
Development of alternatives	2.77
Impact analysis	2.65

1 = not at all important, 2 = not very important, 3 = somewhat important, 4 = very important

Figure 7. Project selection criteria and their relative importance.

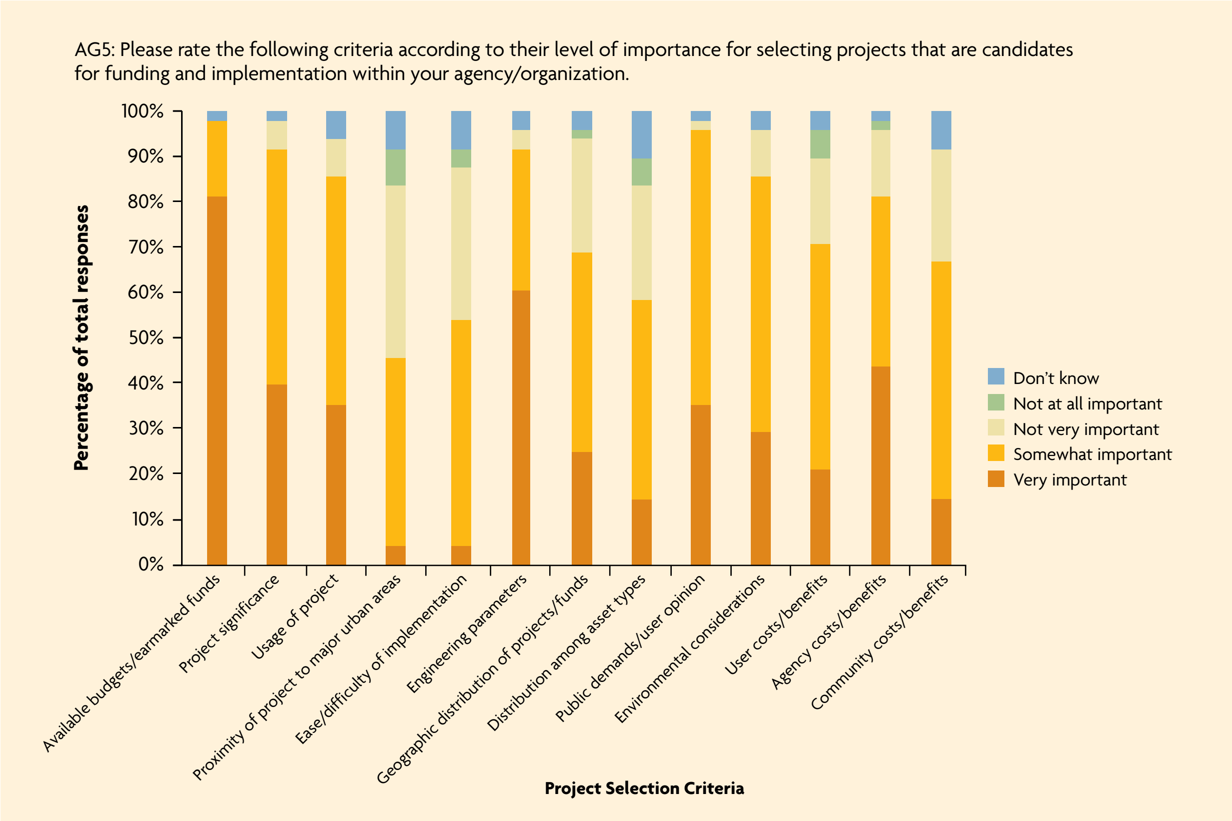


Table 6. Ranking of project selection criteria.

Project Selection Criteria	Average Ranking
Available budgets/earmarked funds	3.75
Engineering parameters	3.44
Public demands/user opinion	3.27
Project significance	3.27
Agency costs/benefits	3.19
Usage of project	3.08
Environmental considerations	3.06
Geographic distribution of projects/funds	2.83
User costs/benefits	2.77
Community costs/benefits	2.65
Distribution among asset types	2.46
Ease/difficulty of implementation	2.38
Proximity of project to major urban areas	2.25

1 = not at all important, 2 = not very important, 3 = somewhat important, 4 = very important

An interesting finding is that public demands/user opinions rank in third place, which shows the increased interest of transportation agencies in public satisfaction from the selection and implementation of projects. To the surprise of the research team, the vast majority (80 percent) of the responding officials agreed that the criteria used for project selection cannot or should not be uniform and consistent for all types of roadway assets.

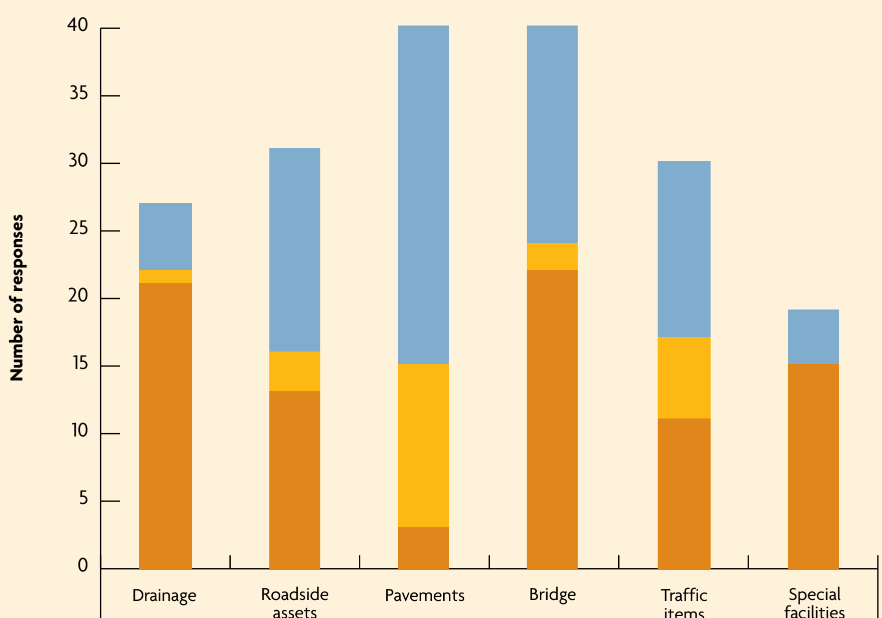
Data Collection Procedures

Most of the responding State agencies (75 percent) had already invested time and money in developing Asset Management roadway inventories and databases. The majority of the remaining agencies reported that they were planning for it. Most agencies have also been collecting data predominantly for their pavements and bridges. Traffic items and roadside assets were also reported to have been collected to a great extent.

Figure 8 summarizes the data collection methods used for the acquisition of such data. Whereas for some assets (e.g., drainage) the collection was reported to have been performed by mostly manual methods, there is a trend toward using a combination of manual and automatic methods. This is consistent with what was reported recently by Flintsch et al. (2004).

Figure 8. Roadway asset data collection types and methods.

RDW2: Please indicate if your agency collects data for each of the following roadway assets types and specify the data collection method.



	Drainage	Roadside assets	Pavements	Bridge	Traffic items	Special facilities
Both	5	15	25	16	13	4
Automatic	1	3	12	2	6	0
Manual	21	13	3	22	11	15

Roadway Asset Types

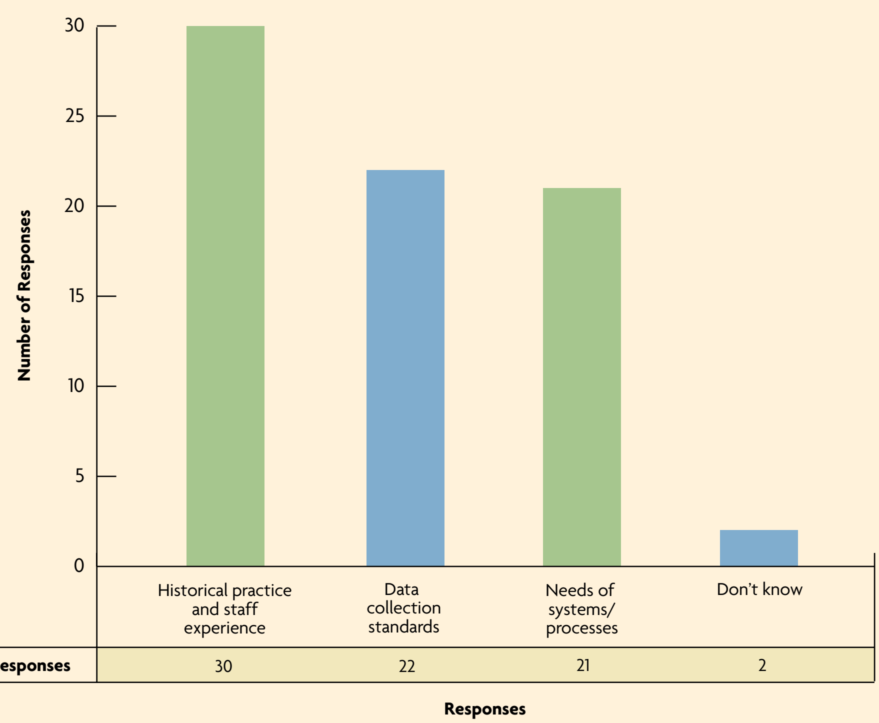
Data Collection Rationale

The officials were also asked to provide information about their rationale behind data collection. These results are summarized in figure 9. The responses confirmed that most agencies still base their data collection decisions on past practices and staff experience. However, many respondents also noted that data collection practices have been based on data collection standards and input needs of utilized management systems or other defined decision processes.

The next question asked officials to rate the importance of identified roadway asset data for the selection between two competitive projects. The ratings are summarized in figure 10 and table 7. As expected, the most important data are the assets' structural and functional conditions, with usage of the assets

Figure 9. Agency data collection rationale

RDW3: Which of the following statements best descibes how your agency/organization decides which data (and their related level of detail) will be collected to support the project selection decisions?



following in third place. The results conform to common sense and also show that the responding officials had predominantly the same perception of the data that would prioritize project selection between different assets.

Finally, the last question of the survey investigated the level at which State transportation agencies are conscious about the existence of links between their data collection activities and project selection. From the responses, it was determined that most agencies have identified (32.5 percent) or identified and documented in a formal way (52.5 percent) the existence of such links. This is an important finding because it shows that most agencies have been trying to rationalize their data collection according to specific decisions to be supported, as least for the project selection level.

Figure 10. Roadway asset data types and their relative importance for project selection.

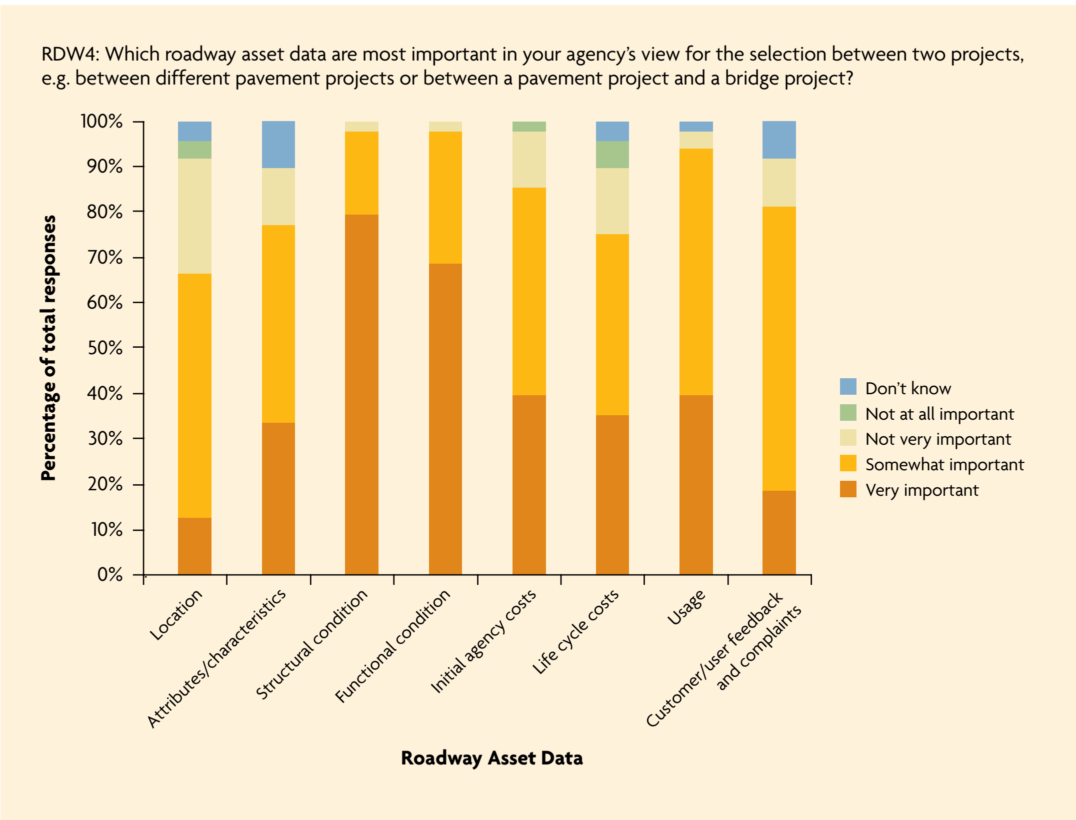


Table 7. Ranking of roadway asset data for project selection.

Roadway Asset Data	Average Ranking
Structural condition	3.77
Functional condition	3.67
Usage	3.29
Initial agency costs	3.23
Life cycle costs	2.96
Attributes/characteristics	2.90
Customer/user feedback and complaints	2.83
Location	2.67

1 = not important at all, 2 = not very important, 3 = somewhat important, 4 = very important

Summary of Survey Findings

The most important findings from the literature review and Web survey are the following:

- Transportation Asset Management implementation in the United States and around the world is still in its initial steps. Most of the surveyed transportation agencies, however, are planning the integration of currently used individual management systems toward this end. The same is true for roadway inventories and databases.
- The most important criteria used for project selection are available budgets/earmarked funds, engineering parameters, and the public demands/user opinions.
- Asset Management practitioners in general agree that project selection criteria cannot or should not be uniform and consistent for all asset types considered.
- U.S. transportation agencies' data collection decisions are still predominantly based on past agency practices and personnel experience. There is, however, a significant trend toward use of data collection standards and input needs of management systems or processes behind the rationalization of data collection.
- Most U.S. transportation officials consider the roadway assets' structural and functional conditions as the most important that data they use to support project selection between competing roadway projects. The usage of the assets is the third most influential data item.
- Most of the U.S. transportation agencies seem to have formally identified and documented existing links between the data they collect and the project selection decisions they wish to support.

CHAPTER 3

Case Studies

By using the information collected from the survey of experts, the research team identified six candidate States for indepth case studies. After communicating with these six State DOTs and reviewing the information provided, four agencies were selected for further study in the second phase of the project. In this phase, the research team met with these agencies to explore in detail the linkages between data collection and the decision process and to document their practices. The agencies selected have used different data collection approaches and represent different degrees of Asset Management implementation.

The first case study covers an agency that is developing a comprehensive Asset Management system using mostly internal resources. It has tried several approaches for data collection and has used both the agency's personnel and consultants. The second case study examines an agency that has focused its system development and data collection efforts on separate engineering management systems for different types of assets and is working on the integration of these systems. In this case, the review focused on the data collection for two types of assets: Pavement and storm water management facilities. The third case study illustrates a different approach for asset management that relies heavily on the private sector support. The reviewed agency outsources most of the maintenance of their assets through performance-based contracts. Although consultants perform most of the data collection, the agency has also emphasized incorporation of citizen input on the asset evaluation process. Finally, the fourth case study focuses on data collection practices that support one of the components of the agency's Asset Management system, the maintenance management system (MMS). The reviewed agency has developed the system and conducted the initial data collection by using a consulting firm that specializes in Asset Management. These examples may provide useful guidance for other agencies planning to undertake similar efforts.

Virginia Department of Transportation (VDOT)

About 10 years ago, VDOT started to develop an integrated infrastructure management system, which has evolved into today's Asset Management system. The work has included data collection, system analysis, automatic reporting, prioritization, and optimization. The current system is the first step in a long-term process, which will include data collection, development of system-wide analysis tools, and implementation. The efforts included the establishment of an Asset Management division, which has used all available information to develop a roadmap to the future for Asset Management. This roadmap includes the identification of core business needs and provides directions for reaching future DOT goals.

Table 8 summarizes the main decisionmaking levels formally identified by VDOT. The Central Office provides information about network performance targets, budget constraints, policy (best practices), and recommended programming results to the district maintenance engineers (DME). There is no explicitly defined Statewide project selection level: Because the districts have more information about their own infrastructures, they decide on specific treatments and projects. A data envelope analysis is used to identify best practices.

Core Asset Management Business Processes

The following core business processes have been identified:

- Condition assessment: This is conducted by the Central Office with support from the districts (pavement and bridges with random condition assessment [RCA] for the other most significant assets).
- Needs-based budget (NBB): Financial modeling is conducted at the network level by the Central Office (Asset Management and information technology groups).
- Project selection: This is conducted at the district level. The DME gets the needs-based budget and allocates the funds to specific projects. There are expert groups that have been appointed to develop and improve decision trees for the various asset classes.
- Feedback: Web-based flexible feedback tools allow permanent recording of any user feedback.
- Work accomplished and inventory updates: There is a module under development that will allow field crews to report their work by using PDAs or laptop computers.

These processes have not been formally associated with the decisionmaking levels included in table 8; however, several of them can be easily assigned as noted in their descriptions. VDOT is planning to address this issue in the near future.

Table 8. Decisionmaking level formally identified by VDOT.

Decisionmaking Level	Definition
Strategic Level	Decisions regarding cross-agency issues and funding allocation across the highway maintenance, mobility management, and operation programs.
Program Level	Operation of the programs (i.e., highway maintenance) to achieve established State network performance targets.
Project Level	Works related to district maintenance engineers, such as identification of funding for various projects.

Needs-Based Budgets

The NBB is the most highly developed Asset Management module and is presented as an example in this section. The NBB is an interactive tool that helps VDOT identify performance targets and computes the level of funding required to obtain the defined performance. At present it is currently an exclusively network-level tool to help the agency identify Statewide maintenance programs sponsored or funded by the commonwealth highway maintenance program (approximately $930 million per year). The Asset Management division has defined a performance measure matrix with the desired performance levels.

It is hoped that in the future NBB also will be a project-level tool used by the districts to set and track their performance standards. The planned process includes developing a performance-based budget for achieving a certain level of performance, sharing these numbers with the districts, and holding the districts accountable; however, the implementation of this process at the district level is in very early stages.

The Asset Management division is developing a module for evaluating the district performance and measuring the condition of their highway assets. This will allow adjustment of the funding distribution between asset groups across a 6-year horizon. It is expected that VDOT will be able to report this information to the public.

Information Needs

The VDOT has assessed the information needed on the basis of the decision models supported. However, the assessment has not been conducted as a holistic process, but more for the various individual processes or models.

There are several sources of information (data streams) collected to produce the needs-based budget:

- Pavements: The pavement condition data is gathered independently from the Asset Management system. There is a pavement management system group that performs condition surveys (at present mostly windshield survey and automatically collected profile data).
- Bridges: The bridge information is collected to feed the PONTIS bridge management system. The information is requested by a Federal mandate for the National Bridge Inventory.
- Other Highway Assets: The information about the other highway assets (eight types at the present time) is gathered through a simple strategy conducted Statewide. The RCA collects data from the assets that are most significant to the maintenance program budget. There is pressure from the field and management to increase the number of assets considered.

One of the lessons learned from the data collection efforts is that the agency needs to target the data collection to the most significant assets and to the decisions to be made. In the late 1990s, VDOT started a project that tried to capture every highway infrastructure asset on every highway Statewide. The project began in three counties as a pilot, and it was found to be too expensive and overwhelming. The current approach is to build the inventory over time.

Project Selection

The various maintenance and rehabilitation (M&R) strategies considered for the main asset types in the NBB have been defined by an expert panel composed of representatives from the Asset Management division and the districts. These panels have also defined the main selection criteria (and consequent data needs) and best practices decision trees. The districts can adjust the criteria on the basis of their knowledge and experience. The criteria are documented in the individual management systems (e.g., for pavement or bridges) and their respective guidelines and manuals. These criteria are used within the asset groups but not to evaluate tradeoffs among different asset classes. At present, VDOT does not conduct cross-asset tradeoff analyses.

Data Collection

Data only are collected for supporting decisions at the network level. Decisions on what data to collect are mainly on the basis of experience. The districts collect data and update information in a central database. The network-level data collection framework is revised annually. Project-level data collection policies (HTRIS) are quite mature. There are many offices involved with Asset Management data collection activities, more specifically, 9 district offices, 45 residences, and 246 area headquarters.

The information is updated annually and stored in a corporate database with a GIS platform. The pavement and bridge data are kept in separate databases that feed the central database once a year. The accuracy needed for the various data items has not been addressed objectively. However, there are good quality assurance procedures in place to check the information collected and input to the system. The agency is planning to conduct a sensitivity analysis to determine which data items have the most impact in the decisions.

The budgeting process defines the frequency of data collection. All the data is collected between January and May and revised during June and July to be used in August for the NBB. There are no good estimates of the data collection cost. The RCA costs approximately $60 per 0.1-mile segment, and the pavement data collection costs approximately $45 per kilometer.

Maryland State Highway Administration (MDSHA)

The MDSHA is also adopting enhanced Asset Management approaches and tools. The agency has developed a Statewide business plan that includes a number of goals and measurable objectives that support the agency vision, mission, and efforts. However, many of the agency's decisions are still made within individual silos, called program funds, which deal with individual asset types (e.g., pavements, bridges, storm water management facilities, etc.). At present, MDSHA does not evaluate tradeoffs among different types of assets in terms of these decisions being data driven or based upon quantifiable outcomes.

The level to which the agency has assessed the information needed to support the identified business processes varies by fund (asset type). The Asset Management steering committee has prioritized the funds and identified six that are currently being analyzed in detail. The inventory and condition data needed for these funds are currently under review. The discussion for this investigation will focus on two of these funds: pavements and storm water management facilities.

The agency spends approximately $1 billion per year in the capital program (including major capital improvements and preservation). The system preservation component accounts for approximately 40 percent ($400 million) of these funds. In addition, the agency spends approximately $200 million per year in its maintenance program, excluding winter maintenance activities.

Overview of the Pavement Management System

The MDSHA started to develop and implement an optimization-based approach for pavement management in 1997. This model follows a two-step process:

1. The pavement division in the Central Office develops network-level investment strategies that meet predefined agency objectives.
2. The engineering districts select individual projects in accordance with the recommendation of the selected network-level strategy.

Table 9 summarizes the main decisionmaking levels identified from the materials provided by MDSHA.

Maryland's pavement preservation program is developed annually based on the budget allocation established in Maryland's 6-year transportation program. The pavement management system has been used to coordinate

Table 9. Decisionmaking level formally identified by MDSHA.

Decisionmaking level	Definition
Strategic Level	Decisions regarding key program performance objectives, including percentage of roads with an acceptable ride quality, percentage of Maryland's National Highway System mileage with acceptable ride quality, and average service life of State Highway Administration pavements.
Program Level	Development of strategies for investment that meet a defined objective such as maximizing condition or minimizing costs. The strategy provides direction in how to invest in the pavement network.
Project-Selection Level	Selection of individual roadway projects by district to match up against the strategy.
Project-Design Level	Detailed project-level design subject to the treatment level and project costs defined in the previous level.

MDSHA's pavement management practices among districts and to develop several performance-based pavement preservation plans. The core processes of this program are: performance monitoring, model development, network optimization, project selection, funding approval, pavement design, and construction and maintenance.

All pavement management planning and pavement design efforts are conducted centrally within the pavement division of the Office of Materials and Technology with funding and project selection approved through the Office of the Chief Engineer. The seven engineering districts recommend projects to be considered in the annual system preservation program and manage the construction and maintenance operations within the district.

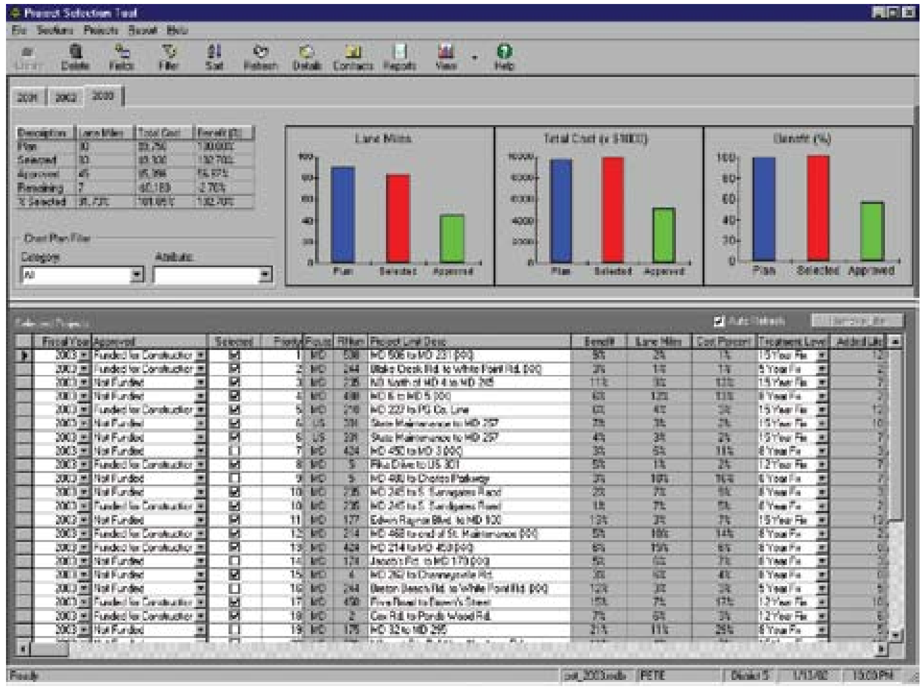
Core Asset Management Business Processes

The following core processes have been identified in the pavement management process:

1. Performance monitoring: Ride quality, rutting, cracking, and friction condition data are collected by the State (and provided to districts for project selection). Data collection decisions are mainly based on history and experience.
2. Model development: The pavement division (Central Office) has developed both probabilistic and deterministic models to predict the future pavement performance when each major treatment is applied to a pavement. Whereas the probabilistic models are used to support the forecasting and planning analyses needed at the network level, the deterministic models are used at the project level. The two kinds of models have been developed to produce consistent predictions. All the prediction models are updated annually.
3. Network optimization: The optimization process identifies optimal investment strategies to meet the performance objectives defined by the analyst (i.e., have 82 percent of the roads in acceptable ride condition). The MDSHA pavement network is organized into groups according to pavement type, traffic level, road type, road class, district, last major treatment level, and condition state (up to 5,040 groups). The output of the optimization is the percentage of each group that should receive each level of treatment.

   The optimization runs for multiple years (typically 5, 10, or 15 years) to evaluate the long-term consequences of the plan. The optimization runs are conducted by the pavement division and produce several investment strategies. The Chief Engineer's Office selects one of the optimization runs to develop the system preservation plan. The target number of lane–miles to be treated, available budget, and expected benefits are then communicated to each district. The benefit of treatment is calculated as the increment in the area below the performance obtained as a result of applying the rehabilitation treatment.

Figure 11. Screen capture of the project selection tool developed by MDSHA.



4. Project Selection: Each district is responsible for selecting the candidate paving projects to meet the three goals defined by the optimization process: lane–miles, budget, and benefits. A software package developed by MDSHA, project selection tool (PST, figure 11), assists the districts in the project selection process. The program is also used to ensure that the final system preservation program meets the goals of the plan.

   The district engineers typically organize a van tour of the network within their jurisdictions and generate a candidate project list. Then they work with the pavement division to verify the project attributes by conducting a windshield site survey by reviewing the digital roadway video logs and by checking with information in the databases. After the preliminary list is obtained and relative attributes are confirmed, the district engineers use the PST to estimate project costs by calculating preoverlay repairs and designing an overlay thickness by following the 1993 AASHTO design guidelines. The PST cost calculations include nonpaving costs for items such as guardrail improvement, contingency costs (a safety factor when the cost estimate is fairly uncertain), and administrative costs for construction management and inspection.

   The program allows the district to change the year for a project, the scope of the project (i.e., select a treatment that increases the pavement life by 8 years instead of 12 years), verify costs, change unit prices, etc. The districts select projects for funding to attend to the needs identified while achieving the line–mile, budget, and benefit goals established by the network-level analysis.
5. Funding approval: After the districts select projects for funding, the Chief Engineer's Office reviews the projects using the PST program and determines if each project will receive funding for design and construction. The Chief Engineer's Office may add projects not submitted by the district.
6. Pavement design: After the project is approved for funding, it moves into the project-level phase. The final pavement design for each project has to be consistent with the treatment selected noted in the previous steps. The pavement division designs a rehabilitation alternative that meets or exceeds the design life defined by the treatment level and that does not exceed the paving costs of the project defined in the PST program.

7. Construction/maintenance: The engineering districts are responsible for managing the construction and maintenance operations within their respective areas.

Project Selection

In the project selection process, the treatments applied to any of the pavement groups are categorized into seven groups on the basis of their life expectancy. The treatment groups are 15, 12, 8, 5, +4, and +2 years, as well as "do nothing." The first four treatment groups (5–15 years) are considered major rehabilitation alternatives that effectively reset the pavement to an original condition. The treatment groups of +4 and +2 years are considered maintenance treatments and are intended to reflect corrective or preventive maintenance strategies that maintain existing conditions or correct only a portion of the pavement and do not reset the pavement to an original condition. The treatment level group was created to reflect differences in performance and cost of rehabilitation improvements and to allow setting constraints that would force a minimum or maximum level of funding in each treatment level group.

Data Collection

The MDSHA collects both network- and project-level pavement condition data. The type and amount of data collected are selected on the basis of the requirements of the business plan, engineering judgment, and safety consideration.

The MDSHA annual network-level data collection includes ride quality, rutting, and friction for all directional miles under the responsibility of MDSHA (100 percent coverage). These data are collected using automatic data collection equipment: an automated roadway analyzer (ARAN) vehicle from Roadware, and a locked–wheel skid tester. The ARAN vehicle collects ride quality, rutting, right-of-way digital video, and downward digital video for automated cracking identification. The network-level distresses are summarized in pavement condition indexes (e.g., smoothness, rutting, and cracking) that are normalized to a scale of 0–100. Each roadway section is classified into condition states (A, B, C, D, or E) based on these indexes. The cost of collecting these data is approximately $40 per mile.

The project-level data collection includes pavement material structure and thickness determination, nondestructive deflection testing, and ride-quality testing. These data are collected using a high-speed profiler, a falling weight deflectometer (FWD), ground-penetrating radar (GPR), drilling/coring rigs, and manual visual surveys (using the PAVER pavement condition index [PCI]).

Data Management

The data contained in the PST program are integrated with the MDSHA pavement management database. Three sources of data are merged to create the PST roadway section data:

- Roadway inventory database: This database contains information on the roadway geometry, designation, and traffic. This data is referenced at 0.1-mile intervals.
- Pavement performance database: This database contains ride quality, rutting, cracking, and friction condition data. This data also is segmented at 0.1-mile intervals.
- Construction history database: This database contains records that identify every layer in the pavement structure including construction, material type, and thickness data. The data is segmented in various lengths based on consistent construction history and typically varies between 0.1 and 2 miles in length.

To create the roadway section data for the project selection program, the data from these three sources are merged and aggregated to provide summary information at the intervals defined in the construction history database.

Overview of the Drainage and Storm Water Facility Management System

The MDSHA uses a national pollutant discharge elimination system (NPDES) to manage drainage and storm water facilities within its jurisdiction. The initial motivation of the NPDES program was to assist in addressing drainage complaints from communities and to meet NPDES regulatory requirements. The highway hydraulics division began managing storm water facilities in 1982. Before the inventory process started, complaints were received by SHA through phone messages, emails, and meetings and were addressed with quick site designs and fixes. The new system allows MDSHA to collect data and manage the facilities more efficiently.

The NPDES is a large program involved in everything from the development of the database to the design of the drainage facilities. MDSHA's NPDES program was conceived as a two-phase Statewide program to address the MDSHA need for managing drainage structures and storm water facilities. The agency must identify, inspect, and maintain the hydraulic access facilities not managed by other divisions to ensure performance and public safety. Other divisions manage larger hydraulics facilities such as bridges. The focus is on storm water management facilities; however, culverts and other drainage features are being added in updates to the drainage inventory and condition assessment.

Core Asset Management Business Processes

Although the division has not formally identified separate business processes, the following processes are key for supporting decisionmaking:

1. Inventory: NPDES inventory process was initially a separate process, but it is now being coordinated with MDSHA's permit process. The inventory is stored using a GIS platform and a relational database developed using Microsoft Access.
2. Project selection and scoping: The division selects a strategy ("do nothing," "maintenance," or "rehabilitation") for each facility on the basis of the inventory and condition information. On-call contractors conduct routine maintenance through work orders. If the problem requires designs, the division creates a project similar to any other State project.
3. Execution of the recommended projects: The projects are outsourced.

Project Selection

The highway hydraulics division expends approximately $13.5 million each year managing hydraulic facilities. It uses open-ended contracts to maintain the facilities, which includes the actual design of the proposed solution. The open-ended contracts were found to be the cheapest and fastest approach to address needs. Routine performance and response inspections are performed every 3 years. If the ratings of the initial inspections suggest that more than maintenance is needed, then a second inspection is performed to confirm such decisions. Project selection decisions are made by the Central Office based on most-dangerous conditions and highest priority. If the need for remediation or retrofit is confirmed by the second inspection, a more formal evaluation is conducted on the basis of expert opinion.

Data Collection

The MDSHA's NPDES started a pilot to inventory hydraulic facilities in 1999. As part of the inventory process, the agency hired contractors to reference each individual node using GPS. These inspectors conduct the initial inspection of the facility. A second inspection is triggered if the performance-based rating is a 4 or 5.

Originally, MDSHA developed the inventory using available plans; however, the process has evolved, and the data are currently verified in the field. Inspectors take the plans to the field, locate the facilities again, and reference their location using GPS. The agency has prepared a detailed inspection manual for engineers to use when they assess these facilities.

The condition of the storm water management facilities is evaluated periodically by using two rating systems:

1. Performance-based rating: This is a performance evaluation of facilities for functional and structural integrity. Each facility is rated according to 45 items using a subjective 1–5 scale.
2. Response rating: This provides an estimate of the level of work required (how the structures will be maintained) and the priority for maintenance and remediation. The facility receives an overall inspection rating from A (no action required) to E (facility failed, hazardous conditions). Facilities with a rating of C or below are candidates for remediation.

Small drainage structures are added when possible. While inspectors collect GPS data (inventory) on the facility they can easily take a picture and provide a brief rating. Given the number of these facilities (hundreds of thousands), the agency cannot afford to inspect these smaller drainage systems on a regular basis. Most of the storm drainage networks are under the roadways and require video inspections because it is hard to get people into some of these facilities.

For example, in Baltimore County, MDSHA inspected 2,500 out of 4,000 structures and rated them by using a scale from 1 (best) to 5 (worst). Less than 10 percent of them were rated as a 4 or 5. The condition data are linked with NPDES data and the overall GIS inventory.

Decisions regarding what data to collect are based on an inspection manual that the MDSHA developed in 1999 to inspect storm water management facilities. No revisions to the manual have been made since its first release. This manual lists 45 items to be inspected for both project selection and project design. The agency also has a design manual that has been updated twice: once in 1980 and again in 2000.

Although there are no precise records about the cost of the various activities, MDSHA was able to provide some estimates. The storm water management division spends approximately $1 million on data collection (inventory and inspection) per year. The data collection cost was approximately $500,000 for the collection of the initial inventory data for one county; however, updating the information the second time was cheaper by approximately half of the initial cost. The most cost effective data collection procedure uses handheld PDAs and GPSs.

District of Columbia Department of Transportation (DDOT)

The DDOT is planning a performance-based comprehensive Asset Management system for the entire city. The department has recently issued two requests for proposals for the development of such systems for tunnels and roadways and is awaiting responses. The Asset Management division of DDOT is responsible for managing the District's transportation infrastructure: pavement, bridges, sidewalk, alleys, culverts, etc. The transportation network under DDOT's management includes: 1,100 miles of streets, 229 bridges, 1,405 miles of sidewalk, 335 miles of alleys, and 17 tunnels.

At present, the agency has several stovepipe systems that are not fully integrated. A pavement management system has been used since the 1980s. A consultant developed the original system, but the agency is currently migrating to PAVER. DDOT uses the AASHTO software PONTIS for bridges, and FHWA's tunnel management system for tunnels. The agency is also developing an engineering management system for alleys and sidewalks.

There are five distinct business units (administrations) inside DDOT: (1) transportation policy and planning administration, (2) infrastructure project management administration (IPMA), (3) public space management administration, (4) traffic services administration, and (5) urban forestry. The district is divided into eight wards, and each administration has its own team for managing the corresponding works under the wards. For example, IPMA has four teams that take care of the eight wards (two wards per team).

Projects are selected based on a combination of technical need and close citizen participation (through advisory neighborhood commissions). The technical offices prepare a list of candidate projects that is shared with the planners in the wards. They review the list, share it with citizens, and provide feedback. A revised list is prepared and submitted to the director and various associate directors, who review the proposals during monthly meetings and select projects based on the technical needs and the priorities established by the District's council and mayor. There are neighborhood infrastructure oversight officers who are responsible for seeking out deficiencies in their respective areas of the city and reporting them to the appropriate administrations. Citizen-reported deficiencies are also distributed to the appropriate person or office through a centralized call center.

In the last couple of years, DDOT started a 5-year pavement restoration program. DDOT implemented the program with two indefinite-delivery-indefinite-quantity contracts: one for local streets and one for federally-owned streets. The contractors work on pavement rehabilitation projects. The Asset Management division has developed performance measures for each asset and is working on a pilot experimental total Asset Management Partnership to include all assets (e.g., signs, lights, sidewalks, etc.) in collaboration with inhouse service providers.

For the 75 miles of the National Highway System (NHS) in the District, DDOT had a 5½-year performance-based contract. The contractor was responsible for maintaining all assets within the right-of-way (ROW) except traffic signals.

Data Collection

The DDOT is conducting a major project to inventory all assets in its transportation system and is developing the ADA Transition Plan. The assets are categorized into 34 groups. A consultant collects the inventory data in the pilot program, and some data also are reduced from the ROW camera information collected for the pavement management system.

In addition, the DDOT collects data for several of their main assets as part of their individual management systems:

- Pavements: DDOT conducts annual condition assessment through contractors to identify different distresses on pavement for each block segment and computes a pavement condition index (PCI on a scale of 0–100) on the basis of the individual distress types. Other performance measures such as the international roughness index (IRI) also are collected. The agency is expanding its pavement data collection by changing from one lane in each direction to every traveled lane in both directions. DDOT used to collect citywide pavement data every year, but the frequency has been reduced to every other year for local pavements and every year for Federal pavements.

- Bridges: Consultants conduct annual bridge condition assessments (following the PONTIS guidelines). If the contractor identifies some critical problem that needs to be fixed immediately, the maintenance contractor will receive a task to fix the problem from DDOT. Approximately one-third of the bridges are assessed every year.
- Sidewalks and alleys: There is an ongoing effort to develop a 6-year sidewalk-and-alley rehabilitation program. Data collected include GPS, pictures, length (extension), condition, and maintenance needs, among other attributes, and sidewalks and alleys are still in the process of inventory. The project selection will be based on both DDOT assessments and requests from citizens.

Public opinion also was considered in the performance rating process. DDOT organized a tour of the transportation system every 2 weeks as part of the assessment for the NHS asset preservation contract to evaluate cleanliness. The evaluators were provided with rating manuals before the tour, and they rated the various management units—3-block segments in the inner city and 2-mile segments on the highway. The results were forwarded to the contractor to help him prepare his work plans. The public also can review the work plans and give comments and suggestions. The process enables DDOT to maintain good communication with its neighborhoods and effectively provide the needed services.

Both the Central Office and individual branch agencies (parking, street lights, signs, and bus and mass transit) collect data on the assets that are their responsibility. The Asset Management division collects more detailed performance data, whereas individual branch agencies collect data that are more related to the selection of appropriate maintenance treatments. DDOT plans to make the asset condition information easily available to the public.

Whereas some of the information is stored in a central database, most of the individual branches maintain their own databases. There is a central repository (Web portal) that was developed for the NHS that includes all documentation related to the project. DDOT is investigating the possibility of expanding it for the entire city.

Data collection methods differ from asset to asset. For sidewalks and alleys, the contractor conducts a walking, visual inspection using laptops and PDAs. Pavement data are collected using automatic data collection vans equipped with cameras. Access equipment and laptops are used to support the bridge data collection.

The data collection costs vary by asset types. For pavement, DDOT paid its contractor $193 per mile for the data collection, which includes individual distresses, ride quality (IRI), and PCI. The contract for sidewalk and alleys has a lump sum cost. The contract included the development of a rating system, a citywide inventorying, and collection of condition information.

Project Selection

The DDOT is trying to evaluate tradeoffs among different types of assets by participating in a pilot program that evaluates the analytical tool recently developed by NCHRP. Currently, most of the project selection is done within the individual stovepipe management systems.

The budget for bridge projects is relatively constant every year. The FHWA provides about $28 million for bridge projects. There is more flexibility with roadway project budgeting even though the district receives some Federal funds every year. The Asset Management division develops a proposal about the works to be done and submits it to the teams. The director and associate directors, in cooperation with the teams, make the final project selection decisions.

The PMS identifies appropriate treatment for each block based on distress types and severity. The system also includes a cost module that is used to calculate costs for the candidate projects. The divisions then use cost–benefit analysis and project-to-project comparisons to determine the final list of prioritized candidate projects submitted for consideration by the director.

Because the assets managed by DDOT are located within the urban area, they cannot be evaluated using the same criteria and performance measures used by other States. For example, the IRI of pavement segments near traffic lights and stop signs could easily go beyond the national threshold value. Congestion (stop/go), multiple manholes, utility cuts, reducing and picking up speed before and after traffic lights, and other urban conditions affect IRI. For bridges, functional deficiencies identified by PONTIS (i.e., geometric design problems) are often overridden because fixing these problems usually is not feasible in a congested urban area.

North Carolina Department of Transportation (NCDOT)

The NCDOT operates the second largest State-maintained highway system in the Nation, which includes more than 78,000 centerline miles of highway and 17,250 bridges collectively spanning 380 miles. The highway system is divided into 14,616 miles of primary highways (Interstate, U.S., and N.C.) and 63,467 miles of secondary roads.

The NCDOT is in the early stages of developing a comprehensive Asset Management system. The agency has several operational engineering management systems, including pavement, bridge, and maintenance management systems that can support decisions regarding individual asset classes independently. However, these systems have not been integrated in a holistic Asset Management system.

Overview of the Agency's Decisionmaking Processes

The NCDOT's Asset Management division is organized in eight operational units: bridge maintenance, equipment and inventory control, intelligent transportation systems, oversize/overweight permits, pavement management, roadside environmental, secondary roads, and state road maintenance.

This review focuses on the state road maintenance unit, which is the largest unit in terms of personnel and budget. The unit operates the agency's MMS, collects road maintenance data, and provides support to other units that use the MMS program. The MMS is operational; however, some of the decision-making processes are still being defined and developed.

Geographically, the State is divided into 14 local division offices that report to the Asset Management division. This division recommends to the board of transportation the distribution of maintenance and resurfacing funds across the 14 geographical divisions and 100 counties, and it provides various program funding and expense reports for field operations and central units.

The field division offices are responsible for implementing the programs and policies established by the board of transportation under the supervision of the State highway administrator and the chief engineer of operations. These division offices are responsible for construction, maintenance, roadside environmental programs, traffic services, and the fiscal and facility operations involved in administering these functions.

Project Selection

The decisions regarding fund allocation and program delivery for the various organizational units can be divided as follows:

- Legislature and board of transportation: This organizational unit approves the budget.
- Highway administrator and NCDOT chief engineer of operations: This unit allocates funding to divisions (geographical locations) and by system.
- Division engineers: This group distributes the funds allocated to the division among the various units (maintenance, bridges, etc.) within the division.
- Division maintenance engineers: This group further distributes the assigned maintenance funds and assigns the budget for each district.
- District engineers and county maintenance engineers: This group selects and scopes projects and assigns work activities, locations, and work functions.

Tradeoffs among investments in different types of assets and units are made at the legislative level. These decisions are not directly based on analysis of condition information, though they use some of the information provided by the engineering management systems. This procedure is expected to change once the agency fully embraces a comprehensive Asset Management approach for the allocation of resources.

Maintenance Management System Overview

The condition of the network for the MMS is assessed periodically using a statistical sampling procedure. The condition of the sample of roads assessed is used for estimating the overall network condition based on certain predefined defects, (e.g., low shoulder). Once the overall condition is determined, the system selects feasible treatments from a list of corrective work functions that are defined for each defect type. Then the system recommends the most appropriate treatment for each condition rating. Appropriate work functions then are selected for these treatments based on generic performance guidelines included in the software. Last, the work functions assigned are used to estimate the funding required for the defect to an acceptable level. The same process is repeated for all defects.

The MMS program uses the efficient frontier method to optimize the allocation of the maintenance funds. The analyst can determine the maintenance level of service (LOS) that can be achieved with a given budget or the budget required to achieve a desired LOS. The agency has defined minimum acceptable LOS for each defect.

The MMS is used to analyze the overall Statewide system and to develop the budget to be proposed to the legislature. Once approved, a formula (based on population, area, etc.) with asset condition as one of its factors is used to allocate the money to each division; however, the agency is moving toward using the MMS to allocate the resources and develop needs-based budgets using the efficient frontier method previously mentioned.

In addition to providing the budget, the central engineering office advises division engineers regarding the areas on which they should concentrate their efforts. The division engineers are responsible for all the different assets within their division, and they allocate funding to different asset classes. These decisions mainly are based on the division engineers' experience and knowledge about the area and the condition data provided by the MMS. The division engineers conduct the tradeoffs and are held accountable to meet the targets for budget and performance or LOS. They have access to the MMS, which can help them with the allocation of maintenance budget. Other units support division engineers with other information. Monthly meetings between the central office personnel and division engineers provide the division engineers with the needed data.

The agency purchased a commercial MMS software package through a contract that included installation and implementation of the system. The NCDOT staff worked closely with the consultants to develop a system that provides NCDOT with the methodology and computer tools necessary to plan, organize, direct, and control maintenance field operations.

The project started in 2001 with the consultant performing onsite interviews with NCDOT personnel located throughout the State. The consultants then conducted a series of subject matter expert orientation and work sessions, customized the software to make it compatible with NCDOT operation business practices, and interfaced it with the agency's existing databases and GIS. Upon the completion of software customization, two pilot division areas (divisions 3 and 9) were selected, and their personnel were trained on the use of the software. After making the necessary adjustments, the system was installed in all other divisions, and Statewide training started soon after.

Maintenance Data Collection

The road maintenance unit has a maintenance condition assessment program. The program periodically evaluates the condition of certain elements, collects and organizes the data, and analyzes the results to determine the LOS of the road system. Every 2 years, the road maintenance unit conducts a condition rating on a statistically representative percentage of the highway systems. The sample size was determined using a statistical analysis that allows determination of the repair cost with a maximum error of $150,000.

The evaluation is used to estimate percentage of asset at each performance level. Twenty-one different defects have been defined. The last inspection conducted in 2004 included samples from each division area. The sampling is performed on rural interstate as well as primary and secondary road systems. The urban road systems also were included in the inspections; however, the agency does not plan to continue to include urban roads in future campaigns. The data collected and the performance measures for different units were determined through committees that have been formed for the different types of assets. The committees will also decide what specific work activities are associated with particular performance measures. The data collected were revised for the first time in 1998. The director of the Asset Management division also is in the process of defining a strategy for handling a broad range of assets across the agency.

The NCDOT units involved in asset data condition collection are road maintenance, pavement management, and bridge maintenance. The road maintenance unit employs two or three data collection teams for each division. The pavement unit uses one team per county, and the bridge unit conducts the assessment using one team per division. Extensive training including distribution of detailed manuals is offered to the data collection teams before the operations. In addition, three quality assurance teams from the road maintenance unit assure the quality of the data collected for the entire State by reevaluating approximately 5 percent of the highway samples (randomly selected) covered by the division teams.

Road maintenance data are stored in a central database, but these data are not integrated with the pavement and bridge management data; rather, each division maintains its own condition database. In addition, preprocessed data from each unit are periodically fed to a State data warehouse, but no analysis has been done using these data. It is expected that once the new Asset Management system is implemented the output from the PMS and BMS also could be used in the MMS. The MMS data collection is done manually. The outsourced data collection cost included with the MMS implementation was approximately $1.5 million. It is expected that in-house data collection will cost less than half of that amount. The agency will conduct the first in-house evaluation in 2006.

Lessons Learned

It is clear from the case studies that there is no one-size-fits-all approach for Asset Management data collection. The most appropriate approach will depend on the agency's needs and culture as well as the availability of economic, technological, and human resources. A gradual implementation of the data collection efforts appears to be the most appropriate approach because it provides opportunities for adapting the processes as data is collected and experience is gained. Most of the data collected is being collected separately as of present for individual assets types that support decisions within their corresponding silos. However, as the agencies embrace the Asset Management philosophy, the need for more consistent data collection among asset types and locations increases. Furthermore, the availability of advanced multipurpose data collection equipment has made this type of data collection not only possible but also more cost effective.

There appears to be a trend toward outsourcing at least part of data collection. In this case, it is very important that the asset owner provide clear expectations in terms of the data to be collected, required precision, and quality control and assurance procedures to evaluate the collected data. One common characteristic of success stories is that the agency has emphasized the usefulness of the information by collecting the data that is needed to support the various asset management efforts within the organization.

The main highlights of the data collection effort and Asset Management implementation in the visited agencies are the following:

- The VDOT has adopted a top-down approach for implementing Asset Management. The agency has focused its efforts on developing a system that can manage all assets and allow preparation of needs-based budgets. The agency used the experience gained from the use of individual engineering management systems to develop a framework that can be used agency-wide. The development effort has been gradual with different modules developed incrementally. Likewise, the agency has engaged in a staged plan to gradually step up the data collection efforts.
- The MDSHA is strengthening its existing management systems for various asset types or funds to then integrate the results and recommendations for these systems at the strategic level. Thus, data collection efforts have been tailored to collect the information necessary within each fund. The agency has developed a comprehensive strategic plan that establishes performance objectives and goals for the various funds.
- The District of Columbia is responsible for a different type of network, and it has used a different approach for managing these assets. DDOT has relied heavily on the private sector not only for development of software tools and data collection, but also for managing the assets through performance-based maintenance contracts. The experience with these pilot contracts has been considered successful. In addition, the agency has incorporated substantial citizen input into the process.

- The NCDOT is in the process of updating their engineering management systems and adjusting the corresponding data collection practices with the support of specialized consultants. The agency plans to integrate these systems and is developing LOS metrics and goals for the various asset types.
- All agencies reviewed have a decentralized approach for project selection, in which decisions on which projects to execute reside with the agencies' field offices. However, they also define desired LOS for the various assets and use those to enhance the service provided to the user of the managed assets and the accountability of the decisionmakers.
- Except for MDSHA, the agencies do not have specific software tools for supporting project selection decisions at the field offices. The project selection tool developed by MDSHA for selecting, communicating, and approving pavement maintenance and rehabilitation projects provides a good example of the type of tool that is needed for this purpose.

CHAPTER 4

Summary, Conclusions, and Recommendations

The majority of the transportation agencies in the United States and the rest of the world have endorsed the concept of Asset Management. The state-of-the-art has been steadily advancing, and various stakeholders have made significant contributions. However, Asset Management implementation is still at its initial stages, and there are many hurdles to overcome. In this respect, the development of integrated roadway inventories and databases is still underway in many agencies and so is the integration of individual management systems.

Transportation agencies in the United States have explicitly defined decisionmaking levels and are moving forward to a rationalization of their data collection activities. Past agency practices and staff culture is still the predominant decision factor behind data collection, but they have started to give way to decisions based on data collection standards and input needs. In the particular area of project selection, there also seems to be a formally established relationship between the data collected and the decisions supported.

Four States that have identified links between decision processes and data collected were selected to illustrate the process. The resulting case studies showed that there is no one-size-fits-all approach for Asset Management data collection. The most appropriate approach will depend on the agency's needs and culture as well as the availability of economic, technological, and human resources. A gradual implementation of the data collection efforts appears to be the most appropriate approach because it provides opportunities for adapting the processes as data is collected and experience is gained.

A data collection framework for project selection is recommended to optimize the data collection activities for project selection. The process provides clear and logical steps toward the complete rationalization of the data needs for these decisions. This framework, however, can only partially optimize the overall agency data collection activities because it only addresses project selection decisions.

Framework for Effective and Efficient Data Collection

The literature review confirmed that research in the area of Asset Management and its data collection has been extensive. Very little information, however, can be found concerning specified data collection in order to support project selection within the framework of Asset Management. This level links the overall network decisions with the individual projects. Consequently, it requires data that are simultaneously neither too general nor too specific. General data would not help in project selection because they would ignore vital project details, but it is usually not cost effective to collect very detailed (i.e., project-level) data for the project selection process.

Furthermore, project selection has traditionally been made between projects that belong to the same asset class. Asset Management encourages the broadening of this traditional practice by encouraging cross-asset comparisons between the candidate projects for selection. This has obviously increased the data needs and has also created the need for the identification and use of effective selection methodologies that can be applied equally and in an unbiased way to all different asset classes.

The survey of practice suggests that U.S. transportation agencies have clearly identified decisionmaking levels and also have relatively uniform perceptions of the importance of various Asset Management decision processes, project selection criteria, and the corresponding asset data that could support selection between competing projects.

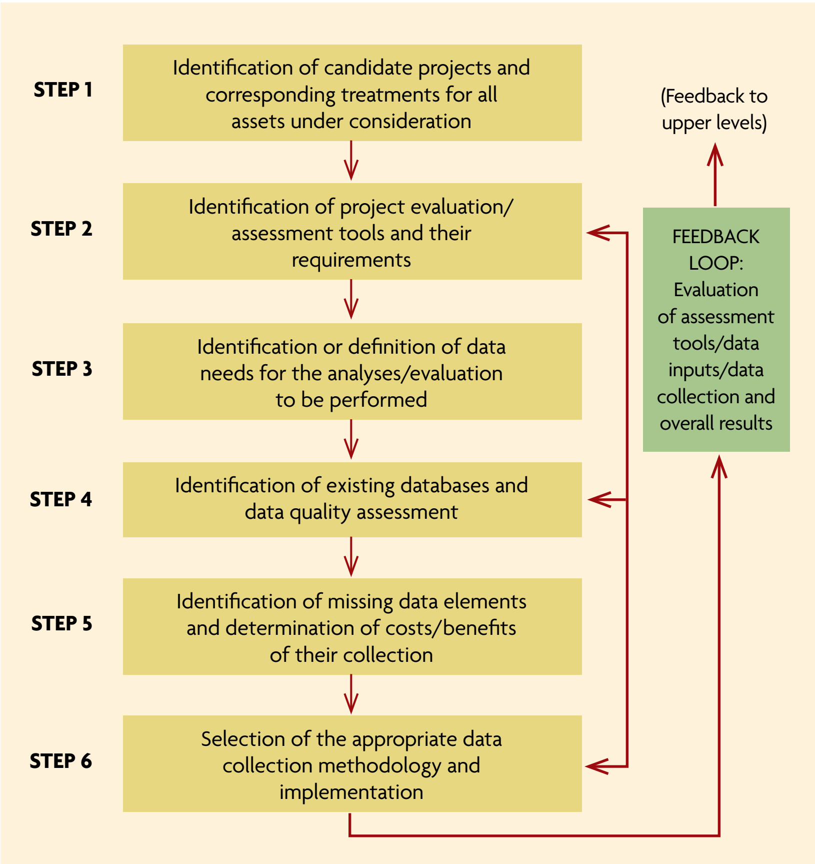
The findings from both the literature review and the survey analysis allowed for the recommendation of the framework for effective and efficient data collection presented in figure 12. In order for an agency to evaluate its data collection needs for project selection, the transportation officials should ask (and reply to) the following questions:

- What are the various types of roadway assets that need work?
- What is the LOS expected for these assets?
- What are the various types of treatments that should be considered?
- What are the evaluation models, techniques, and criteria used by the agency to judge the usefulness of the projects and rank and prioritize them?
- What are the inputs required by these models and techniques for the various projects to be assessed?
- What are the available data?
- What additional data need to be collected?

Once the needed data have been identified, then the agencies can decide on the level of accuracy, precision, and resolution needed and the most appropriate data collection method. The database population and data collection should be as simple as possible without compromising the quality of the decisions. As a final element of the proposed framework, a feedback loop should be established after the missing data have been collected and the analyses performed in order to evaluate the effectiveness of the models and the yielded results and to refine the models, data inputs, databases, and collection methods.

This framework can function as a starting point for transportation agencies that wish to handle project selection in a more systematic way and achieve cost reductions by optimizing their data collection in order to support project selection decisionmaking.

Figure 12. Proposed framework for project selection data collection.



However, it is obvious that the use of the proposed framework would only lead to a partial optimization of an agency's data collection activities. This framework addresses only project selection decisions without taking into account the needs of the other levels of decisionmaking that might require overlapping or complementary data and hence require new or extended data collection activities. A similar rationale can be defined for other levels of Asset Management decisionmaking.

For true optimization the data needs of all levels of decisionmaking should be taken into consideration, and a more comprehensive framework for data collection should be established. Further research in the area of project selection data collection should be undertaken to determine the factors that render project selection criteria incapable of handling cross-asset comparisons. Additional effort is also needed to generalize the proposed data collection framework to overall data collection optimization, taking into account all agency decision levels. Complementarily, the identification of champions in the field of data collection to support project selection decisions would allow the derivation of best practices in order to further enhance the proposed framework and eventually develop standards in this area.

This research can help transportation agencies tailor their data collection activities according to their real decisionmaking needs. In this way, it contributes both to the reduction of data collection costs and to a more effective and efficient implementation of Asset Management in its everyday practice. By focusing on the use of the data and the needs of the decision levels and processes to be supported, transportation agencies could define which assets and which data about these assets are most important for decisionmaking, and they could tailor their data collection accordingly.

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APPENDIX A

Transportation Asset Management Web-Based Survey

ASSET MANAGEMENT DATA COLLECTION FOR SUPPORTING DECISION PROCESSES

Web-Based Electronic Survey

Introduction

The Virginia Tech Transportation Institute (VTTI) in conjunction with the Virginia Transportation Research Council (VTRC) and the Virginia Department of Transportation (VDOT) are studying the area of Asset Management data collection. The goals are to document the existing state-of-the-practice and to investigate the relations between data collection and supported decision processes. The investigation focus is on the data needed for the selection of projects for funding and implementation.

In the following questionnaire you are being asked to provide information from your State's experience and practice on various topics including: asset management implementation; data collection, management and integration; and decisionmaking processes and level. The information asked can refer either to planned or already implemented efforts in the related fields. Your individual answers will be used for statistical analysis in order to extract current trends and identify champions in this area; they will also be used to support the development of the project objectives by leading to scientific results on this very interesting and important topic.

The survey should take about 5–15 minutes to complete.

Please complete the electronic survey at ___________ by ________________.

For questions on the survey please contact:

Dr. Gerardo W. Flintsch
3500 Transportation Research Plaza
Blacksburg, VA 24060
Tel: 540–231–9748
Fax: 540–231–7532
Email: tamsurvey@vt.edu

Section 1: General Agency Information on Asset Management, Decision Levels, and Decision Processes

1. Has your agency/organization implemented or is planning to implement an Asset Management System (please check one)?

❑ Yes, it has already implemented an Asset Management System.

❑ No, it does not plan to implement an Asset Management System.

❑ It is planning to implement an Asset Management System but it does not have one yet.

❑ Don't know.

2. Please check the management systems your agency/organization currently has, along with the status of each system within an overall Asset Management framework (please check all that apply):

Stand-alone management system:	Integrated within Asset Management framework			
❑ Pavement (PMS)	❑ Yes	❑ No	❑ Planned	❑ Don't know
❑ Bridge (BMS)	❑ Yes	❑ No	❑ Planned	❑ Don't know
❑ Highway Safety (SMS)	❑ Yes	❑ No	❑ Planned	❑ Don't know
❑ Traffic Congestion (CMS)	❑ Yes	❑ No	❑ Planned	❑ Don't know
❑ Public Transportation Facilities and Equipment (PTMS)	❑ Yes	❑ No	❑ Planned	❑ Don't know
❑ Intermodal Transportation Facilities and Systems (ITMS)	❑ Yes	❑ No	❑ Planned	❑ Don't know
❑ Maintenance Management (MMS)	❑ Yes	❑ No	❑ Planned	❑ Don't know

Please list any other management systems used by your agency/organization:

3. Please specify the decisionmaking levels that have been explicitly defined in your agency/organization (check all that apply):

❑ No explicit definitions for decisionmaking levels (skip to Question 4).

❑ Strategic level (i.e., concerning policy of decisions for the overall network).

❑ Programming and budgeting level (i.e., concerning overall resource allocations for design, maintenance and rehabilitation throughout the entire network).

❑ Project selection level (i.e., selection of individual projects or groups of projects for funding and/or implementation).

❑ Project level (i.e., design of concerning specific treatments or action for the selected projects).

❑ Don't know what decision levels are defined.

4. Please rate the following Asset Management decision processes in terms of their relative importance within your agency/organization:

Asset Management Decision Processes	Level of Importance				
	Very Important	Somewhat Important	Not very Important	Not at all Important	Don't know
Policy formulation	❑	❑	❑	❑	❑
Performance evaluation and monitoring	❑	❑	❑	❑	❑
Fiscal planning	❑	❑	❑	❑	❑
Program optimization and trade-offs	❑	❑	❑	❑	❑
Development of alternatives (for sustaining assets through their life-cycle)	❑	❑	❑	❑	❑
Impact analysis	❑	❑	❑	❑	❑
Performance-based budgeting	❑	❑	❑	❑	❑
Project selection	❑	❑	❑	❑	❑
Resource allocations	❑	❑	❑	❑	❑
Program delivery/project implementation	❑	❑	❑	❑	❑
Audit, reporting and communication	❑	❑	❑	❑	❑

Please list up to three other decision processes important for your agency/organization:

____

____

____

5. Please rate the following criteria according to their level of importance for selecting projects that are candidates for funding and implementation within your agency/organization:

Project Selection Criteria	Level of Importance				
	Very Important	Somewhat Important	Not very Important	Not at all Important	Don't know
Available budget/ earmarked funds	❑	❑	❑	❑	❑
Project significance	❑	❑	❑	❑	❑
Usage of the project	❑	❑	❑	❑	❑
Proximity of the project to major urban areas	❑	❑	❑	❑	❑
Ease/difficulty of implementation	❑	❑	❑	❑	❑
Engineering parameters (including asset condition)	❑	❑	❑	❑	❑
Geographic distribution of projects/funds	❑	❑	❑	❑	❑
Distribution among asset types	❑	❑	❑	❑	❑
Public demands/user opinion	❑	❑	❑	❑	❑
Environmental consideration	❑	❑	❑	❑	❑
User costs/benefits	❑	❑	❑	❑	❑
Agency costs/benefits	❑	❑	❑	❑	❑
Community costs/benefits	❑	❑	❑	❑	❑

Please list up to three other criteria important for project selection within your agency/ organization:

____

____

____

6. Do you think that the above criteria that are used by an agency in order to select between different projects or groups of projects are or should be uniform and consistent for all types of different roadway assets (please click one)?

❏ Yes.

❏ No.

❏ Don't know.

If Yes please explain why:

Section 2: Information regarding data collection, management and integration and their relation to the Project Selection decision level of Roadway Assets

1. Does your agency/organization have an Asset Management roadway inventory/ database or is planning to develop one (please check one)?

❏ Yes, it already has an Asset Management inventory.

❏ No, it does not have an Asset Management inventory.

❏ It is planning to develop an Asset Management inventory but it does not possess one.

❏ Don't know.

2. Please indicate if your agency collects data for each of the following roadway assets types and specify the data collection method (check all that apply).

Roadway Assets:	Data Collection Method:		
❏ Drainage	❏ Manual*	❏ Automatic**	❏ Both
❏ Roadside Assets	❏ Manual	❏ Auto	❏ Both
❏ Pavements	❏ Manual	❏ Auto	❏ Both
❏ Bridge	❏ Manual	❏ Auto	❏ Both
❏ Traffic Items	❏ Manual	❏ Auto	❏ Both
❏ Special Facilities	❏ Manual	❏ Auto	❏ Both

* **Manual data collection** involves two or more data collectors that record the data either with pen or most recently with hand-held computers.

** **Automatic data collection** involves the use of some type of data collection vehicle or equipment, e.g., video cameras, laser sensors, etc. to capture, store, and process the collected data

3. Which of the following statements best describes how your agency/organization decides which data (and their related level of detail) will be collected to support the project selection decisions? Check all that apply:

Data collection decisions are:

❏ Based on historical practice and staff experience defined within the agency/organization (agency and staff culture).

❏ Based on widely accepted data collection standards.

❏ Based on specific needs of individual or integrated management systems/decision processes to be supported.

❏ Don't know exactly.

Please list any other consideration(s) that your agency's data collection decisions are based on:

4. Which roadway asset data are most important in your agency's view for the selection between two projects, e.g. between different pavement projects or between a pavement project and a bridge project (please rate all data types)?

Roadway Asset Data	Level of Importance				
	Very Important	Somewhat Important	Not very Important	Not at all Important	Don't know
Location	❏	❏	❏	❏	❏
Attributes/characteristics (i.e., materials, service life, geometry, etc.)	❏	❏	❏	❏	❏
Structural condition (i.e., how adequate it is for its purpose)	❏	❏	❏	❏	❏
Functional condition (i.e., how well it can serve the public)	❏	❏	❏	❏	❏
Initial agency cost (construction/provision)	❏	❏	❏	❏	❏
Life-cycle costs (including M&R and user costs)	❏	❏	❏	❏	❏
Usage (i.e., how many users utilize it on a specific time basis, e.g., a day)	❏	❏	❏	❏	❏
Customer/user feedback and/or complaints	❏	❏	❏	❏	❏

Please list up to three other data attributes that you think are important for your agency/organization but were not included in the previous table:

5. **Has your agency/organization identified and/or formally documented any relationship between the roadway data collected to support Project Selection and the decisions made? Please check one:**

- ❑ Only identified.
- ❑ Identified and formally documented.
- ❑ Neither identified nor formally documented.
- ❑ Don't know.

6. **Please provide details and contact information (if available) about any agency/organization (other than your own) that has documented links between data collection and decisionmaking processes:**

____

____

____

____

Supplementary Information

Please provide the following information about yourself:

Name: ____

Current Position/Title: ____

Agency: ____

Address: ____

City: ______________________ State: __________Zip: ______________

Telephone: ______________________ Fax: ______________________

Email: ____

Please provide any other thoughts, information or contacts concerning data collection for supporting decisionmaking in Asset Management that you believe may be of benefit to this project.

____

____

____

____

THANK YOU!!

APPENDIX B

Transportation Asset Management Survey Analysis

Introduction

A total of 48 answers from 40 different States were received. Therefore, the response percentage resulted in 78 percent in terms of individual States and 47 percent in terms of individual respondents. The obtained responses were downloaded from the database and stored in Excel spreadsheets. The responses were statistically analyzed, and charts and tables were created. A discussion of the results follows hereafter.

Answers to essay questions were not considered in this statistical analysis, but rather used as a guide for the resolution of discrepancies and also as a compass for the overall status of the responding State in relation to the researched topics. Information from the essay questions can and will be utilized in the future for the determination of champions for the second phase of the investigation.

Part 1: General Agency Information on Asset Management, Decision Levels, and Decision Processes

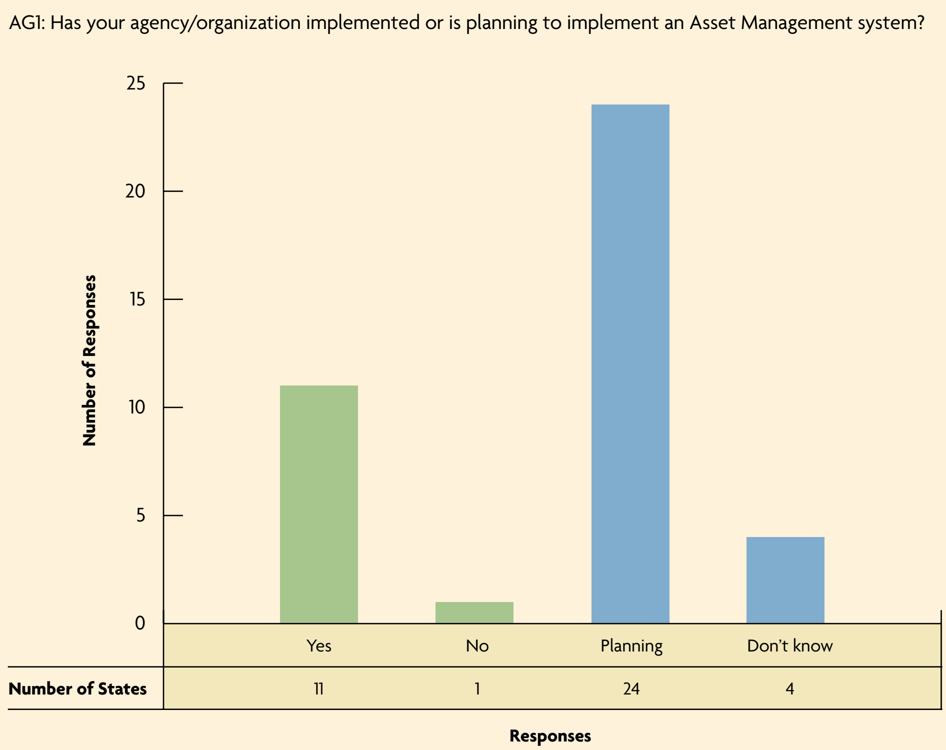
This part required transportation officials to give information regarding the following:

- Asset Management endorsement and implementation by the State DOTs.
- Existing and future planned other transportation and infrastructure management systems.
- Existing levels of decisionmaking within State DOTs.
- Identification and rating of existing Asset Management decision processes and functions within State DOTs.
- Identification and rating of existing criteria used by the agencies for project selection.

Question 1: Has your agency/organization implemented, or plan to implement an Asset Management system?

The responses to the first question concerning the implementation stage of an Asset Management system revealed that most of the responding States (24) are still in the phase of planning. Only one quarter (11) of the respondents indicated that they have already implemented an Asset Management System. The responses are summarized in figure 1.

Figure 1. Asset Management implementation.



Question 2: Please indicate the management system(s) your agency/organization currently has, along with the status of each system within an overall Asset Management framework.

The responses to this question revealed that most of the responding States have been using individual management systems with the most predominant among them being pavement (39), bridge (39), and maintenance management systems (34) shown by the aggregated results in table 1. Other systems include highway safety (SMS), traffic congestion (CMS), public transportation (PTMS), and intermodal transportation management systems (ITMS).

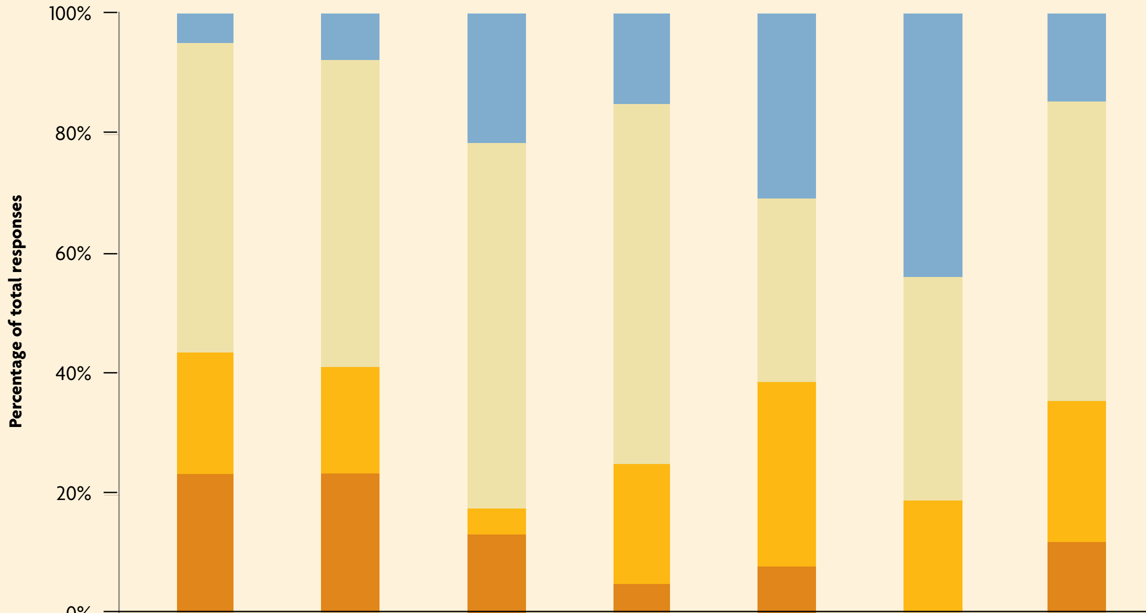
However, for most of these States, the level of integration of individual systems within an overall Asset Management framework is still in the planning phase. Pavement and bridge management systems seem to be one step ahead of the remaining ones in terms of this integration. The attained responses are summarized in figure 2.

Table 1. Aggregated number of States that use individual management systems.

PMS	BMS	SMS	CMS	PTMS	ITMS	MMS
39	39	23	20	13	16	34

Figure 2. Use of individual management systems and integration within Asset Management.

AG2: Please indicate the management systems your agency/organization currently has, along with the status of each system within the overall Asset Management framework.



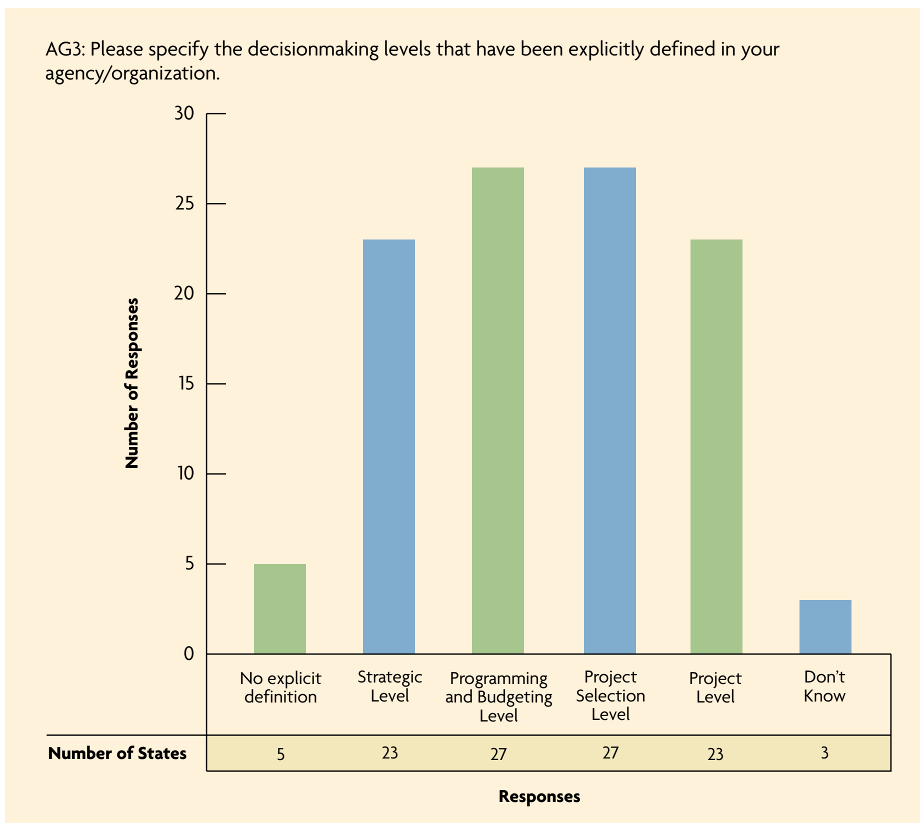
	PMS	BMS	SMS	CMS	PTMS	ITMS	MMS
Don't know	2	3	5	3	4	7	5
Planned	20	20	14	12	4	6	17
No	8	7	1	4	4	3	8
Yes	9	9	3	1	1	0	4

Individual Management Systems

Question 3: Please specify the decisionmaking level(s) that are defined explicitly by your agency/organization.

When asked to report on their defined decisionmaking levels, most of the responding transportation agencies indicated that they have explicitly defined decisionmaking levels that coincide with the ones found in the literature (figure 3). Most of the answers were obtained for the programming and budgeting and the project selection levels. This confirms that the responding transportation officials were rightly selected because they were familiar with these levels of decisionmaking, and that the agencies have focused their attention to these intermediate levels of decisionmaking that connect the generic strategic decisions of the strategic level with the actual project implementation at the project level.

Figure 3. Defined levels of decisionmaking.



Question 4: Please rate the following Asset Management decision processes in terms of their relative importance within your agency/ organization.

State transportation officials were asked to rate a list of identified Asset Management decision processes in terms of their relative importance. As mentioned before, all 48 responses for this question were considered in the analysis. Figure 4 summarizes the responses. This plot shows that most of the listed decision processes fall in the "very important" or "somewhat important" category.

Table 2 ranks the decision processes in terms of their normalized importance by importance category. The relative importance of the decision processes was determined by computing the average importance rating for each decision process using a score from 1 = not important at all to 4 = very important. Table 3 shows that the most important decision process turned out to be performance evaluation and monitoring with fiscal planning following closely behind. Project selection, which is the main interest of this study, ranked third along with resource allocations, which denotes the anticipated significance of the business decision process to the responding transportation officials.

Table 2. Normalized importance of decision processes per importance category. (AG4)

Ranking of normalized importance of Asset Management decision processes per importance category.									
Very important		Somewhat important		Not very important		Not at all important		Don't know	
0.69	Performance evaluation and monitoring	0.46	Policy formulation	0.17	Impact analysis	0.02	Development of alternatives	0.13	Development of alternatives
0.60	Fiscal planning	0.46	Impact analysis	0.17	Performance-based budgeting	0.02	Impact analysis	0.13	Impact analysis
0.54	Resource allocations	0.46	Audit, reporting and communication	0.17	Audit, reporting and communication	0.02	Performance-based budgeting	0.08	Policy formulation
0.50	Project selection	0.42	Development of alternatives	0.13	Program optimization and trade-offs	0.02	Program delivery/ project implementation	0.08	Performance-based budgeting
0.44	Program delivery/ project implementation	0.42	Project selection	0.13	Development of alternatives	0.02	Audit, reporting and communication	0.08	Program delivery/ project implementation
0.42	Policy formulation	0.40	Program optimization and trade-offs	0.13	Program delivery/ project implementation	0.00	Policy formulation	0.08	Audit, reporting and and communication
0.42	Program optimization and trade-offs	0.35	Fiscal planning	0.04	Policy formulation	0.00	Performance evaluation and monitoring	0.06	Program optimization and trade-offs
0.42	Performance-based budgeting	0.35	Resource allocations	0.04	Project selection	0.00	Fiscal planning	0.06	Resource allocations
0.31	Development of alternatives	0.33	Program delivery/ project implementation	0.04	Resource allocations	0.00	Program optimization and trade-offs	0.04	Performance evaluation and monitoring
0.27	Audit, reporting and communication	0.31	Performance-based budgeting	0.02	Performance evaluation and monitoring	0.00	Project selection	0.04	Fiscal planning
0.23	Impact analysis	0.25	Performance evaluation and monitoring	0.00	Fiscal planning	0.00	Resource allocations	0.04	Project selection

Figure 4. Asset Management decision processes and their anticipated importance.

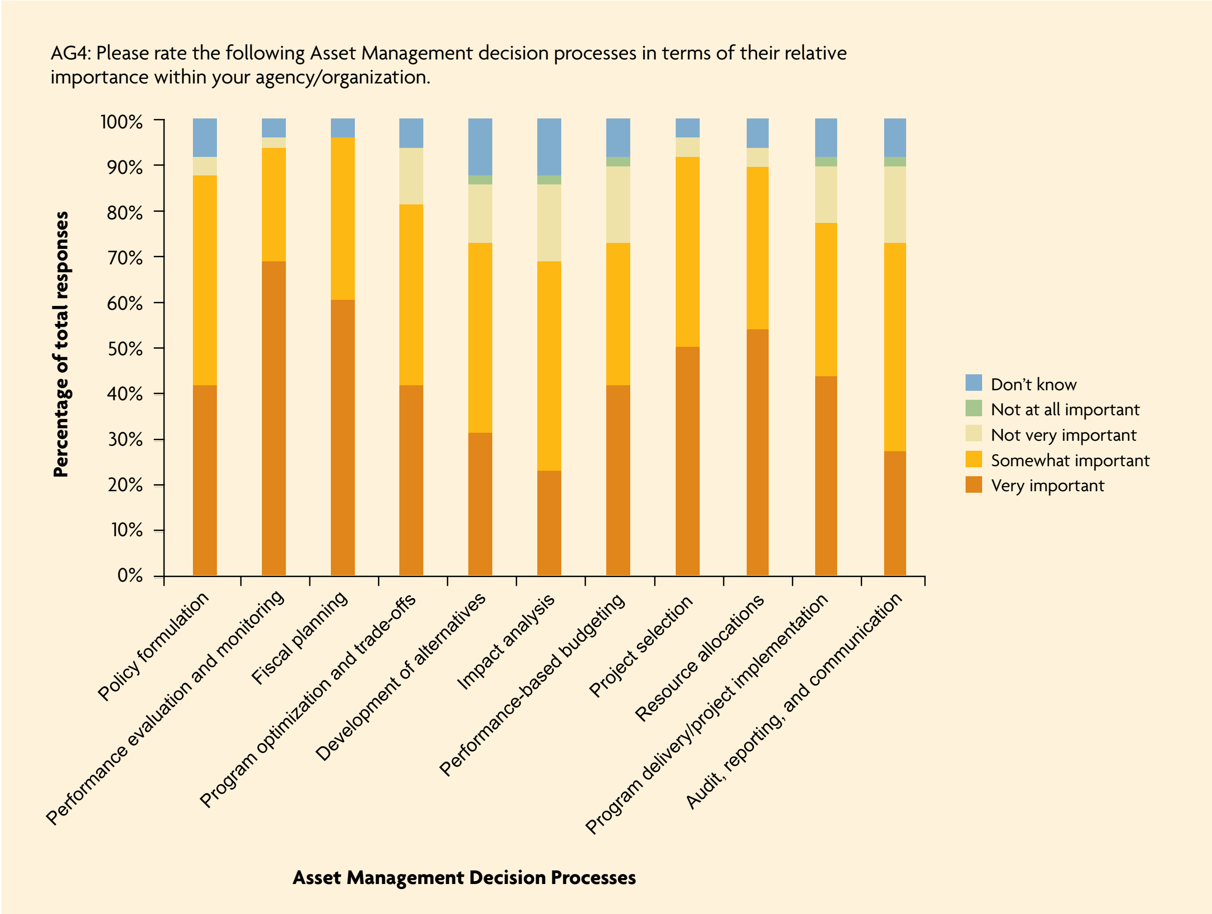
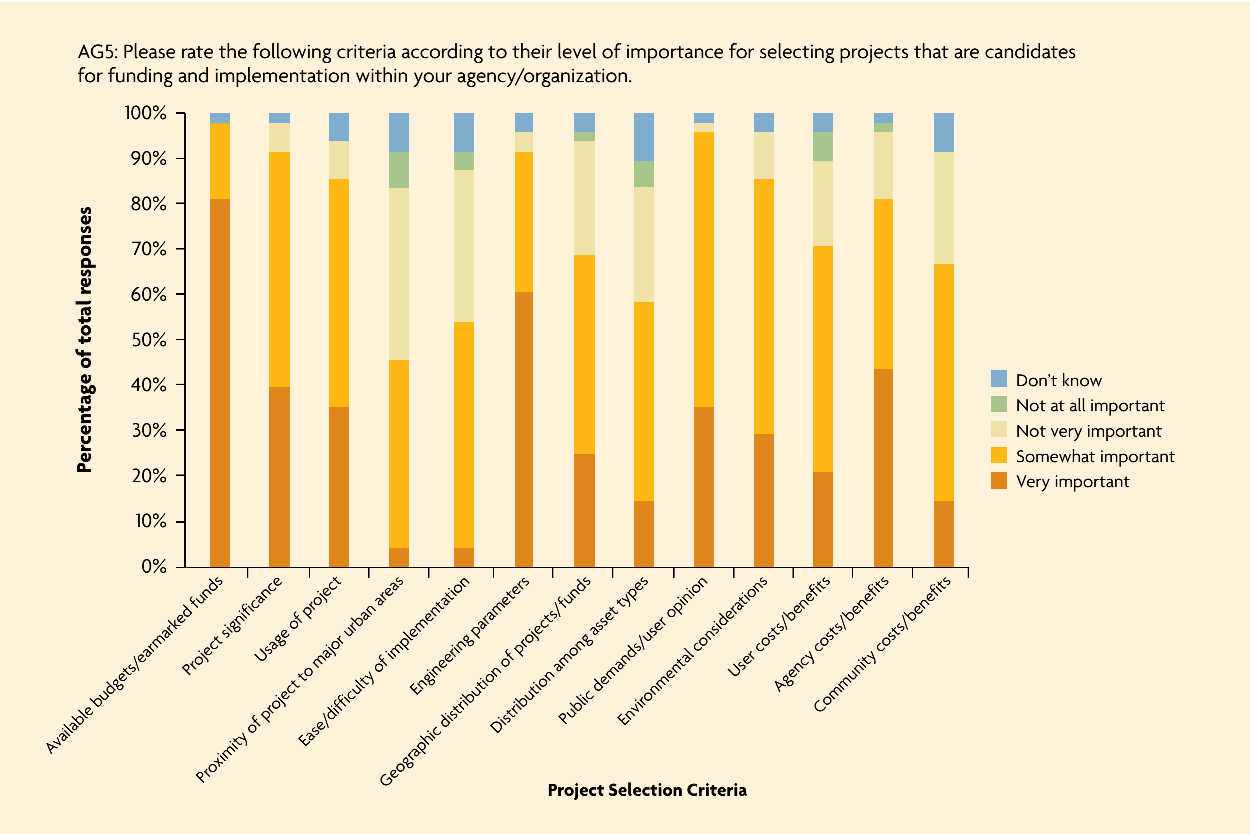


Table 3. Ranking of Asset Management decision processes.

Asset Management Decision Processes	Average Ranking
Performance evaluation and monitoring	3.54
Fiscal planning	3.48
Project selection	3.33
Resource allocations	3.31
Policy formulation	3.13
Program optimization and trade-offs	3.10
Program delivery/ project implementation	3.02
Performance-based budgeting	2.96
Audit, reporting and communication	2.81
Development of alternatives	2.77
Impact analysis	2.65

Key: 1 = not important at all, 2 = not very important, 3 = somewhat important, 4 = very important

Figure 5. Project selection criteria and their anticipated importance.



Question 5: Please rate the following criteria according to their level of importance for selecting projects that are candidates for funding and implementation within your agency/organization.

In this question the transportation officials were asked to rate the importance of specific project selection criteria. Figure 5 summarizes the relative importance assigned by the State transportation officials to a list of the considered specific project selection criteria. As expected, the variability of opinions is more significant in this category than the others. However, the criterion of available budgets/earmarked funds stands out as the most important criterion, followed closely by engineering parameters and public demands/user opinions. The average rankings for all the listed criteria are presented in tables 4 and 5. An interesting finding is that public demands/user opinions rank in the third place, which shows the increased interest of transportation agencies in public satisfaction from the selection and implementation of projects.

Table 4. Normalized Importance of project selection criteria per importance category. (AG5)

Ranking of normalized importance of project selection criteria according per importance category.									
Very important		Somewhat important		Not very important		Not at all important		Don't know	
0.81	Available budgets/ earmarked funds	0.60	Public demands/ user opinion	0.38	Proximity of project to major urban areas	0.08	Proximity of project to major urban areas	0.10	Distribution among asset types
0.60	Engineering parameters	0.56	Environmental considerations	0.33	Ease/difficulty of implementation	0.06	Distribution among asset types	0.08	Proximity of project to major urban areas
0.44	Agency costs/benefits	0.52	Project significance	0.25	Geographic distribution projects/funds	0.06	User costs/benefits	0.08	Ease/difficulty of implementation
0.40	Project significance	0.52	Community costs/ benefits	0.25	Distribution among asset types	0.04	Ease/difficulty of implementation	0.08	Community costs/ benefits
0.35	Usage of project	0.50	Usage of project	0.25	Community costs/ benefits	0.02	Geographic distribution of projects/funds	0.06	Usage of project
0.35	Public demands/ user opinion	0.50	Ease/difficulty of implementation	0.19	User costs/benefits	0.02	Agency costs/benefits	0.04	Engineering parameters
0.29	Environmental considerations	0.50	User costs/benefits	0.15	Agency costs/benefits	0.00	Available budgets/ earmarked funds	0.04	Geographic distribution of projects/funds
0.25	Geographic distribution of projects/funds	0.44	Geographic distribution of projects/funds	0.10	Environmental considerations	0.00	Project significance	0.04	Environmental considerations
0.21	User costs/benefits	0.44	Distribution among asset types	0.08	Usage of project	0.00	Usage of project	0.04	User costs/benefits
0.15	Distribution among asset types	0.42	Proximity of project to major urban areas	0.06	Project significance	0.00	Engineering parameters	0.02	Available budgets/ earmarked funds
0.15	Community costs/ benefits	0.38	Agency costs/benefits	0.04	Engineering parameters	0.00	Public demands/ user opinion	0.02	Project significance
0.04	Proximity of project to major urban areas	0.31	Engineering parameters	0.02	Public demands/ user opinion	0.00	Environmental considerations	0.02	Public demands/ user opinion
0.04	Ease/difficulty of implementation	0.17	Available budgets/ earmarked funds	0.00	Available budgets/ earmarked funds	0.00	Community costs/ benefits	0.02	Agency costs/benefits

Table 5. Ranking of project selection criteria.

Project Selection Criteria	Average Ranking
Available budgets/earmarked funds	3.75
Engineering parameters	3.44
Public demands/user opinion	3.27
Project significance	3.27
Agency costs/benefits	3.19
Usage of project	3.08
Environmental considerations	3.06
Geographic distribution of projects/funds	2.83
User costs/benefits	2.77
Community costs/benefits	2.65
Distribution among asset types	2.46
Ease/difficulty of implementation	2.38
Proximity of project to major urban areas	2.25

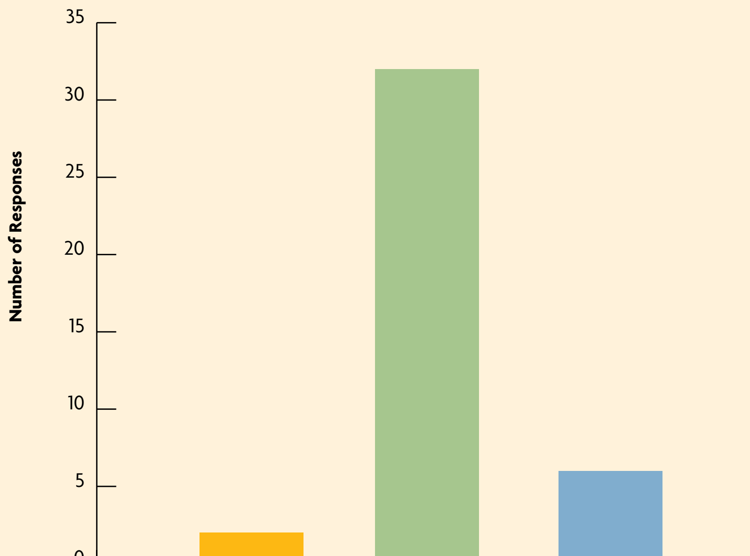
Key: 1 = not important at all, 2 = not very important, 3 = somewhat important, 4 = very important

Question 6: Do you think that the above criteria that are used by an agency in order to select between different projects or groups of projects are or should be uniform and consistent for all types of different roadway assets?

This question attempted to clarify whether the above-mentioned criteria for project selection would be suitable for use regardless of the asset type under consideration. To the surprise of the research team, the majority (80 percent) of the responding officials agreed that the criteria used for project selection cannot and should not be uniform and consistent for all types of roadway assets. The responses are summarized in figure 6.

Figure 6. Consistency of project selection criteria for different asset types.

AG6: Do you think that the above criteria that are used by an agency in order to select between different projects or groups of projects are or should be uniform and consistent for all types of different roadway assets?



	Yes	No	Don't know
Number of individual responses	2	32	6

Responses

Questionnaire Part 2—Information Regarding Data Collection, Management, and Integration and Their Relation to the Project Selection Decision Level of Roadway Assets

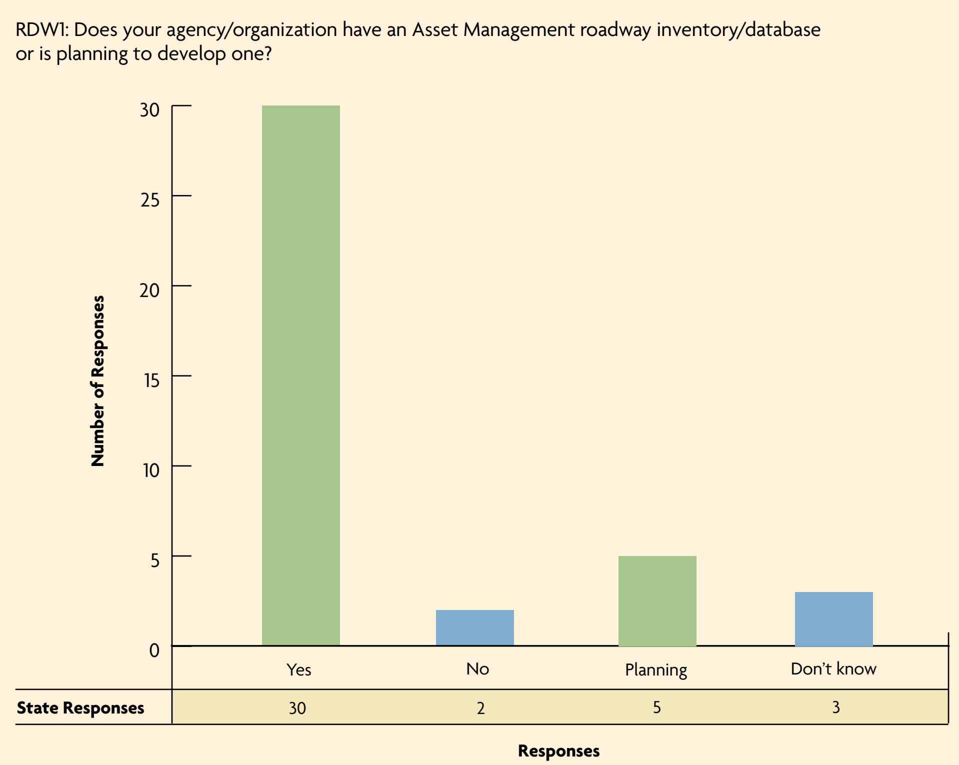
This part required transportation officials to provide information on the following:

- Data management, collection methods, and integration.
- Rationale behind existing and future planned data collection.
- Evaluation of roadway asset data used for project selection.
- Identification of formally documented links between data collection and project selection or Asset Management decision processes in general.

Question 1: Does your agency/organization have an Asset Management roadway inventory/database, or is planning to develop one?

From this question it was clearly shown that most of the responding State agencies (75 percent) had already invested time and money in developing Asset Management roadway inventories and databases. The majority of the remaining responses indicated that they are in the planning stages. The responses are summarized in figure 7.

Figure 7. Existence of Asset Management inventory/database.

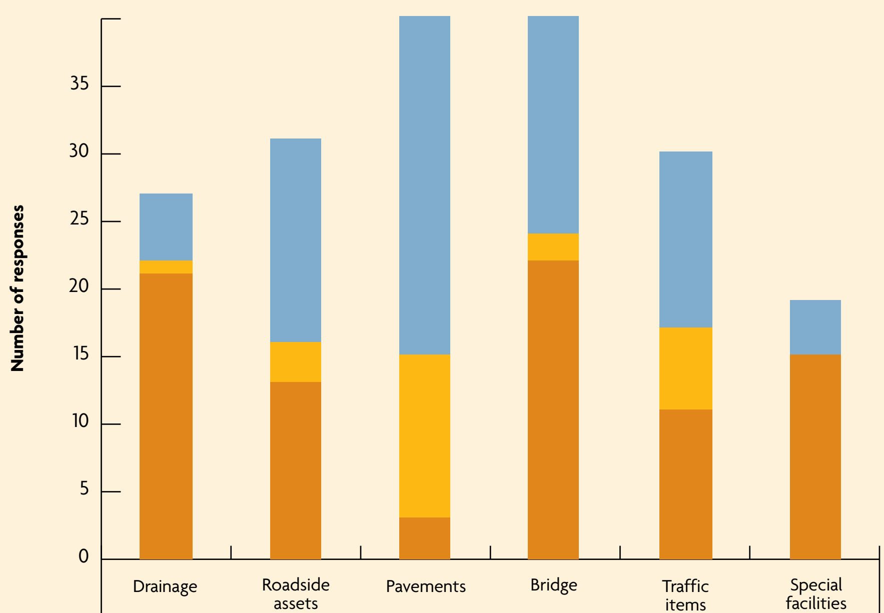


Question 2: Please indicate if your agency collects data for each of the following roadway asset types and specify the data collection method.

From this question it was revealed that most agencies have been collecting data predominantly for their pavements and bridges. To a great extent, traffic items and roadside assets also were reported to be collected. Figure 8 summarizes the data collection methods used for the acquisition of the above data. Whereas for some assets (e.g., drainage) the collection is reported to have been performed by mostly manual methods, there is a trend towards using a combination of manual and automatic methods.

Figure 8. Roadway asset type data collection and corresponding collection methods.

RDW2: Please indicate if your agency collects data for each of the following roadway assets types and specify the data collection method.



	Drainage	Roadside assets	Pavements	Bridge	Traffic items	Special facilities
Both	5	15	25	16	13	4
Automatic	1	3	12	2	6	0
Manual	21	13	3	22	11	15

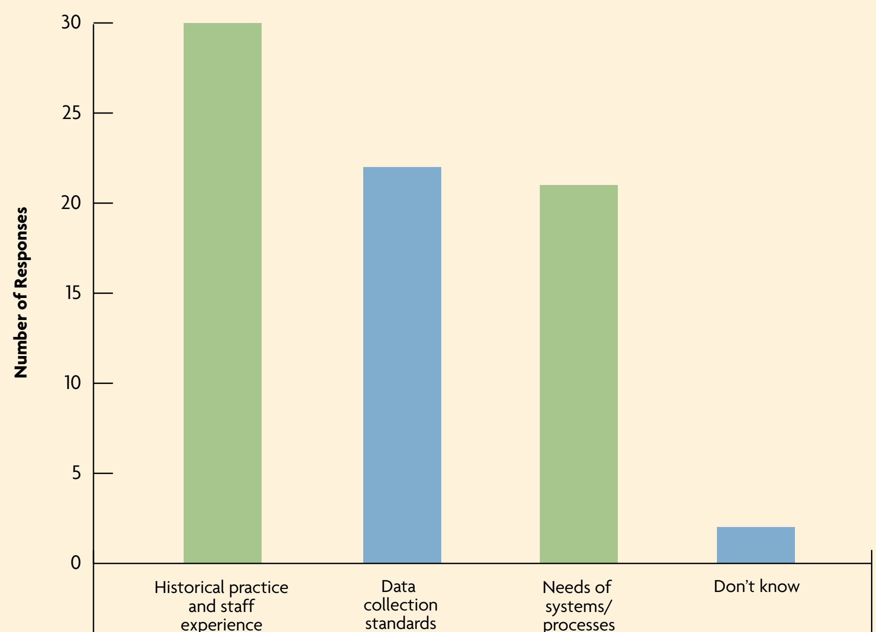
Roadway Asset Types

Question 3: Which of the following statements best describes how your agency/organization decides which data (and their related level of detail) will be collected to support the project selection decisions?

This question attempted to capture the agencies' culture and rationale behind data collection. These results are summarized in figure 9. The responses confirmed that most agencies still base their data collection decisions on past practices and staff experience. However, many respondents also indicated that data collection practices have been based on data collection standards and input needs of utilized management systems or other defined decision processes.

Figure 9. Agency data collection rationale.

RDW3: Which of the following statements best describes how your agency/organization decides which data (and their related level of detail) will be collected to support the project selection decisions?



	Historical practice and staff experience	Data collection standards	Needs of systems/ processes	Don't know
State Responses	30	22	21	2

Responses

Question 4: Which roadway asset data are most important in your agency's view for the selection between two projects, e.g., between different pavement projects or between a pavement project and a bridge project?

State transportation officials were asked to rate the importance of identified roadway asset data for the selection between two competitive projects. The ratings are summarized figure 10 and tables 6 and 7. As expected, the most important data are the assets' structural and functional conditions, with usage of the assets following in the third place. The results conform to common sense and also show that the responding transportation officials had predominantly the same perception of the data that would prioritize project selection between different assets.

Figure 10. Roadway asset data and their anticipated importance for project selection.

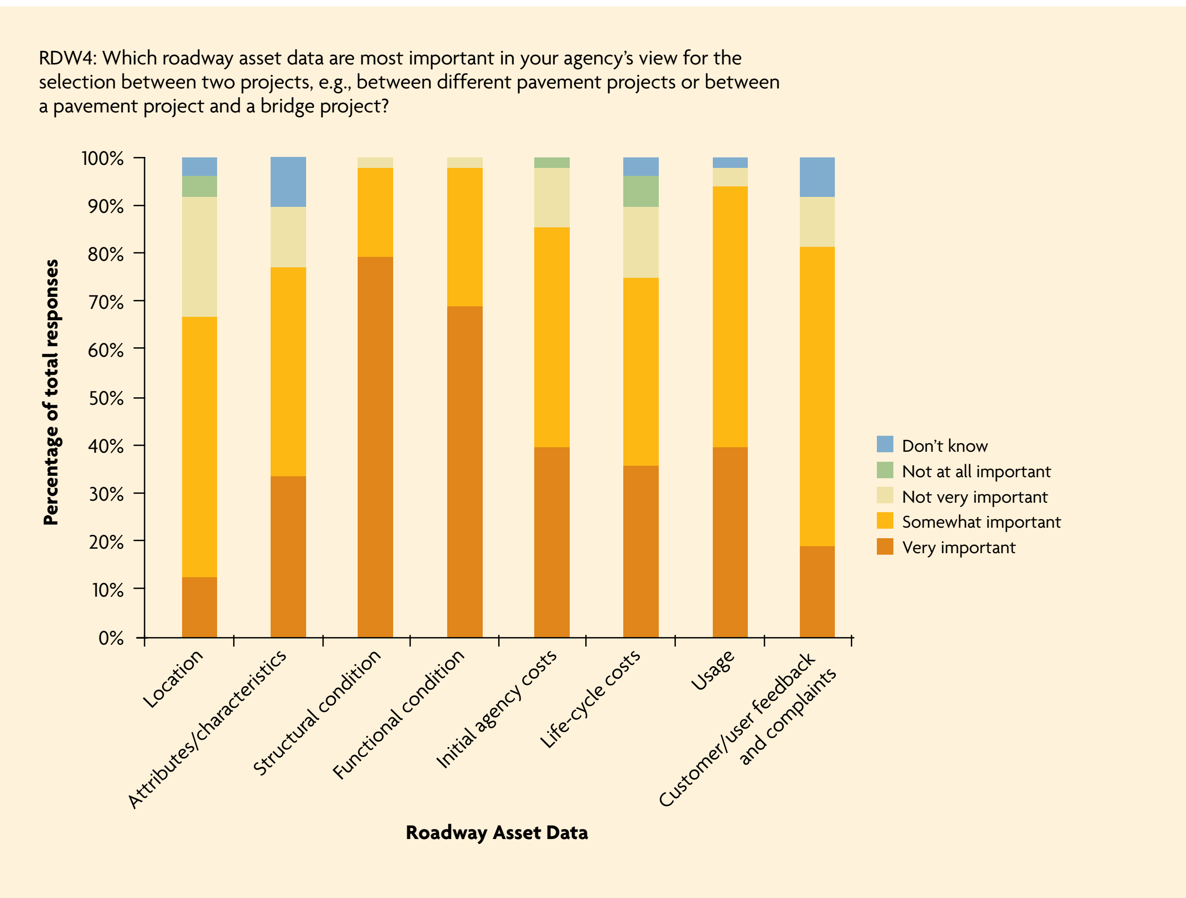


Table 6. Normalized importance of roadway asset data per importance category. (RDW4)

Ranking of normalized importance of Asset Management decision processes per importance category.									
Very important		Somewhat important		Not very important		Not at all important		Don't know	
0.79	Structural condition	0.63	Customer/user feedback	0.25	Location	0.06	Life-cycle costs	0.10	Attributes/ characteristics
0.69	Functional condition	0.54	Location	0.15	Life-cycle costs	0.04	Location	0.08	Customer/user feed-back and complaints
0.40	Initial agency costs	0.54	Usage	0.13	Attributes/characteristics	0.02	Initial agency costs	0.04	Location
0.40	Usage	0.46	Initial agency costs	0.13	Initial agency costs	0.00	Attributes/characteristics	0.04	Life-cycle costs
0.35	Life-cycle costs	0.44	Attributes/characteristics	0.10	Customer/user feedback and complaints	0.00	Structural condition	0.02	Usage
0.33	Attributes/characteristics	0.40	Life-cycle costs	0.04	Usage	0.00	Functional condition	0.00	Structural condition
0.19	Customer/user feedback and complaints	0.29	Functional condition	0.02	Structural condition	0.00	Usage	0.00	Functional condition
0.13	Location	0.19	Structural condition	0.02	Functional condition	0.00	Customer/user feedback and complaints	0.00	Initial agency costs

Table 7. Ranking of roadway asset data for project selection.

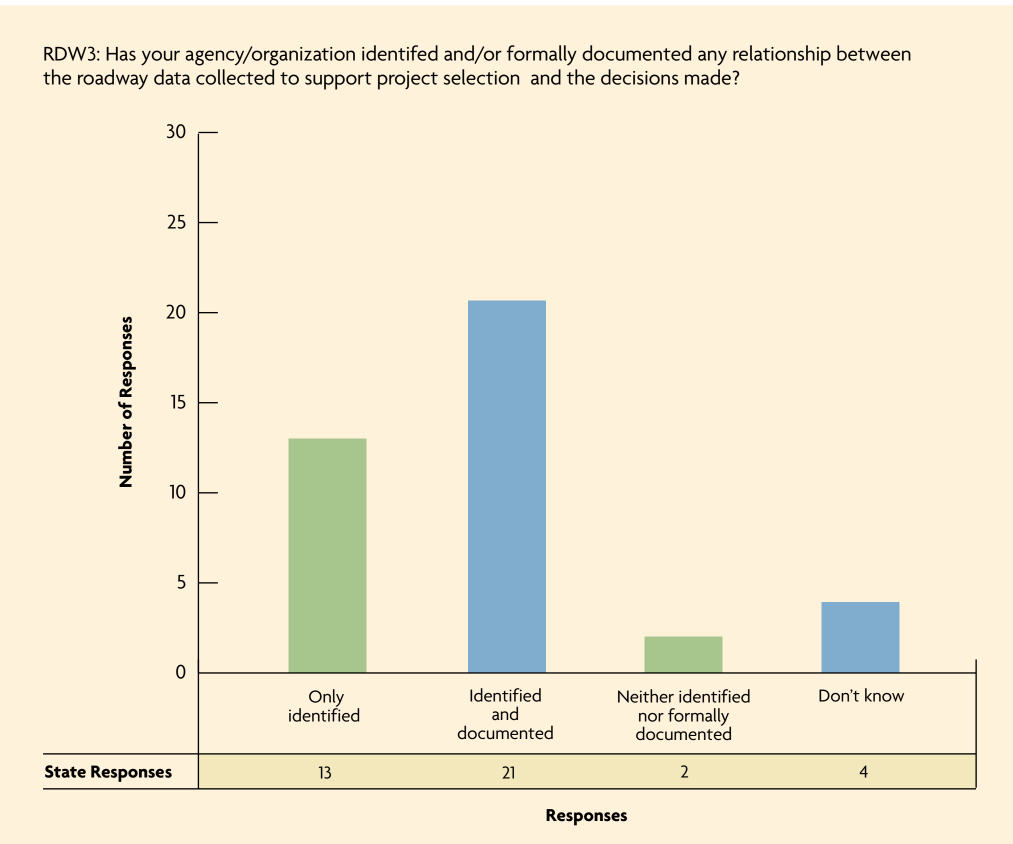
Roadway Asset Data	Average Ranking
Structural condition	3.77
Functional condition	3.67
Usage	3.29
Initial agency costs	3.23
Life-cycle costs	2.96
Attributes/characteristics	2.90
Customer/user feedback and complaints	2.83
Location	2.67

Key: 1 = not important at all, 2 = not very important, 3 = somewhat important, 4 = very important

Question 5: Has your agency/organization identified and formally documented any relationship between the roadway data collected to support project selection and the decisions made?

The last question of the survey investigated the level at which State transportation agencies are conscious about the existence of links between their data collection activities and project selection. It was determined from the responses that most agencies have identified (32.5 percent) or identified and documented in a formal way (52.5 percent) the existence of such links. This is a very important finding because it shows that most agencies are trying to rationalize their data collection according to specific decisions to be supported at least for the particular level of project selection. The responses are summarized in figure 11.

Figure 11. Identification and documentation of links between data collection and project selection.



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