Asset Management Data Collection For Supporting Decision Processes

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Abstract

Transportation agencies engage in extensive data collection activities in order to support their decision processes at various levels. However, not all the data collected supply transportation officials with useful information for efficient and effective decision-making.

This thesis presents research aimed at formally identifying links between data collection and the supported decision processes. The research objective identifies existing relationships between Asset Management data collection and the decision processes to be supported by them, particularly in the project selection level. It also proposes a framework for effective and efficient data collection. The motivation of the project was to help transportation agencies optimize their data collection processes and cut down data collection and management costs.

The methodology used entailed two parts: a comprehensive literature review that collected information from various academic and industrial sources around the world (mostly from Europe, Australia and Canada) and the development of a web survey that was e-mailed to specific expert individuals within the 50 U.S. Departments of Transportation (DOTs) and Puerto Rico. The electronic questionnaire was designed to capture state officials' experience and practice on: asset management endorsement and implementation; data collection, management and integration; decision-making levels and decision processes; and identified relations between decision processes and data collection. The responses obtained from the web survey were analyzed statistically and combined with the additional resources in order to develop the proposed framework and recommendations. The results of this research are expected to help transportation agencies and organizations not only reduce costs in their data collection but also make more effective project selection decisions.

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Literature review

Asset Management

Historic Overview - Definitions

The concept of infrastructure management and more particularly of transportation infrastructure management is neither new to the United States nor to the rest of the world. In the second half of the 20th century, efforts and approaches focused on managing individual transportation infrastructure asset types. Pavement, bridge, tunnel, traffic equipment, congestion, public transportation and various other types of individual management systems have emerged during the last decades. Research in these areas is still ongoing with important findings and continuous progress. Pavement management systems are the oldest and most abundant of these engineering management systems. This is due to the fact that pavements constitute almost 60% of the total infrastructure assets managed by transportation agencies (Haas et al. 1994).

During the last decade of the 20th century, there has been a slow but consistent movement towards a more holistic approach to the management of these assets. Transportation agencies in the US and around the world have begun 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 Federal Highway Administration (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 decision-making. 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 that also widen its scope beyond solely physical assets (McNeil 2000). Examples of this sort include the definition from the Transportation Association of Canada (TAC):

> "*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),"

and the one from the American Public Works Association (APWA):

> "*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 towards 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 fifty 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 good and 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 have been 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 US's transportation infrastructure sums up to a staggering $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 becomes paramount.

Meanwhile, Asset Management had already been widely accepted by the private sector worldwide and was already being practiced since the mid-1990s by transportation agencies in the UK, Australian and New Zealand (Stalebrink and Gifford 2002). Hence, transportation agencies in North America had one more reason to investigate whether or not 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's (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 (Orndoff 2004).

GASB 34 intends to make financial reports more useful to legislators, investors and creditors (GASB 1999) and "*establishes methods for governments to be more accountable to bond market analysts and underwriters, citizens, and other financial users.*" 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 Management's Discussion and Analysis (MDA) section which is a non-technical narrative that summarizes the financial performance of the agency, comparing it with the performance of the previous year (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. As most of the infrastructure assets deteriorate with time due to usage, environmental effects and aging, agencies can chose to report their value either by depreciating them or by using a modified approach. In the first case the asset value is being reported as a historical cost minus depreciation which is usually determined 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 (Orndoff 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 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, comply with the financial reporting mandates of Statement No.34, and produce 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 aiming at enhancing the way of managing infrastructure, which emphasizes good business practices and asserts 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:

- By applying strategic rather than tactical measures, goals and policies,
- By addressing decisions usually in a network, system-wide rather than a project level,
- By integrating existing individual infrastructure systems and databases in a common interoperable environment,

- By introducing and incorporating financial and economic performance measures, ideas and theories and treating the infrastructure management process as a "business", which has to be done efficiently and effectively,
- By modeling the way the internal processes are undertaken after the private sector, and
- By establishing ways for efficient documentation and communication of the decision making process with two significant benefits: (1) making management decisions transparent to all kinds of shareholders, and (2) rendering decision makers 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,
- Decision making regarding short – and long – term project selection,
- Implementation of designed programs and evaluation processes,
- Use of evaluation results for overall process feedback, redevelopment, or refinement.

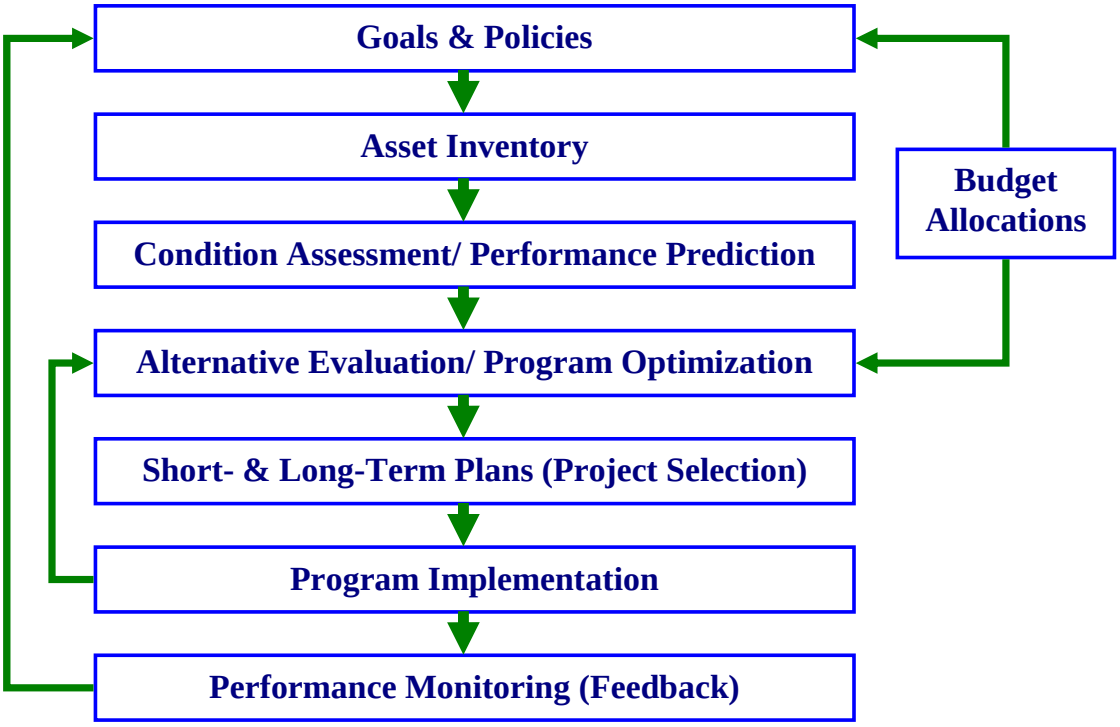

Figure 1. Generic Asset Management System Components

Overview of Implementation Efforts

The theoretical concepts behind Asset Management have been rigorously investigated in the past years by many transportation agencies, educational/academic institutions, and governmental and industrial organizations. Research is still ongoing and the world-wide literature on the subject is annually enlarging. Few results, however, have so far been reported from implementing Asset Management in practice. Although several US 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 is yet to achieve similar extent. The actual implementation has been proven to be more difficult than initially anticipated. Many of the reasons behind the lag between theory and practice have been acknowledged and documented in previous studies (AASHTO 1996). The most commonly mentioned hurdles to overcome include: (1) the fact that there is no unique way of establishing an Asset Management system but rather a large number of

alternatives to choose from, and (2) difficulties to integrate together 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 phased by private and/or governmental transportation agencies on their way to implement Asset Management Systems. These efforts are presented in more detail in a later section of this document, with milestone examples that are of interest to this research following hereafter.

As a milestone domestic reference, the American Association of State Highway and Transportation Officials (AASHTO) has developed a "Transportation Asset Management Guide" (AASHTO 2002). This guide was prepared in order to assist State Departments of Transportation 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 decision making: resource allocation and utilization. Asset Management can touch on nearly every aspect of the business functions of a transportation agency, including planning, engineering, finance, programming, construction, maintenance and information systems.

A schematic representation of the overall Asset Management process – with emphasis on resource allocation and utilization – is illustrated in Figure 2. The described process is oriented to the actual implementation of the Asset Management concepts and methodologies.

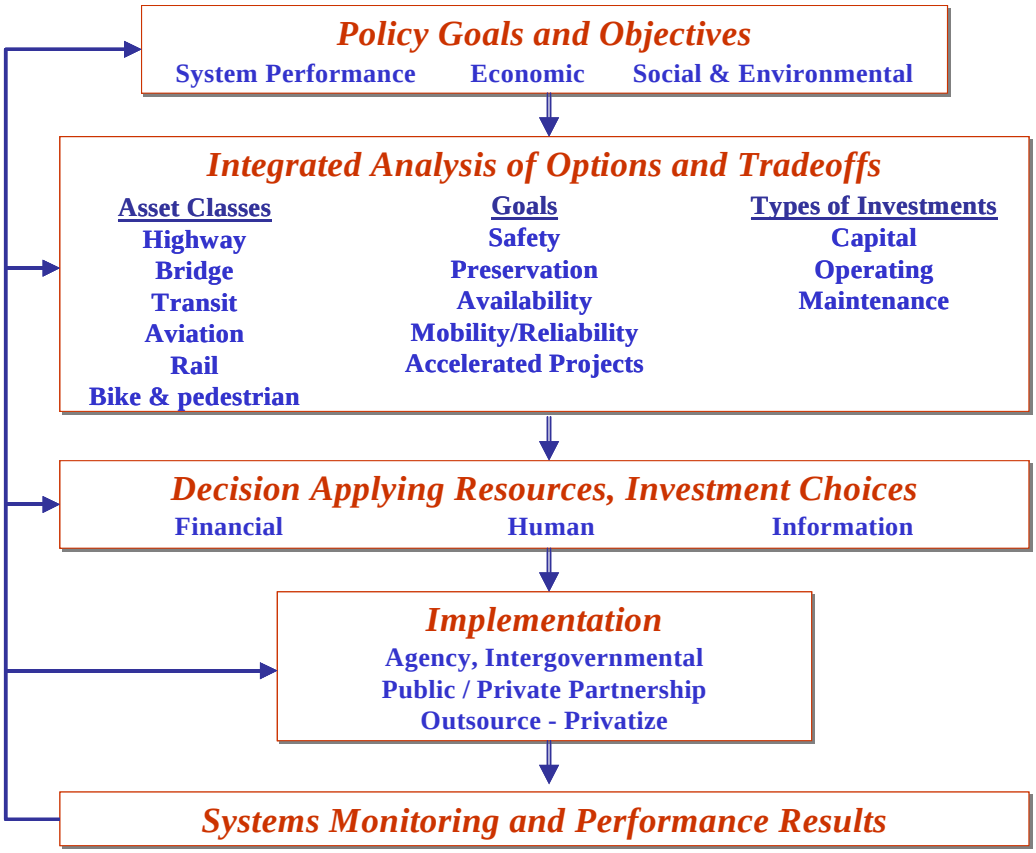

Figure 2. Framework for Transportation Asset Management as a Resource

Similar initiatives have been undertaken by several DOTs in an effort to implement the concept of Asset Management. However, there is still a long road to be traveled by state agencies in order to comprehensively implement Asset Management and move from today's theory to tomorrow's practice.

For example, the Virginia Department of Transportation (VDOT) has been among the nation's leaders in creating an Asset Management database and inventory information system. VDOT has created a pilot for a comprehensive state-wide highway inventory system by utilizing state-of-the-art procedures and cutting-edge technology (Larson and Skrypczuk (a), (b) 2004). The cost of the venture and the size of the created database led to the conclusion that such a practice was not necessarily the best one, and created skepticism on 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 2004 (b)). 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). This thesis draws from this effort and focuses on researching the links between data collection and Asset Management decisions processes.

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 decision making. 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 dependant on the intended use of the data. It is obvious that the level of detail and the depth needed for the collected data varies according to the hierarchical level of the decisions that need to be made. Although all decision-making 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 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:

(1) Location: actual location of the asset as denoted using a linear referencing system or GPR coordinates.

(2) Physical attributes: description of the considered assets that can include: material type, size, length, etc.

(3) 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/or quantitative in accordance to established practices and standards (e.g., Pavement Condition Index, bridge health indices, etc).

Data Collection Methods

Infrastructure data collection has been an ongoing process since the 1960's. In the last decades the various methods and technologies used have shown a trend towards automation and computerization.

Methods used for the collection of asset management data include: (1) manual, (2) automated, (3) semi-automated, 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 is presented following (VDOT 2004):

(1) Manual collection: The method employs two or more data collectors and a distance measuring device. The collected data are documented either with pen and paper or in most recent cases with hand-held computers equipped with GPS (Larson and Skrypczuk (a) 2004). 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 along the travel line; 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 semi-automated methods.

(2) Automated collection: The method involves the use of a multipurpose vehicle which is equipped with a distance measuring device, digital video cameras (downward and/or forward looking), a gyroscope, laser sensors, computer hardware and potentially 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 in order to visualize in three dimensions the location of the transportation assets from the digital two-dimension frames. The newest data collection equipments have achieved high automation and accuracy and are capable of very fast and 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.

(3) Semi-automated 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.

(4) 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 (lasers, aerial photos, aerial GPR, 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 the following (VDOT 2004):

- Photolog: Was the original data collection method which was used from the 1960's to the 1980's. Data had to be viewed through sequential image access or film. (VDOT 2004).
- Videolog: Mainly used during the 1980's but in some cases it is still in use today. Data could be randomly accessed as long as they were placed on a laser disk. Today's practice includes mostly digital video.
- Regular resolution digital images (i.e. 640 by 480 dpi): Mainly used from the mid 1990's to present. Images are placed on various storage media (magnetic tapes, CD's, DVD's etc) and on network servers.
- High resolution digital images (i.e. 1300 by 1000 dpi): Mainly used from the end of the 1990's until present. Images also placed in magnetic disks but mainly in 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 data collection frequencies may vary accordingly to its purpose. Data collection frequency usually depends on asset type, as some assets require more frequent data collection than others, asset condition, and other factors. More information on data frequencies can be found elsewhere in VDOT (2004).

Data Characteristics and Properties

The research of various sources on how agencies worldwide deal with decision making 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, and
- Security: sensitive, confidential and important data are protected by restricting access to them and by properly ensuring systematic and frequent "backing-up" in other storage media.

As a fifth characteristic 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/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 update should be based on the needs and resources of the agency/ organization,
- Reliability: the data should exhibit the required accuracy, spatial coverage, completeness and currency, and
- 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 take into account and determine the following parameters:

- The specification of the data to be collected,
- Their frequency of collection,
- The accuracy and quality that the data should exhibit, and

- Their 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

Once the data have been acquired by one or more of the above described methods and technologies they are stored in various formats and storage media. Data formats include: paper format, electronic databases, and geo-referenced database systems (such as Geographic Information Systems, GIS). The storage media employed can be paper forms (still in use in many agencies), hard disks, magnetic tapes, CDs, DVDs and combinations of thereafter.

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 stand-alone or part of a database system.

Organizational culture has traditionally prompted agencies to create database/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 as the aforementioned systems often use different data management technologies and information system environments (e.g. database design, software, hardware, etc.) (FHWA 2001 (f)). 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, and stored in varying formats and media, there is naturally a need for data integration. Data integration is essential to transform the data into useful information, able to support decision making at the various management levels. Transportation agencies must organize the available data into suitable forms for applications at the different organizational levels of decision making. This venture presents a big challenge, as data integration is nothing but easy to implement.

According to FHWA (2001 (b),(e),(f)) 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 among the two integration strategies depends on many factors and is clearly a judgment call for the agency officials. The factors to be considered include:

- Intended use of the integrated data (by whom and for what purpose),
- Characteristics of the already existing databases/information systems,
- Type and volume of the data that need to be integrated,
- Currently available information technology,
- Level of staff and resource allocation that will be dedicated to the process, and

- Structure of the agency/organization itself (business units and their roles, data needs, people and information systems).

As 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 2001 (f)).

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 of vital help to the effort of data integration, regardless of the integration strategy implemented. However, there have been many challenges identified by agencies that have tried to develop and implement data standards and that have attempted to convert 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 as much as possible the effort and resources needed in order to develop and implement the standards (FHWA 2001 (f)).

Decision Processes and Data Collection

Independent of the data integration strategy chosen and level of integration achieved, there are many dimensions inherent in the analytical and decision making processes concerning transportation assets that need be taken into account.

Decision processes can be either:

- At an operational level (e.g. how to repair a bridge component) or

- At a more generalized strategic level (e.g. how often to resurface a road).

They can address:

- A specific project that is geographically restricted and has a narrow scope (e.g. a route or a highway section) or
- A complete network of roadways (e.g. all state rural arterials).

Furthermore, they can refer to resource allocation and analysis of alternatives:

- Across different assets (e.g. pavements, bridges, tunnels, signs, etc) or
- Across different governmental jurisdictions (e.g. counties, districts, etc).

Therefore, large and diverse amounts of data are needed in order to fully support the decision processes in all their possible dimensions and in all levels of decision making within the agencies.

In addition, the resulting system's complexity is big enough to intimidate even carefully designed strategies and high levels of data integration that are chosen to be implemented (FHWA 2001 (f)). A carefully conceptualized thought process of rationalizing which data are needed to support which type or level of decision processes needs to be developed. This process can lead to a more effective and efficient data integration within the intended scope of the data and the decision systems they support. This section discusses the decision processes of transportation agencies and explores the link between them and data collection – if any.

The data needed in order 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 seems to be occasionally forgotten. In that context, a cost-effective and rational approach to data collection is currently needed by transportation agencies and organizations. 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.

All forms of management have an internal hierarchy of decision making levels. There is a structured process inherent in most corporate systems that aggregates information and generalizes the scope of decisions to be made as one moves upwards in this hierarchy. Infrastructure management and Asset Management are not different than the rest. There are various decision-making levels that represent different perspectives on the system, which range from very specific, detailed project-oriented views to generalized, comprehensive and strategic ones. The decision levels pertaining to Asset Management as identified in literature are three: the strategic level, the network level and the project level (Haas et al. 1994; Hudson et al. 1997; AASHTO 2001). All of them are strongly interconnected and in various cases present a significant amount of overlapping as there cannot be very strict and impermeable boundaries in decision making within an organization and as communication between the various levels is paramount for the overall success of the management process. They have, however, different scope and require different data and information inputs in order for the decision making to be carried out effectively and efficiently.

Furthermore, there is a significant difference in the scope of Asset Management decision making at the various levels of government. As one moves from a local agency or town government entity to a state-wide one, the complexity of the implementation of an asset management system and the size of the considered network of assets increase. However, although the scope increases, the principles and concepts behind the decision-making remain the same and the decision making levels as presented and analyzed in the following section also remain the same.

Asset Management Decision Levels

As mentioned above, the main levels of decision making are strategic, network, and project level. The strategic decision-making 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 decision making is concerned with generic and strategic resource allocation and utilization decisions within the man-made environment.

Network level decision-making pertains to determining the overall agency-wide maintenance, rehabilitation and construction strategies and works programs. This decision level considers system-wide decisions but the scope is narrower than the strategic level. 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 decision-making level is concerned with the overall, network-wide programming of actions and allocations. It's a level involving 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 two previous ones. It serves as a link between the network level and the subsequent project level of analysis.

The project level of decision making and analysis pertains to the specific, mode-wise, asset-wise and geographically determined projects. It addresses the overall work plan that needs to be developed at this level, for the specifically selected project in order 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 decision making are clearly defined, there exists significant overlapping among what the management needs to do at every level. The identification of the actual data needed in every decision making level is a very challenging task. This is partly due to that significant overlapping between the various decision levels. Another important reason is also the lack of relevant research initiatives in this field up to date.

Asset Management Decision Processes

As mentioned before, Asset Management is an overall methodology and decision making framework that aims to the evidence-based justification and optimization of investments in infrastructure assets. Although it is mostly perceived as a strategic level tool, it nevertheless affects and can equally be successful in lower levels of decision making within a transportation agency.

Asset management decision processes are the individual decisions that need be made in every level of decision making, whether that is of a strategic, network, or project focus. Decision processes can therefore be concerned with budget allocations, network optimization, works programming, and selection of alternative implementation methods, among others. 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 decision making these processes support. The analyst can then assess the level of aggregation of the data needed and identify the data needs for those specific decision making processes and problems.

The data needed to support the various decisions at any of the various levels are different. Higher levels require more generalized information while lower ones tend to need more detailed and specific data. This is illustrated in Figure 3 (Haas et al. 1994). The detail of information required and its correlation with the considered network size and the complexity of the analytical models used have a specific relation with the different levels of decision making.

Furthermore, different levels of decision making have different focus on the network and the transportation system: higher levels are mostly concerned with overall budget allocations and system utilization, while lower levels tend to focus more on the administration, funding and engineering of specific functions and processes. Also different people with different backgrounds and different interests are the ones that make the actual decisions. As a result, the decisions at each level are different in scope and data aggregation level and so should be the corresponding detail and quantity of the collected data. This concept is illustrated in Figure 3.

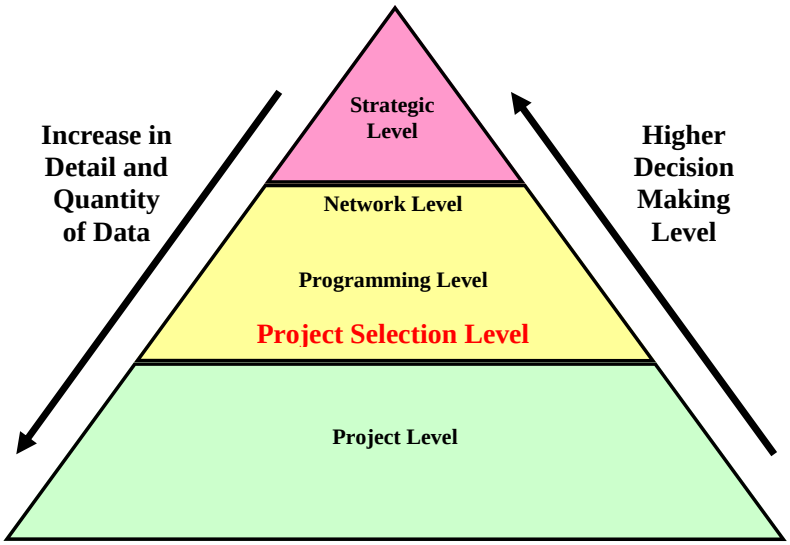

Figure 3. Relation between the different decision making levels and the corresponding detail and amount of needed data

Information Quality Levels

To link the amount of information detail with the level of decision supported, researchers have defined Information Quality Levels (IQL). According to the World Bank (2004), there are five information quality levels in road management (IQL 1 to 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.

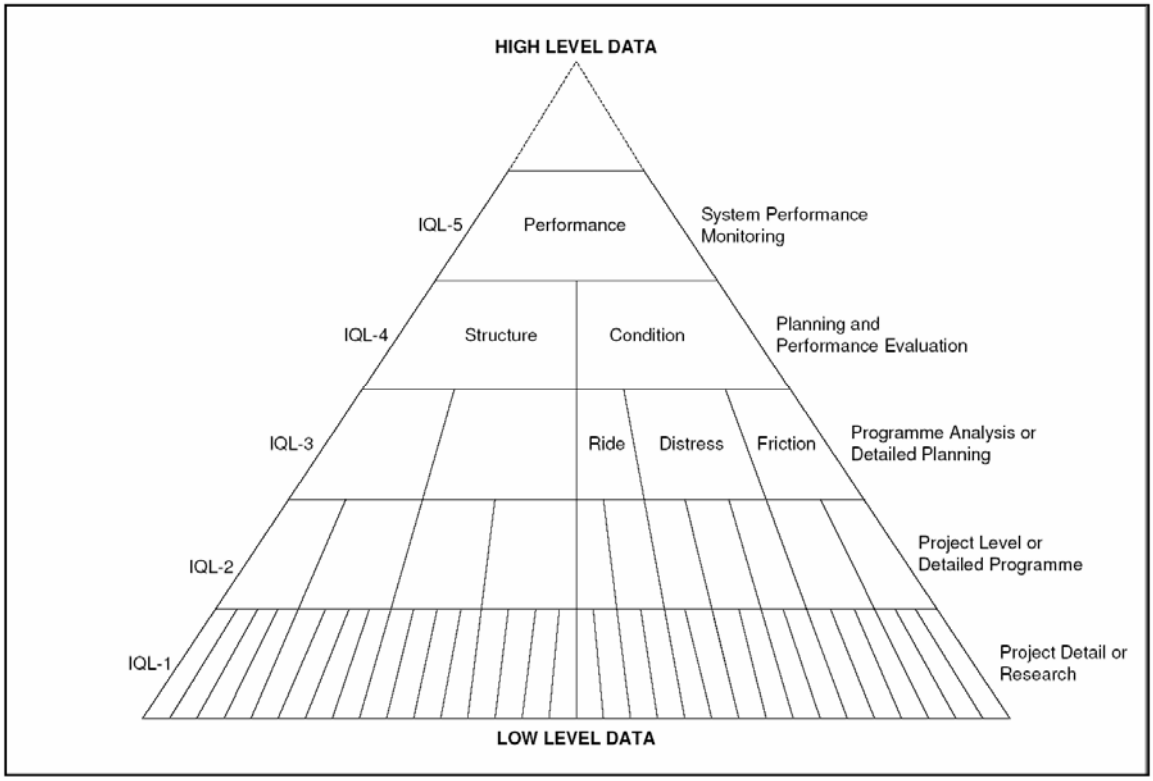

Figure 4: Information Quality Level concept

Each IQL focuses on a different level of road management and requires different levels of detail and quality in the collected data to support the corresponding decision making processes. The classification of the information for every level by quality and detail is presented in Table 1 (World Bank 2004). The differences in quality and detail for each Information Quality Level translate into different methods and frequencies of data collection.

Table 1: 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 a fundamental research. Would also be used in detailed field investigations for an in-depth diagnosis of problems, and for high-class project design. Normally used at project-level in special cases and 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, would suit elementary methods such as catalogue-type with meager data needs and low-volume road/bridge design methods. Can be collected in network surveys by semi-automated 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 semi-automated, provide direct but approximate measures and suit small or resource-poor agencies. Alternatively, the statistics may be computed from more detailed data.

It is therefore imperative for the determination of data needs to pre-specify the decision level of interest. The tailoring of the data collected for effective decision making 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.

Project Selection and Related Tools

Project selection is a level of decision making that entails the evaluation of the attributes of different candidate projects for the purpose of funding and implementation. As a decision making level it addresses decisions pertaining to network level analysis and it functions as a "bridge" between high-level network decisions and site-specific, detailed project level decision making. The project selection analysis is based on information that is aggregate enough to be able to see the "big picture" of the competitive projects and therefore identify and assess their usefulness and overall impact but also detailed enough in order to capture the individuality of each project and be able to provide accurate cost estimates and identify implementation implications for the agencies and the users.

The nature of project selection presents a particular individuality, as in many cases the candidate projects concern different assets and also different types of work to be done either in the same or in different assets. As an example, candidate projects for this type of decision making may be a project concerning the rehabilitation of an existing flexible pavement through milling and repaving and a project concerning the maintenance of a concrete pavement through crack sealing; or the maintenance of the roadside drainage system of a particular segment of a highway versus the rehabilitation of the concrete deck of a bridge 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. A list of roadway assets identified by the Virginia DOT with their corresponding definitions is presented in Table 2.

Table 2: Roadway Asset Types and Definitions

Roadway Assets	Definition
Pavements	Flexible Pavements (HMA), PCC 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 Under-drains, 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 Bridge, Sound Barriers and Retaining Walls
Special Facilities	Movable Bridges, Rest Areas, River and Mountain Tunnels, Weigh Stations and Traffic Monitoring Systems

According to the academic literature (Hudson et al. 1997) the project selection follows the overall network programming decisions regarding the general funds that are going to be allocated in the different types of agency works. After the agency has decided on the amount of funds to be spend 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 types of prioritization models. These models usually employ optimization, near-optimization or other techniques in order to lead to results that can be used by the

transportation officials to support decision making (Haas et al. 1994). The most used prioritization methods have been summarized by Hudson et al. (1997) and are presented in Table 3 along with their advantages and disadvantages.

Table 3: Classes of Methods that can be Used in Priority Analysis

Class of Method	Advantages/Disadvantages
Simple subjective ranking of projects based on judgment	Quick, 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 competent models that include economic analysis and multi-year prioritization in the optimization process. Some of these models take also into account the effects of certainty, risk and uncertainty in the outcome of the prioritization results (Li and Sinha 2004).

This has focused the 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 these techniques are not new and have been used by transportation agencies in the past. The most commonly used techniques are the following (Haas et al. 2004):

- Benefit/Cost Ratio Method
- Internal Rate of Return
- Present Worth Method or Net Present Value (NPV)
- Equivalent Uniform Annual Costs (EUAC) and
- Cost-Effectiveness Method

Parallel to the existence of these economic evaluation techniques has been the procurement of tools for engineering economic analysis and also the development of specified software. Flintsch and Kuttesch (2004) identified various pavement engineering economic analysis software tools and listed their area of application and their advantages/disadvantages. The reviewed software tools were the following:

- MicroBENCOST
- StartBENCOST
- HERS/ST
- Pavement Investment Decisions (PID)
- FHWA Probabilistic LCCA Spreadsheet
- Asphalt Paving Association (APA) LCCA software and
- HDM – 4

All the above mentioned techniques and software tools constitute valid approaches for supporting project selection decision making, provided that they are used in full recognition of their capabilities and limitations.

Since 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 decision making 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.

State-of-the-Practice

This section presents a review of the State-of-the-Practice in the US 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 in the US and the rest of the world, little information can be found in the literature about the data needs of the various decision making processes that transportation agencies have to undertake. This is partly due to the fact that this is a relatively new issue for most agencies (private or public) and affects only the ones that have already taken the initial step of developing inventories and databases to support some sort of Asset Management implementation. As the concept of Asset Management is relatively new and as there have been many hurdles in its implementation process to begin with, it is not surprising that formal links between decision making 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 of them have reportedly been moving towards the integration of these systems. Asset Management efforts are underway but, as mentioned also in a previous section, with many implementation hurdles yet to overcome. There have been several efforts to capture the state-of-the-practice in the US 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 PMS data types (Table 4). In this investigation State DOTs were asked to report if their Pavement Management System (PMS) was using specifically identified data items, if these items were collected by the PMS's data collection activities, and the data collection methods.

Table 4: Number of DOTs that Use and Collect Each Major 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
ESALs	31	60%	3	6%	6	11	12	29
M&R History	44	85%	26	50%	34	1	8	43

In order to get more specific about the U.S. practice, one has to recognize all the actors that influence the development, endorsement, and implementation of Asset Management in the U.S. Stalebrink and Gifford (2002) identified three levels of government (federal, state and local), various organizations, academia, and consulting firms. In addition, the contribution to the Asset Management know-how of the private sector 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 towards an integration of individual management systems and databases to support Asset Management. For example, 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 2004 (a)), 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 on 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 2002 (a), (b)). Some of these universities have even created courses addressing Asset Management in their graduate degree programs (Stalebrink and Gifford 2002).

Finally, consulting firms and the private sector in general, have participated in several peer exchanging conferences and symposiums in order to bridge the gap between them and the public sector, regarding Asset Management implementation efforts and challenges (AASHTO 1999). Furthermore, the American Public Works Association has dedicated resources in 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 U.S. Canadian transportation agencies, universities, and public and private organizations have been promoting Asset Management and funding associated research from 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 lead 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 2001), 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 actual implementation of Asset Management in Canada has yet to be seen, as 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 the recent years, there are efforts to draw from the past experience on the utilization of these systems for promoting the implementation of Asset Management. The focus has been mainly 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 1980's and since then a lot of research has taken place in this subject area (Sheldon 2004). Australian transportation agencies conducted early studies towards the state-of-the-art of Asset Management (Burns et al. 1999) and were the first ones in the world to capitalize and record their road and bridge infrastructure in their annual reports in 1990 (Sheldon 2004). One of the first comprehensive guides to Asset Management, "Total Asset Management", was issued in

1996. A revised version has recently been published by the Australian Procurement and Construction Council, entitled “Asset Management 2001” (APCC 2001).

Australian transportation organizations and authorities have been constantly reporting on their progress towards 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); decision making 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 towards the issuing of performance oriented maintenance contracts for their road networks, creating in this way 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 of the European countries are still in the phase of developing or investigating the potential advantages of the use 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 already existing management systems within an overall Asset Management framework.

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

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; Sund 2003; WERD 2003; Sund et al. 2004; Potucek and Lang 2004). 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 counties 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. 2003 (a), (b)), 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 towards 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 the 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 or 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, i.e. overall interstate mileage, total number of bridges, etc.

On the other hand, there have been advances in the project level of decision making with the implementation of one or more individual management systems, i.e. 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 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. The project level is important to the agencies' management efforts as this is the level in which implementation actions occur. Decisions and subsequent actions successfully carried out at the project level define the success of the agencies' implementation program and provide the feedback for the evaluation of the success of all the higher levels of management and decision making. Therefore, strong emphasis has traditionally been placed on the data needs of project level decision making 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.

Lastly, at the utmost of implementation efforts have been cases where common databases have been or are attempted to be created in order to minimize data storage and enhance interoperability between different management systems. These efforts do not usually address any particular decision making 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, 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 been found profusely in the literature.

The undertaken literature review has revealed that although there has been progress and research in almost all levels of decision making, the level that has received the least attention in terms of its data needs is the project selection one. 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. Project selection has unique data needs: they are detailed enough to effectively assist the understanding and rationalization of project selection and at the same time aggregate enough to be able to allow the addressing of projects of different nature and scope within the entire network. This decision making level requires therefore data that are in the middle of being too general and too specific at the same time. While general data would not help in the selection project as they would

ignore vital project details, it is usually not cost-effective to collect very detailed (e.g, project-level) data for the project selection process. Furthermore, project selection has been traditionally 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 unbiased to all different asset classes.

Asset Management Data Collection for Supporting Decision Processes

Aristeidis Pantelias[(1)], Gerardo W. Flintsch[(2)], James W. Bryant[(3)] and Chen Chen[(1)]

Abstract

Transportation agencies engage in extensive data collection activities in order to support their decision processes at various levels. However, not all the data collected supply transportation officials with useful information for efficient and effective decision-making.

This paper summarizes research aimed at formally identifying links between data collection and the supported decision processes. The research objective identifies existing relationships between Asset Management data collection and the decision processes to be supported by them, particularly in the project selection level. It also proposes a framework for effective and efficient data collection. The motivation of the project was to help transportation agencies optimize their data collection processes and cut down data collection and management costs.

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Keywords: Asset Management, Data Collection, Decision Processes, Decision levels, Project Selection, Web Survey

Background

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

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 data collection and integration procedures necessary to support the comprehensive analyses and evaluation processes needed for Asset Management (Flintsch et al. 2004).

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 the collection of very large amounts of data and the creation of 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 placed a large emphasis on collecting and integrating data, little effort has been placed on 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 decision making and tailor their data collection accordingly.

The objective of this research was two-fold: to investigate the level in which State Departments of Transportation (DOTs) have adopted Asset Management tools and methodologies in their current practice and to investigate how they are linking their data collection policies, standards, and practices to their decision making processes, especially for project selection. This decision-making level functions as an intermediate stage between high-level strategic decisions and low-level, project-specific decisions.

Methodology

This investigation started with a comprehensive and thorough literature review in order to retrieve related experience from academia and industry sources throughout the world. Several reports have documented current and past practices in this area in the United

States, Canada, as well as in Europe and Australia. The literature review summarizes the state-of-the-art and corresponding state-of-the-practice implementation efforts in Asset Management and identifies the main confronted issues.

To complement the literature review, a web survey was developed and sent to the DOTs in all 50 states and Puerto Rico, in order to capture their 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 decision making.

The knowledge gained from these activities was used to develop a framework for effective and efficient data collection, as well as recommendations for further refinements and enhancements of this area of civil engineering practice.

Literature Review

Asset Management, Data Collection and Decision Levels

The concept of Asset Management is not new. Many definitions of the concept have been provided by various governmental organizations, transportation agencies, and industry groups (Danylo and Lemer 1998; TAC 1999; OECD 2000). Probably the most common one is still the one proposed by the Federal Highway Administration (FHWA):

> "*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 decision-making. Thus, asset management provides a framework for handling both short- and long-range planning* (FHWA, 1999)."

The state-of-the-art of Asset Management has been extensively researched and many contributions have been made to date by transportation agencies and other related stakeholders in the United States and around the world. Details about these contributions can be found in Pantelias (2005).

One of the key building blocks of any Asset Management system is a comprehensive inventory of the 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 (FHWA 2001; Larson and Skrypczuk 2004; VDOT 2004).

The decision making supported by Asset Management takes place within the internal hierarchical structure of transportation agencies and organizations. The academic literature breaks down decision making into three broad levels: a strategic level, a network level, and a project level (Haas et al. 1994). The intermediate network level of decision making is further divided into a programming level and a project selection level

(Haas et al. 1994). The data needed to support decision making in each of these levels is of paramount importance to the success of an Asset Management system and is also very much related to the data collection costs.

Different levels of decision making have different foci: higher levels are mostly concerned with overall budget allocations and system utilization, while lower levels tend to focus more on the administration, funding, and engineering of specific functions and processes. Also, different people with different backgrounds and areas of expertise are the ones that make the actual decisions. As a result, the decisions at each level are different in scope and data aggregation level and so the corresponding detail and quantity of the collected data should be as well. This concept is illustrated in Journal Figure 1. This investigation focused on the data needs of the project selection level of decision making.

Project Selection Level of Decision Making

Project selection entails the evaluation of the attributes of different candidate projects for the purpose of funding and implementation. As a decision making level it addresses decisions pertaining to network-level analysis and it functions as a “bridge” between high-level network decisions and site-specific, detailed project-level decision making. The project selection analysis is based on information that is aggregate enough to be able to see the “big picture” of the competitive projects and therefore assess their usefulness and overall impact, but is also detailed enough in order 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 presents a particular individuality, as in many cases the candidate projects concern different assets and types of work to be done either in the same or in different assets. As an example, trade-offs may consider the rehabilitation of an existing flexible pavement through milling and repaving versus the maintenance of a concrete pavement through crack sealing; or 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.

According to Hudson et al. (1997), project selection follows the overall network programming decisions regarding the general funds that are going to be allocated in the different types of agency works. After the agency has decided on the amount of funds to be spent on 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 prioritization models. These models usually employ optimization, near-optimization, or other techniques in order to lead to results that can be used by the transportation officials to support decision making (Haas et al. 1994).

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 competent models that include economic analysis and multi-year 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).

This has focused the attention on the economic parameters of infrastructure management and their effects on the project selection. The most commonly used economic analysis techniques include: Benefit/Cost Ratio Method, Internal Rate of Return, Present Worth Method or Net Present Value (NPV), Equivalent Uniform Annual Costs (EUAC), and Cost-Effectiveness Method (Haas et al. 2004).

These techniques have been incorporated into software tools for engineering economic analysis. Flintsch and Kuttesch (2004) identified various pavement engineering economic analysis software tools and listed their area of application and their advantages/disadvantages.

Project selection data needs should focus on the specific inputs that the project evaluation models require. As different agencies employ different models and techniques for project selection, the data needed for each agency are also bound to be different.

Data Characteristics and Properties

Another important data collection issue relates to the particular attributes and characteristics that the collected data should possess in order to be useful for supporting decision making. Regardless of the uses planned for the collected data, it is of paramount importance that 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, and
- Security: sensitive, confidential and important data are protected by restricting access to them and by properly ensuring systematic and frequent "backing-up" in other storage media.

As a fifth characteristic it is also recommended that the data elements be rigorously defined in a Data Dictionary and – in the most ideal of all cases – these definitions be common between all agencies and parties involved in the area of practice (Deighton 1991).

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

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

Consequently, agencies planning to engage in data collection should take into account the specification of the data to be collected, their frequency of collection, the accuracy and quality that they should exhibit, and their completeness and currency (WERD 2003). 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 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).

Implementation Efforts

Many agencies around 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 (Pantelias 2005).

Asset Management implementation efforts have focused mainly on the overarching strategic or network (program) levels. For example, there have been efforts to link Asset Management systems with strategic planning and overall network improvements (Ogard et al. 2004). Data needs for this type of decision comprise aggregated overall network performance indices and overall network characteristics, i.e. overall interstate mileage, total number of bridges, etc.

On the other hand, there have been advances in the project level of decision making. 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 as-needed basis. It is collected only for a reduced number of assets that have been identified as needing work, usually from the network-

level analysis. The project level is important to the agencies' management efforts as this is where implementation actions occur. Decisions and subsequent actions successfully carried out at the project level define the success of the agencies' implementation program and provide feedback for the evaluation of success at the higher levels of management. Therefore, strong emphasis has traditionally been placed on the data needs of project-level decision making and will continue to be so, although these needs depend on individual management systems and the processes employed at this decision level (Pantelias 2005).

Lastly, at the utmost of implementation efforts have been cases where common databases have been created (or have been attempted) in order to minimize data storage and enhance interoperability between various management systems. These efforts do not usually address any particular decision making 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.

Web-based Transportation Asset Management Survey

A web-based survey was formulated and posted on the Internet to capture the state-of-the-practice in the United States. The survey was made available on the server hosted by the Virginia Tech Web Hosting. A link to the survey was sent to 103 transportation officials and their responses were stored in a specifically designed database.

Various sources were utilized in order to retrieve similar past experiences and facilitate the formulation of the questionnaire, 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 of the terminology used and the actual information requested from the survey recipients. The questionnaire was divided into two major parts.

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

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

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

- Data management, collection methods and integration.
- Rationale behind existing and/or future planned data collection,
- Evaluation of roadway asset data used for project selection, and

- Identification of formally documented links between data collection and project selection or Asset Management decision processes in general.

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

The webpage of the survey was developed using Macromedia Dreamweaver MX 2004 and was uploaded at www.am.vtti.vt.edu. 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 log in. An email was then sent in order to provide the recipients with the survey's webpage address link and also explain the purpose of the research and its anticipated importance. The survey was open to responses for three weeks. Reminder emails were sent to the survey recipients who had not yet responded.

All responses were stored in a project-specific database. The database was created using the MySQL tool and contained three different tables; the database structure is presented in Journal Figure 2.

The contents of the survey were refined several times by the research team for suitability of the contents, the wording of the questions, and the suitability of the format used for the various questions. Complementarily, the survey was also sent for review and commenting to the Statistics and Survey Departments of Virginia Tech. Various changes were made 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 supervising the project in order to receive comments on the contents of the questions and provide feedback on the usefulness of the survey and its anticipated importance. The feedback received validated the structure and contents of the questions and further refinements were completed.

Analysis

A total of 48 completed questionnaires 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. The responses were statistically analyzed and charts and tables were created. The details of the analysis were documented in Pantelias (2005); a discussion of the results follows.

For seven states, more than one transportation official responded to the survey. Furthermore, while some questions were state-specific and required only one valid answer per responding state, others inquired about the personal opinion of the responding state transportation officials. Due to this difference, two approaches were followed for processing the responses from the states that provided more than one response:

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

  According to the above criteria, the ultimately considered state response consisted of excerpts from responses provided by different officials.

- In the remaining cases, where the survey questions asked for individual opinions, all answers (48) were considered valid and utilized in the analysis.

Answers to essay questions were not considered in the 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.

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 phase of planning. 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, with 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 ones in terms of this integration.

Decision Levels and Processes

When asked to report on their defined decision making levels, most of the responding transportation agencies indicated that they have explicitly defined decision making levels that coincide with the ones found in the literature (Journal Figure 3). The main levels identified were Programming and Budgeting and Project Selection. This confirms that the right transportation officials were selected as they were familiar with these levels of decision making and that the agencies have been focusing their attention to these intermediate levels that connect the generic strategic decisions of the Strategic Level with the actual project implementation at the Project Level.

Further on, the state transportation officials were asked to rate 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.

Journal Figure 4 summarizes the responses. From this plot it can be discerned that most of the listed decision processes fall in the "Very Important" or "Somewhat Important" 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 to 4 (4 = Very Important to 1 = Not Important at All). Journal Table 1 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.

Journal Figure 5 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. The average rankings for all the listed criteria are presented in Journal Table 2. An interesting finding is that Public Demands/User Opinions rank in the third place, showing 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 can not/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 ones responded to be in a stage of 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 be collected in a great extent.

Journal Figure 6 summarizes the data collection methods used for the acquisition of the above data. While for some assets (e.g. drainage), the collection is reported to be taking place mostly using manual methods, there is a trend towards using a combination of manual and automatic methods. This is consistent with what was reported recently by Flintsch et al. (2004).

Data Collection Rationale

The officials were also asked to provide information about their rationale behind data collection. These results are summarized in Journal Figure 7. 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.

In the next question officials were asked to rate the importance of identified roadway asset data for the selection between two competitive projects. The ratings are summarized in Journal Figure 8 and Journal Table 3. 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 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 as 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.

Recommended 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 during the past years. 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 too general and too specific at the same time. While general data would not help in the project selection as they would ignore vital project details, it is usually not cost-effective to collect very detailed (e.g. 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 web survey suggests that U.S. transportation agencies have clearly identified decision making levels and have also relatively uniform perceptions of the importance of various asset management decision processes, project selection criteria and the corresponding asset data that could support the 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 Journal Figure 9. 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 are the various types of treatments that should be considered?
- What are the evaluation models, techniques and criteria used by the agency in order to judge the usefulness of the projects and rank/prioritize them?
- What are the inputs required by these models/techniques in order for the various projects to be assessed?
- What are the available data?

- What additional data needs 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 aimed to 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 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 from optimizing their data collection in order to support project-selection decision making.

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 just addresses project selection decisions without taking into account the needs of the other levels of decision making that might require overlapping or complementary data and hence require new or extended data collection activities. For a true optimization the data needs of all levels of decision making should be taken into consideration and a more comprehensive framework for data collection should be established. For this purpose, the findings of the survey concerning the most important Asset Management decision

processes can be used. These decision processes can be attributed to all different decision making levels and hence the consideration of the individual data needs of each one of them and the generalization of the proposed framework so as to include all of them and their interactions can possibly lead to a higher level of universal data collection efficiency.

Findings

The most important findings from the undertaken literature review and web survey are:

- Transportation Asset Management implementation in the United States and around the world is still at its initial steps. Most of the surveyed transportation agencies, however, are planning the integration of individual management systems they already use towards 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 can not/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 towards 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 data they use in order 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.

Conclusions and Recommendations

The concept of Asset Management has been endorsed by the majority of the transportation agencies in the United States and the rest of the world. The state-of-the-art has been steadily advancing and significant contributions have been made by various stakeholders. However, Asset Management implementation is still at its initial stages as 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 decision making 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 it has 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.

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 towards the complete rationalization of the data needs for these decisions. This framework, however, can only partially optimize the overall agency data collection activities as it only addresses project selection decisions.

Further research in the area of the project selection data collection should be undertaken in order to determine the reasons that render project selection criteria incapable of handling cross-asset comparisons. Additional effort is also needed in order to generalize the proposed data collection framework for an 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 deriving "best practices" in order to further enhance the proposed framework and eventually develop standards in this area.

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Journal Table 1. Ranking of Asset Management Decision Processes

Asset Management Decision Processes (1)	Average Ranking (2)
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: 4 = Very Important, 3 = Somewhat Important,
2 = Not Very Important, 1 = Not Important at All

Journal Table 2. Ranking of Project Selection Criteria

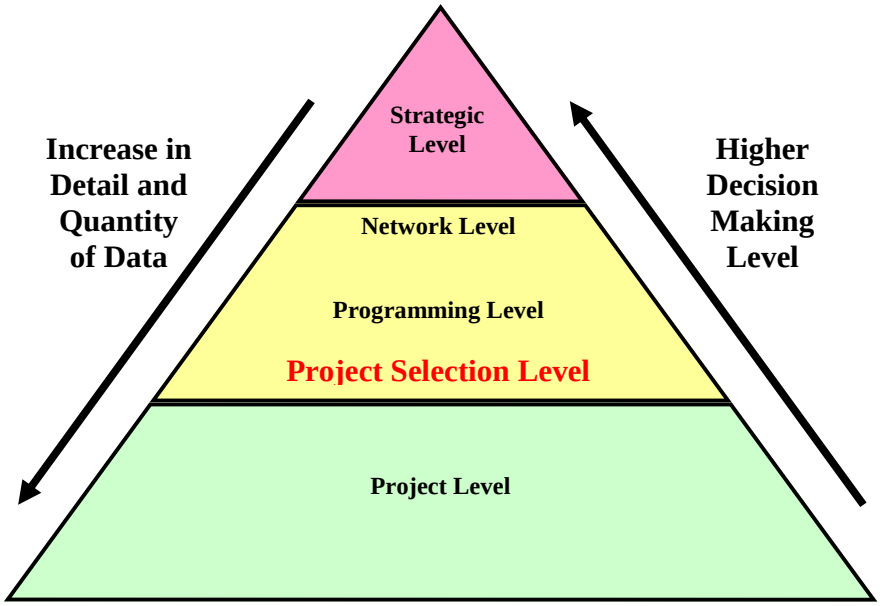
Project Selection Criteria (1)	Average Ranking (2)
Available budgets/ earmarked funds	3.75
Engineering parameters	3.44
Public demands/ user opinion	3.27
Project significance	3.27
Agency costs/ benefits	3.19
Usage of project	3.08
Environmental considerations	3.06
Geographic distribution of projects/ funds	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: 4 = Very Important, 3 = Somewhat Important,
2 = Not Very Important, 1 = Not Important at All

Journal Table 3. Ranking of Roadway Asset Data for Project Selection

Roadway Asset Data (1)	Average Ranking (2)
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: 4 = Very Important, 3 = Somewhat Important,
2 = Not Very Important, 1 = Not Important at All



Journal Figure 1. Relation between decision making levels and the corresponding detail and amount of needed data

Table: user

PRIMARY	Email
UNIQUE	userid
	firstname
	lastname
	title
	agency
	street
	city
	state
	zip
	phone
	fax
	suggestion
	completed

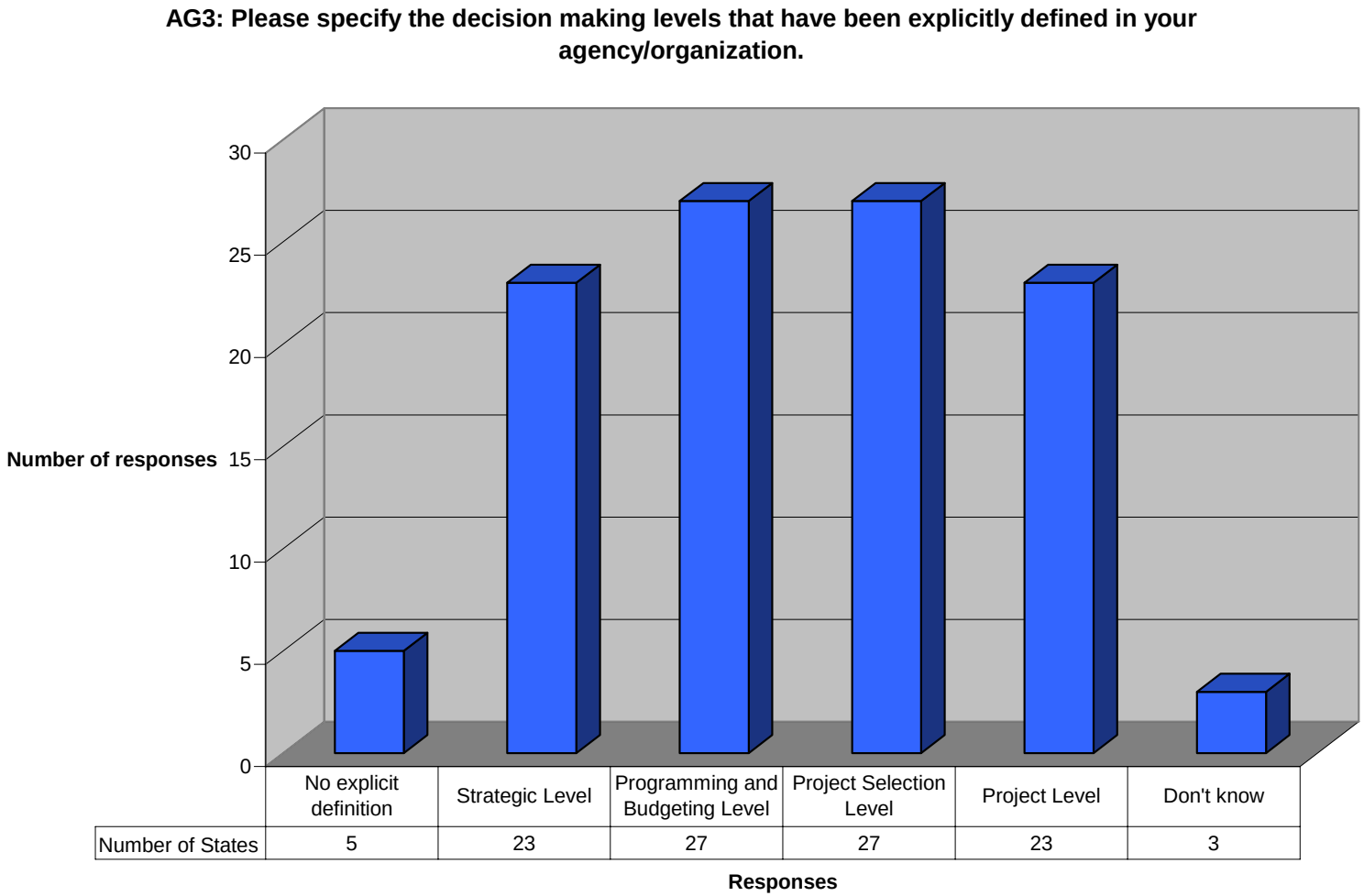
Table: agency

PRIMARY	userid
	amri
	drainage
	roadside
	pavement
	bridge
	traffic
	special
	other
	mtdrainage
	mtroadside
	mtpavement
	mtbridge
	…

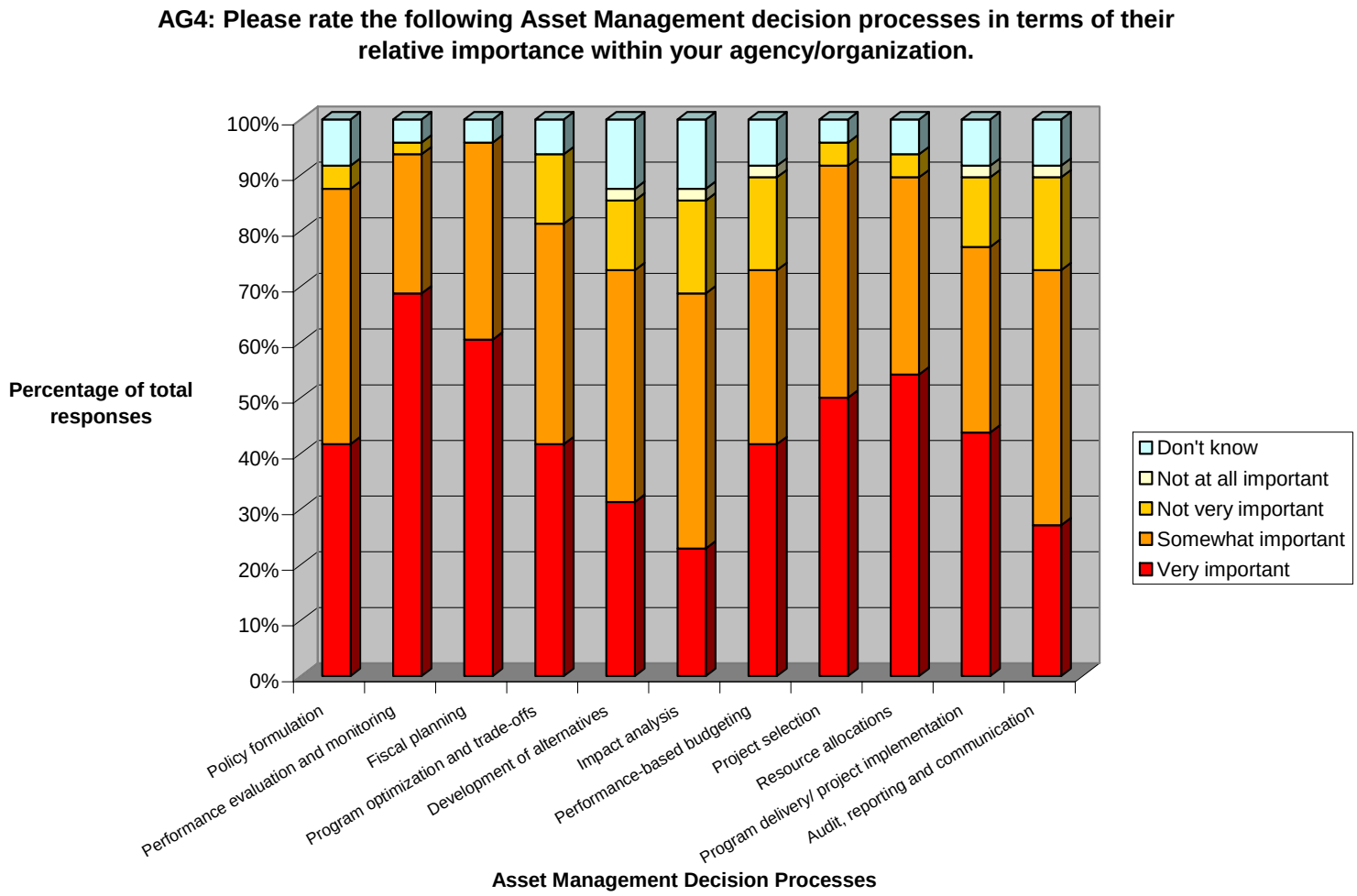
Table: roadway

PRIMARY	userid
	ams
	pms
	iamspms
	bms
	iamsbms
	sms
	iamssms
	cms
	iamssms
	ptms
	iamsptms
	itms
	…

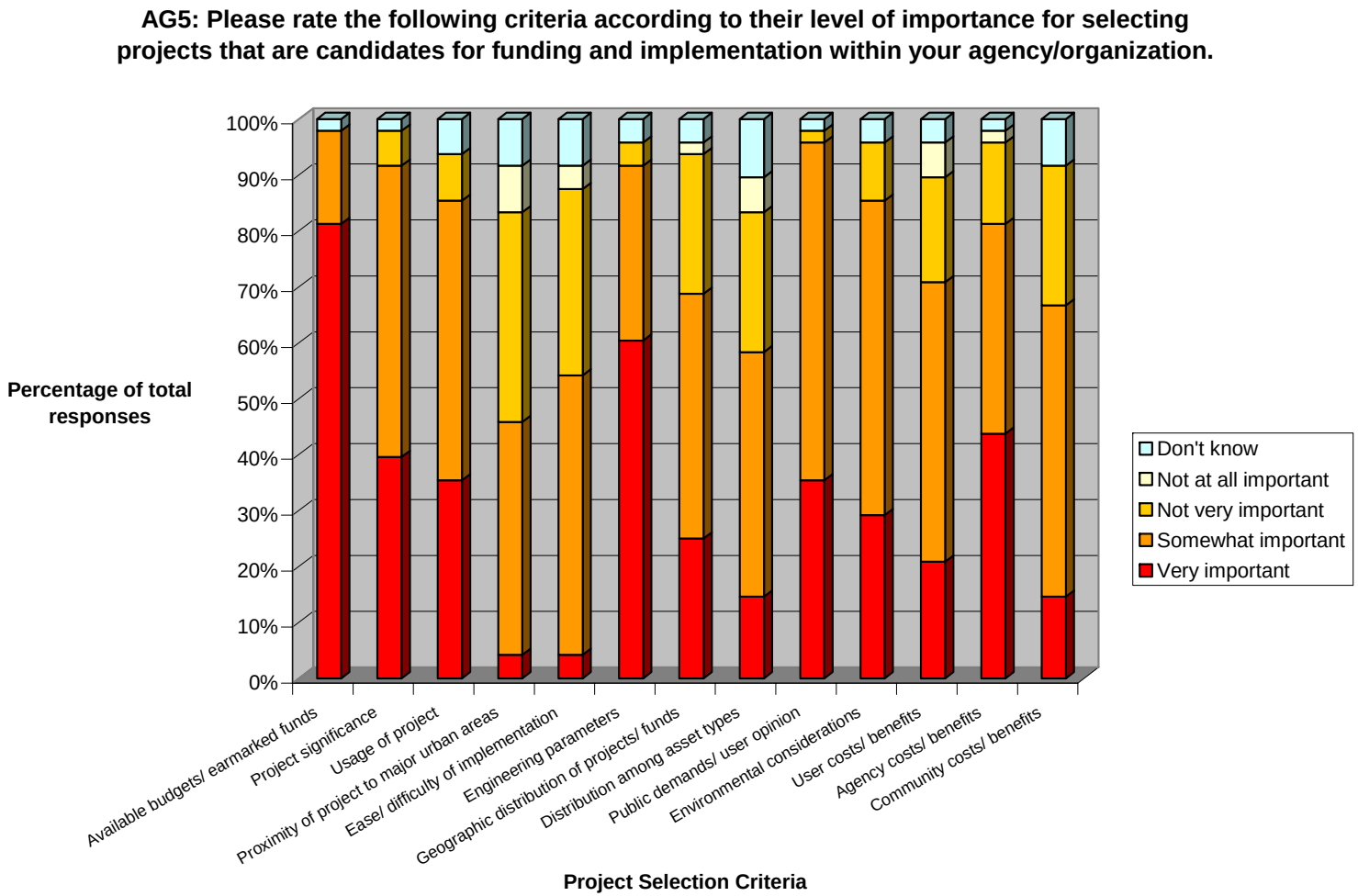
Journal Figure 2. Asset Management survey database structure



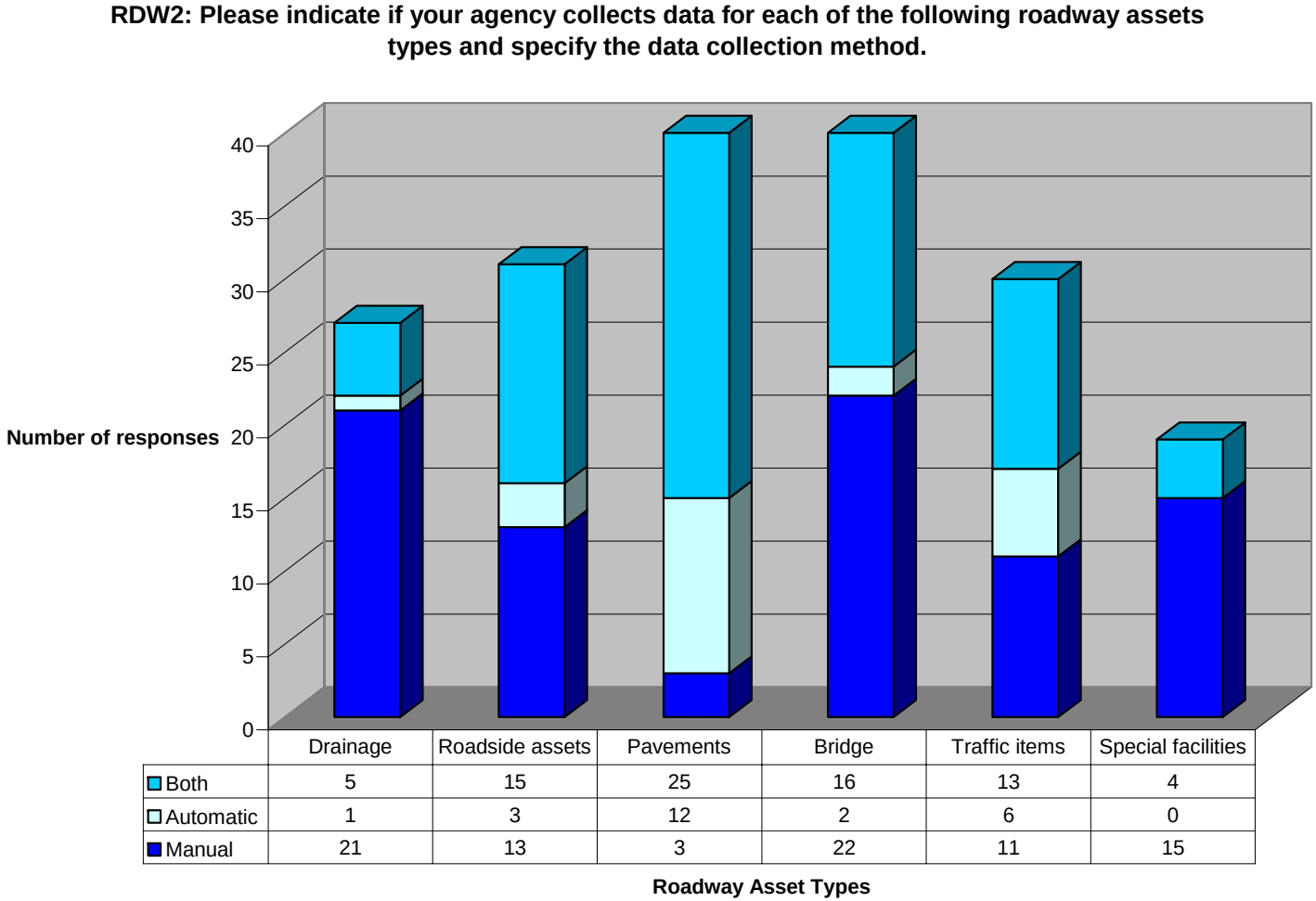
Journal Figure 3. Defined decision making levels



Journal Figure 4. Asset Management decision processes and their relative importance

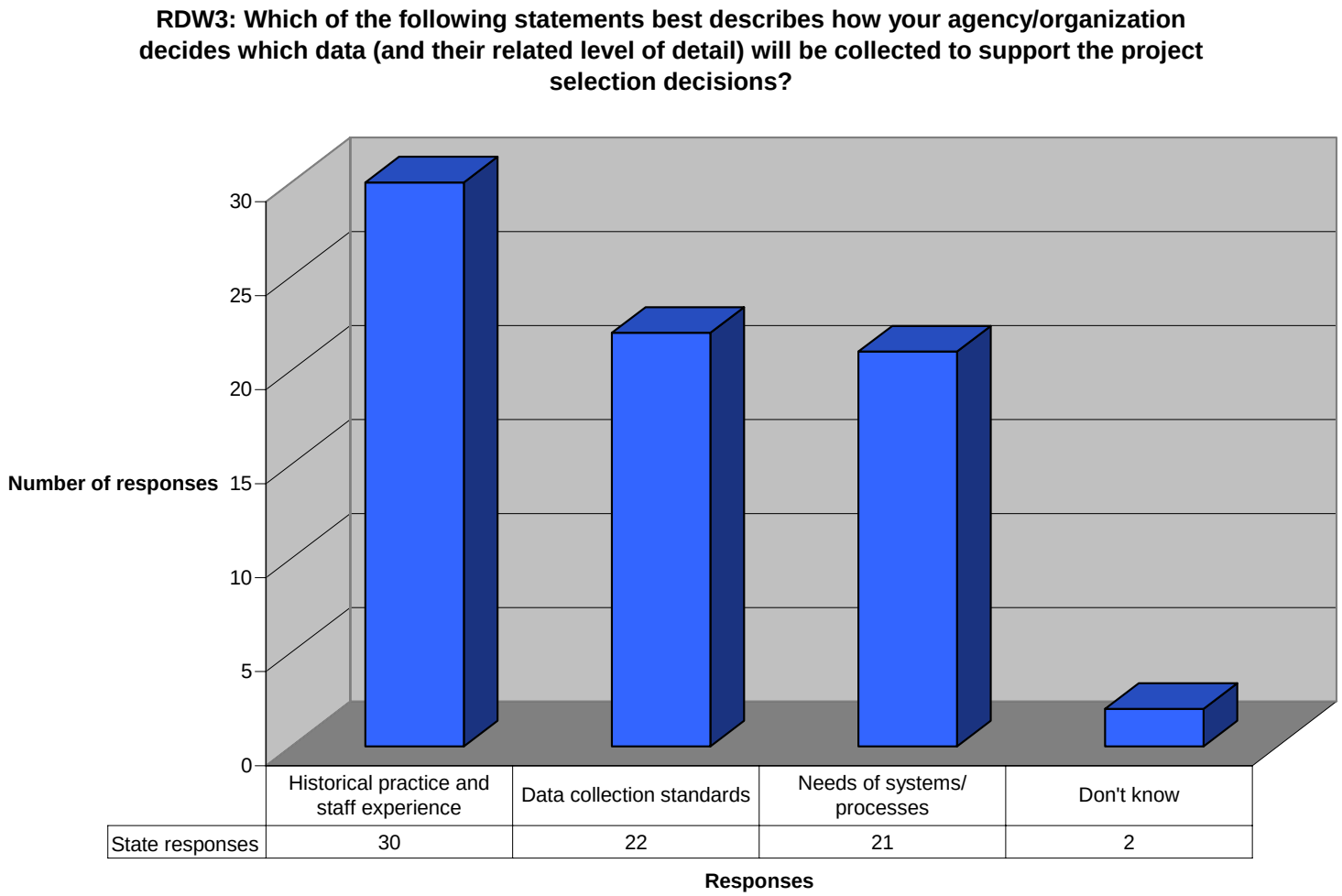


Journal Figure 5. Project Selection criteria and their relative importance

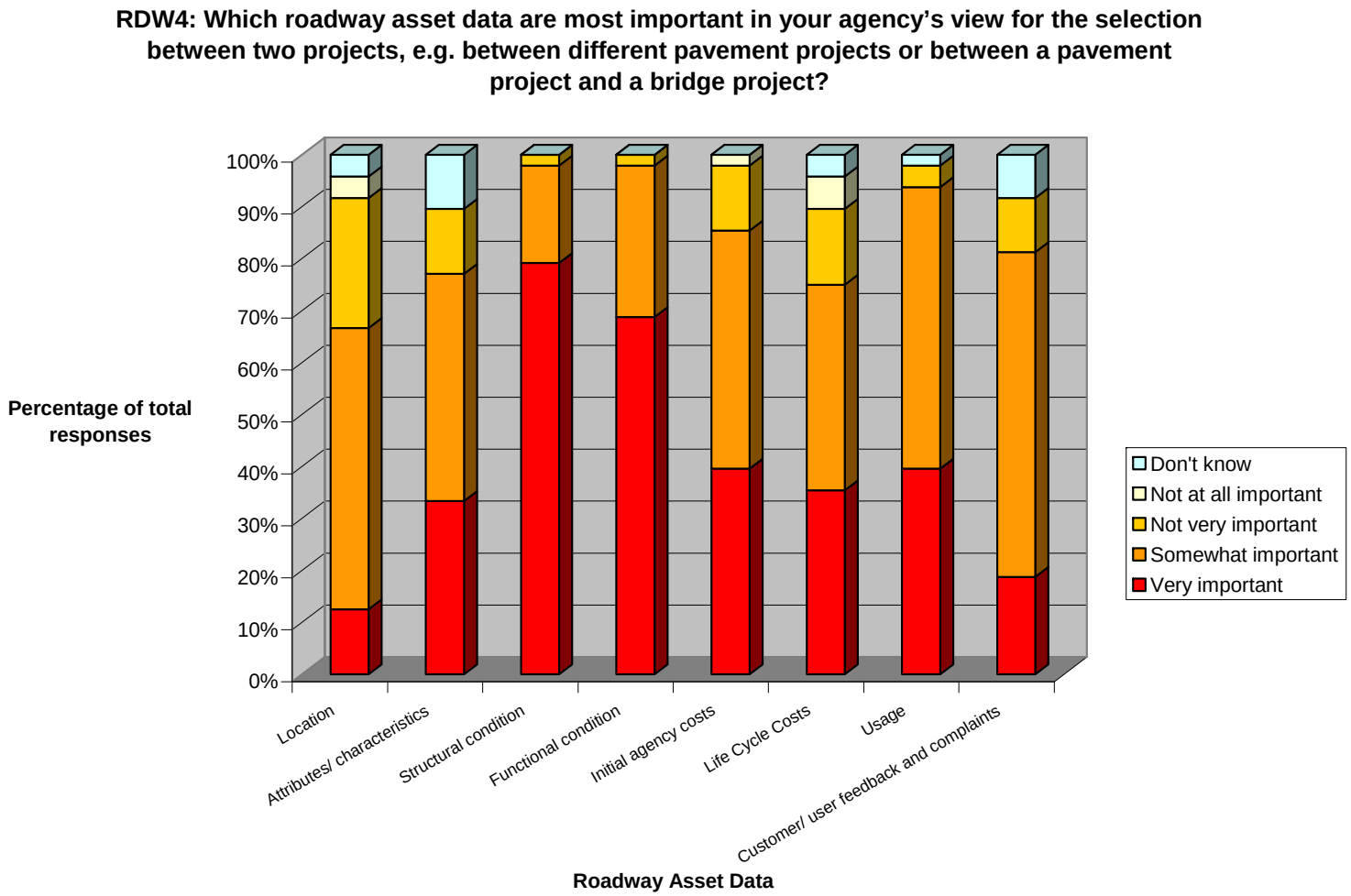


	Drainage	Roadside assets	Pavements	Bridge	Traffic items	Special facilities
Both	5	15	25	16	13	4
Automatic	1	3	12	2	6	0
Manual	21	13	3	22	11	15

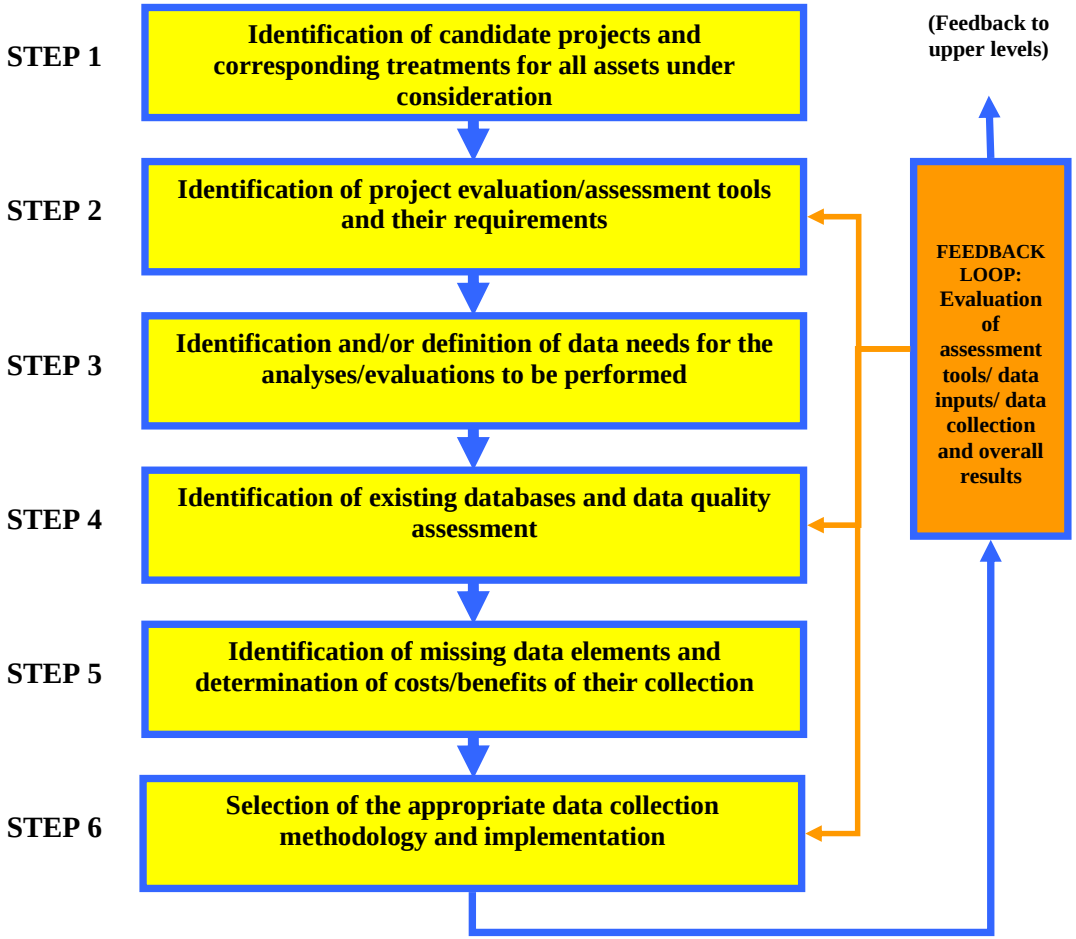
Journal Figure 6. Roadway asset data collection types and methods



Journal Figure 7. Agency data collection rationale



Journal Figure 8. Roadway asset data types and their relative importance for Project Selection



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Engineering significance

This research aimed at having a significant contribution to both academia and the industry concerned with Transportation Asset Management.

Regarding its academic significance, this research identified current practices of Asset Management in the US and the world and investigated the connection between data collection and project selection decision making. The outcome of this investigation is the formulation of a data collection framework particularly for project selection and the identification of major criteria and data attributes to this decision making level.

Regarding its contribution to the transportation industry, this research aids Transportation Agencies tailor their data collection activities according to their real decision making needs, in particular at the project selection level. In this way it contributes both in cutting down data collection costs and also in bolstering a more effective and efficient implementation of Asset Management in their everyday practice.

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APPENDICES

APPENDIX A: Transportation Asset Management Web-based Survey Questionnaire

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 decision making 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:

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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 decision making levels that have been explicitly defined in your agency/organization (check all that apply):

☐ No explicit definitions for decision making 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 decision making 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 decision making in Asset Management that you believe may be of benefit to this project.

THANK YOU!!

APPENDIX B: Transportation Asset Management Web-based Survey Analysis

A total of 48 answers from 40 different states were received. Therefore, the response percentage turned out to be 78% in terms of individual states and 47% 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.

For seven states, more than one transportation official responded to the survey. Furthermore, while some of the questions on the survey were state-specific and required only one valid answer per responding state, others inquired about the personal opinion of the responding state transportation officials. Due to this difference two approaches were followed for processing the responses from the states that provided more than one response:

- In the first case the various answers within the same state were compared discrepancies were resolved so that only one answer would be kept, as complete as possible, based on the following criteria:
  - Priority was given to the most complete responses; for example in the case where one transportation official would report that the state agency possessed two individual management systems and another one would report the possession of these two and an additional one, then the final considered response would contain all three individual management systems from the second response; and
  - Priority was given to the responses of transportation officials whose area of expertise most closely coincided with that of the survey's questions and required input fields.

According to the above criteria, in some cases the ultimately considered state response consisted of excerpts from responses provided by different officials.

- In the remaining cases where the survey questions asked for individual opinions, all answers (48) were considered valid and utilized in the analysis.

Answers on 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.

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

This part required transportation officials to give information about:

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

Question 1: Has your agency/organization implemented or is planning 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

Question 2: Please indicate the management systems 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 utilizing individual management systems, with the most predominant among them being Pavement (39), Bridge (39) and Maintenance (34) management systems as shown by the aggregated results of Table 1. Other systems include Highway Safety (SMS), Traffic 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 ones in terms of this integration. The attained responses are summarized in Figure 2Figure .

Question 3: Please specify the decision making levels that have been explicitly defined in your agency/organization.

When asked to report on their defined decision making levels, most of the responding transportation agencies indicated that they have explicitly defined decision making levels that coincide with the ones found in the literature (Figure 3). The most answers were obtained for the Programming and Budgeting and the Project Selection levels. This confirms that the responding transportation officials were rightly selected as they were familiar with these levels of decision making and that the agencies have been focusing their attention to these intermediate levels of decision making that connect the generic strategic decisions of the Strategic Level with the actual project implementation at the Project Level.

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. From this plot it can be discerned 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 to 4 (4 = Very Important to 1 = Not Important at All). 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 this business decision process to the responding transportation officials.

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.

Again 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 specific project selection criteria considered. As expected, the variability of opinions is more significant in this one. 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 Table 4 and Table 5. An interesting finding is that Public Demands/ User Opinions rank in the

third place, showing the increased interest of transportation agencies in public satisfaction from the selection and implementation of projects.

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 vast majority (80%) of the responding officials agreed that the criteria used for project selection can not/ should not be uniform and consistent for all types of roadway assets. The responses are summarized in Figure 6.

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:

- Data management, collection methods and integration
- Rationale behind existing and/or future planned data collection
- Evaluation of roadway asset data used for project selection and
- 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 clear that most of the responding state agencies (75%) had already invested time and money in developing Asset Management roadway inventories

and databases. The majority of the remaining ones responded to be in a stage of planning for it. The responses are summarized in Figure 7.

Question 2: Please indicate if your agency collects data for each of the following roadway assets 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. Traffic items and roadside assets were also reported to be collected in a great extend. Figure 8 summarizes the data collection methods used for the acquisition of the above data. While for some assets (e.g. drainage) the collection is reported to be taking place mostly using manual methods, there is a trend towards using a combination of manual and automatic methods.

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 rational 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 denoted that data collection practices have been based on data collection standards and input needs of utilized management systems or other defined decision processes.

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, Table 6 and Table 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.

Question 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?

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%) or identified and documented in a formal way (52.5%) the existence of such links. This is a very important finding as it shows that most agencies have been trying to rationalize their data collection according to specific decisions to be supported, as least for the particular level of Project Selection. The responses are summarized in Figure 11.

Table1. Aggregated Number of States that Use Individual Management Systems

States with individual management systems						
PMS	**BMS**	**SMS**	**CMS**	**PTMS**	**ITMS**	**MMS**
39	39	23	20	13	16	34

Table 2. Normalized Importance of Decision Processes per Importance Category

AG - Question 4									
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 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

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: 4 = Very Important, 3 = Somewhat Important, 2 = Not Very Important, 1 = Not Important at All	

Table 4. Normalized Importance of Project Selection Criteria per Importance Category

AG - Question 5									
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 of 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: 4 = Very Important, 3 = Somewhat Important, 2 = Not Very Important, 1 = Not Important at All	

Table 6. Normalized Importance of Roadway Asset Data per Importance Category

RDW - Question 4									
Ranking of normalized roadway asset data importance for project selection 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 and complaints	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 feedback 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: 4 = Very Important, 3 = Somewhat Important, 2 = Not Very Important, 1 = Not Important at All	

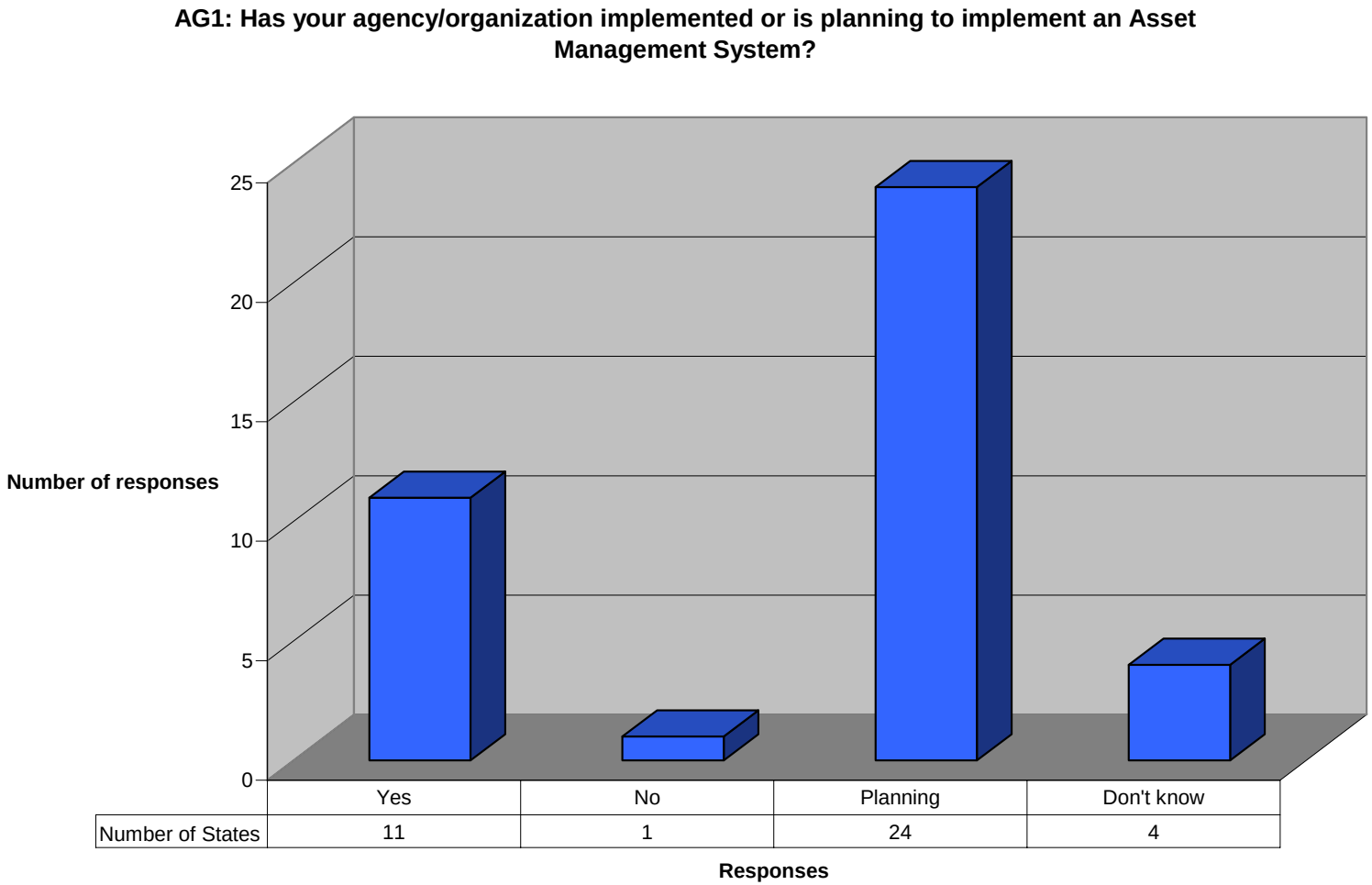
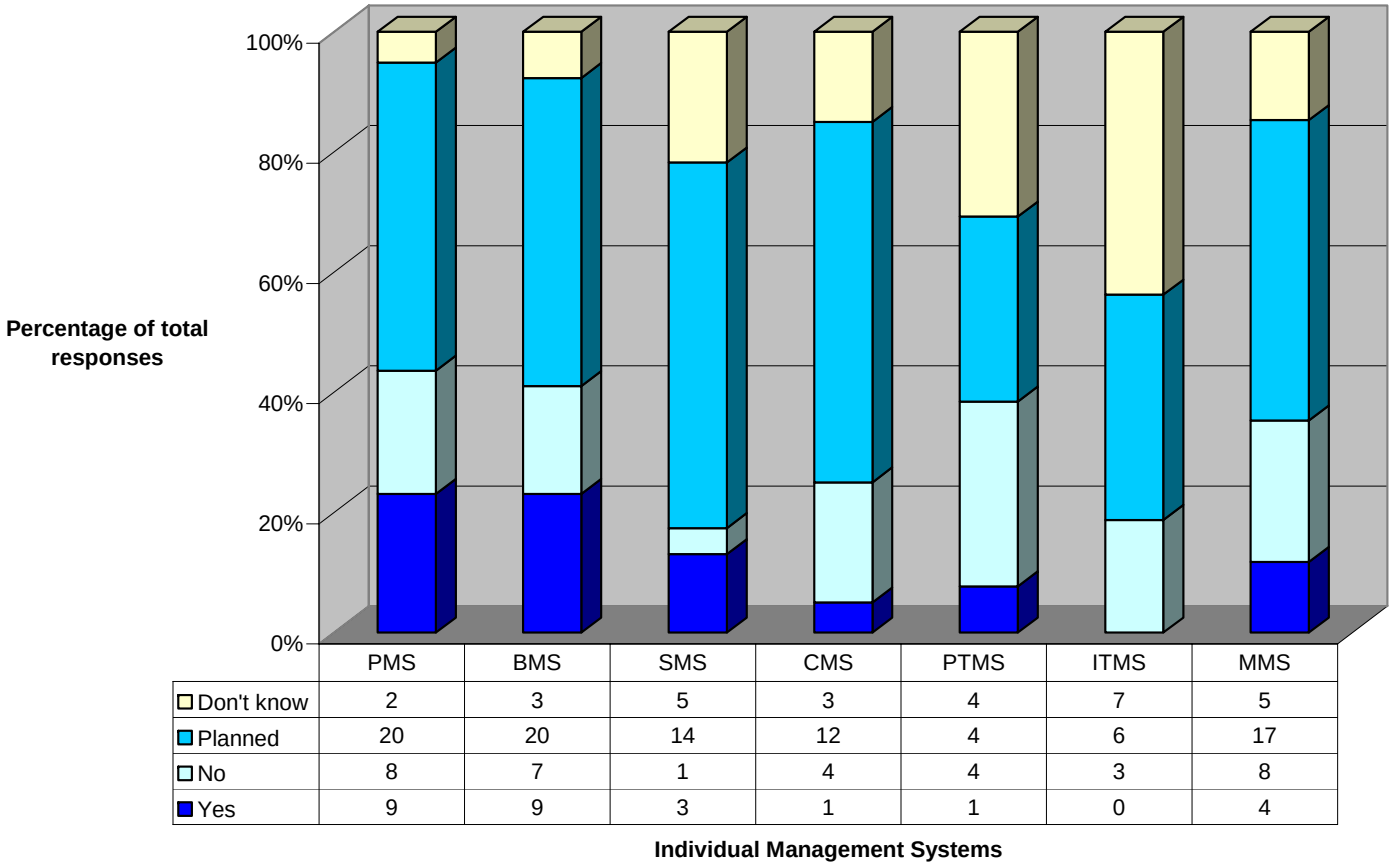


Figure 1. Asset Management implementation

AG2: Please indicate the management systems your agency/organization currently has, along with the status of each system within an 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

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

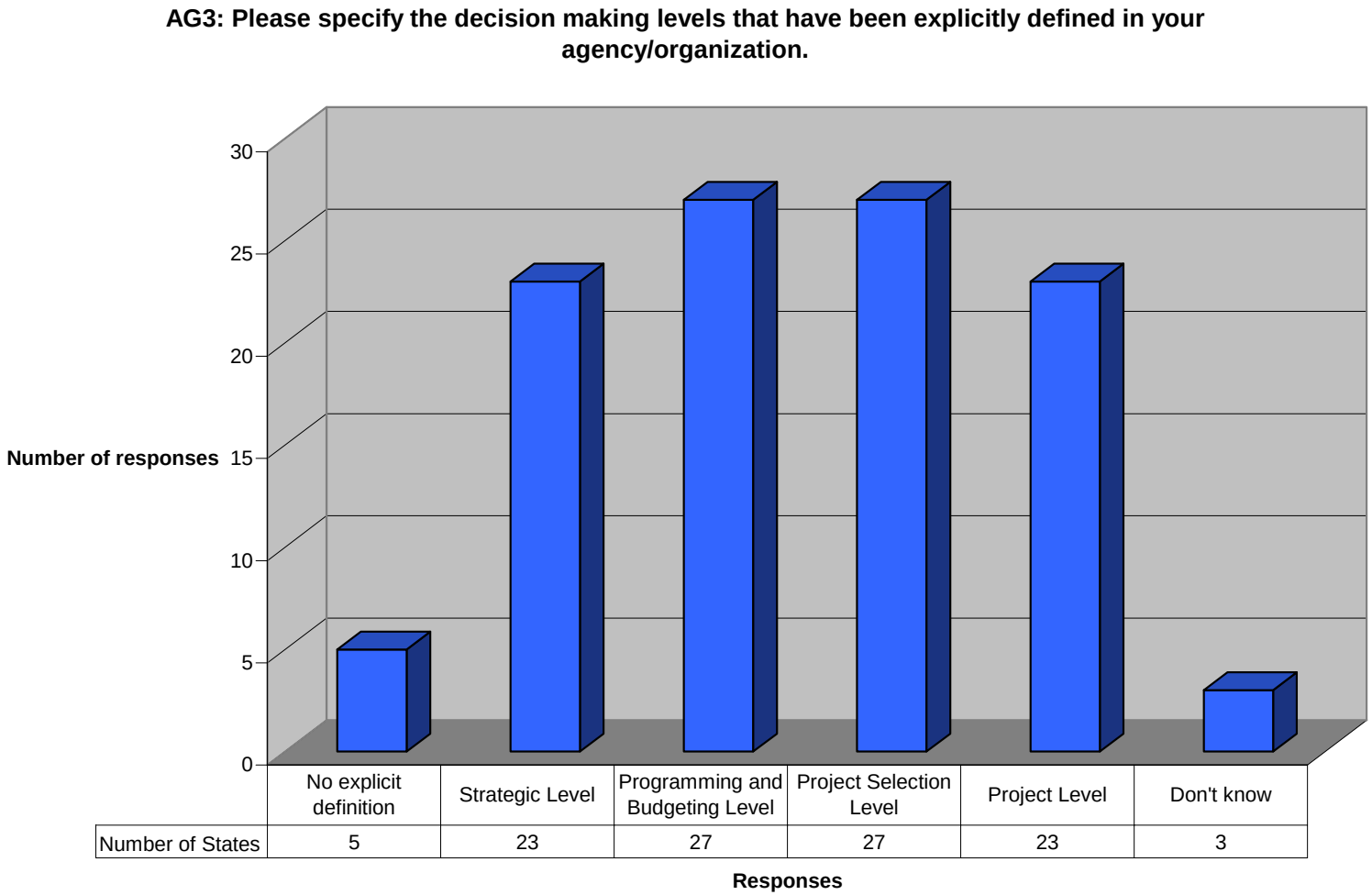


Figure 3. Defined levels of decision making

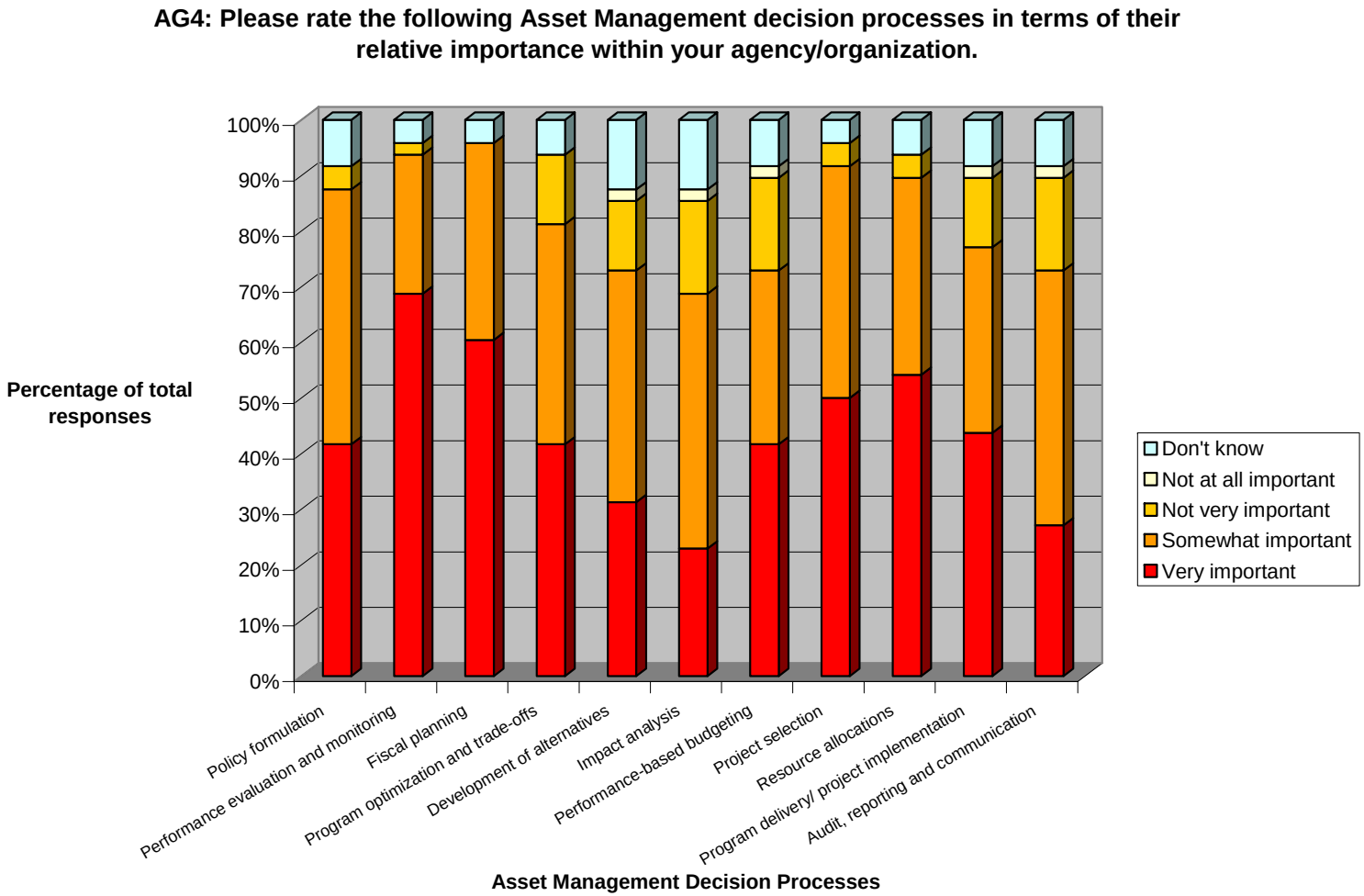


Figure 4. Asset Management decision processes and their anticipated importance

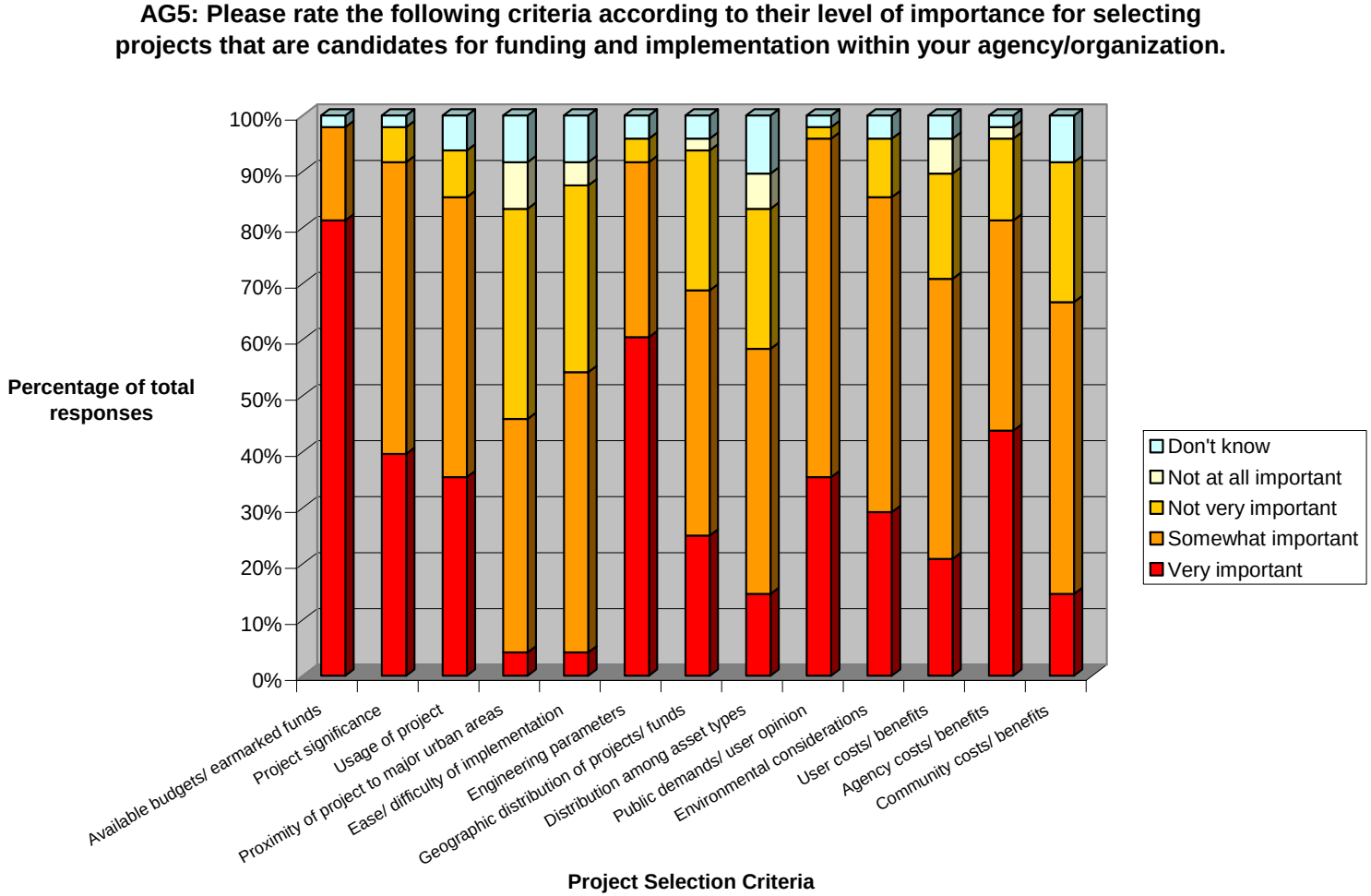


Figure 5. Project Selection criteria and their anticipated importance

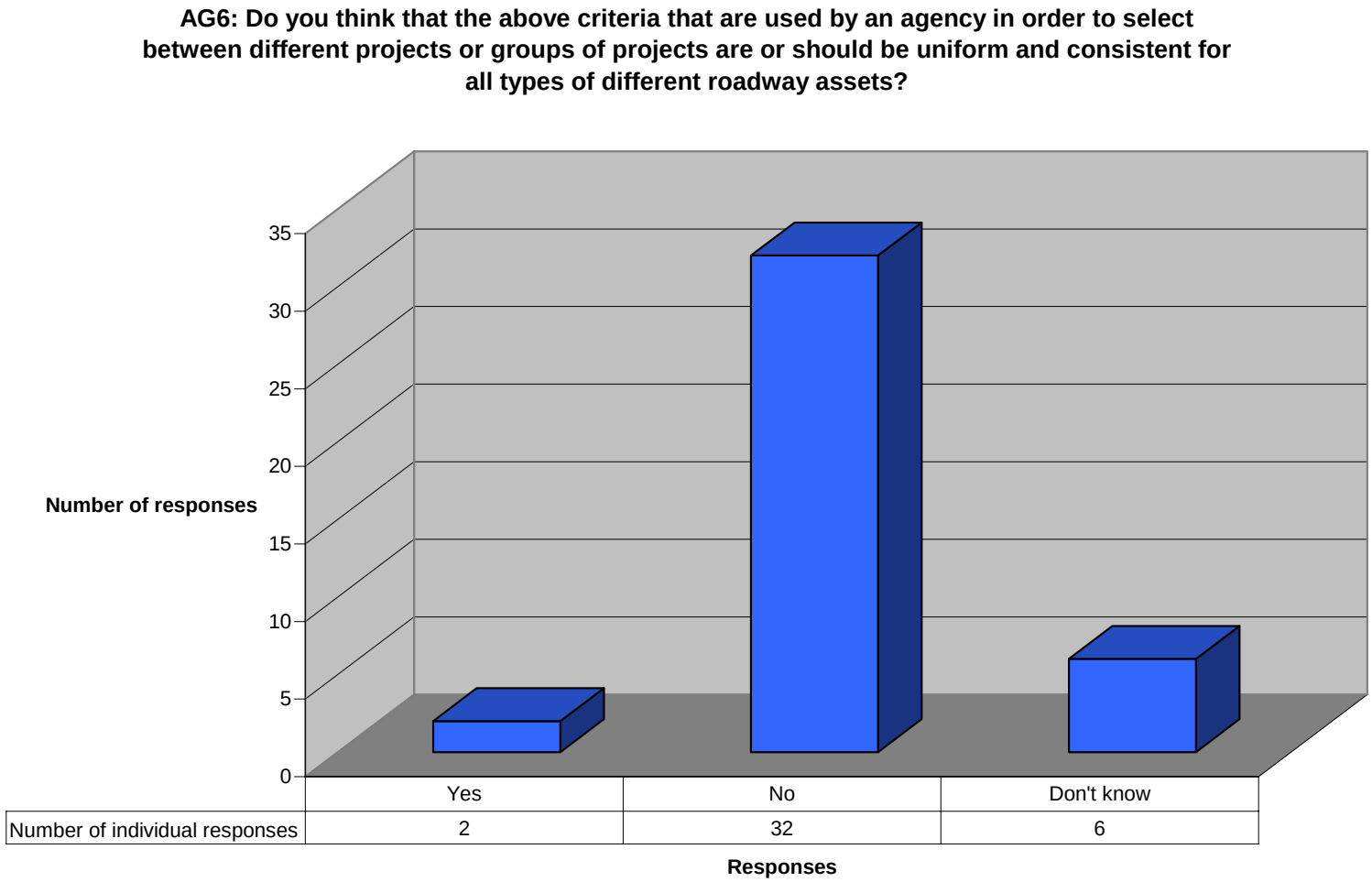


Figure 6. Consistency of Project Selection criteria for different asset types

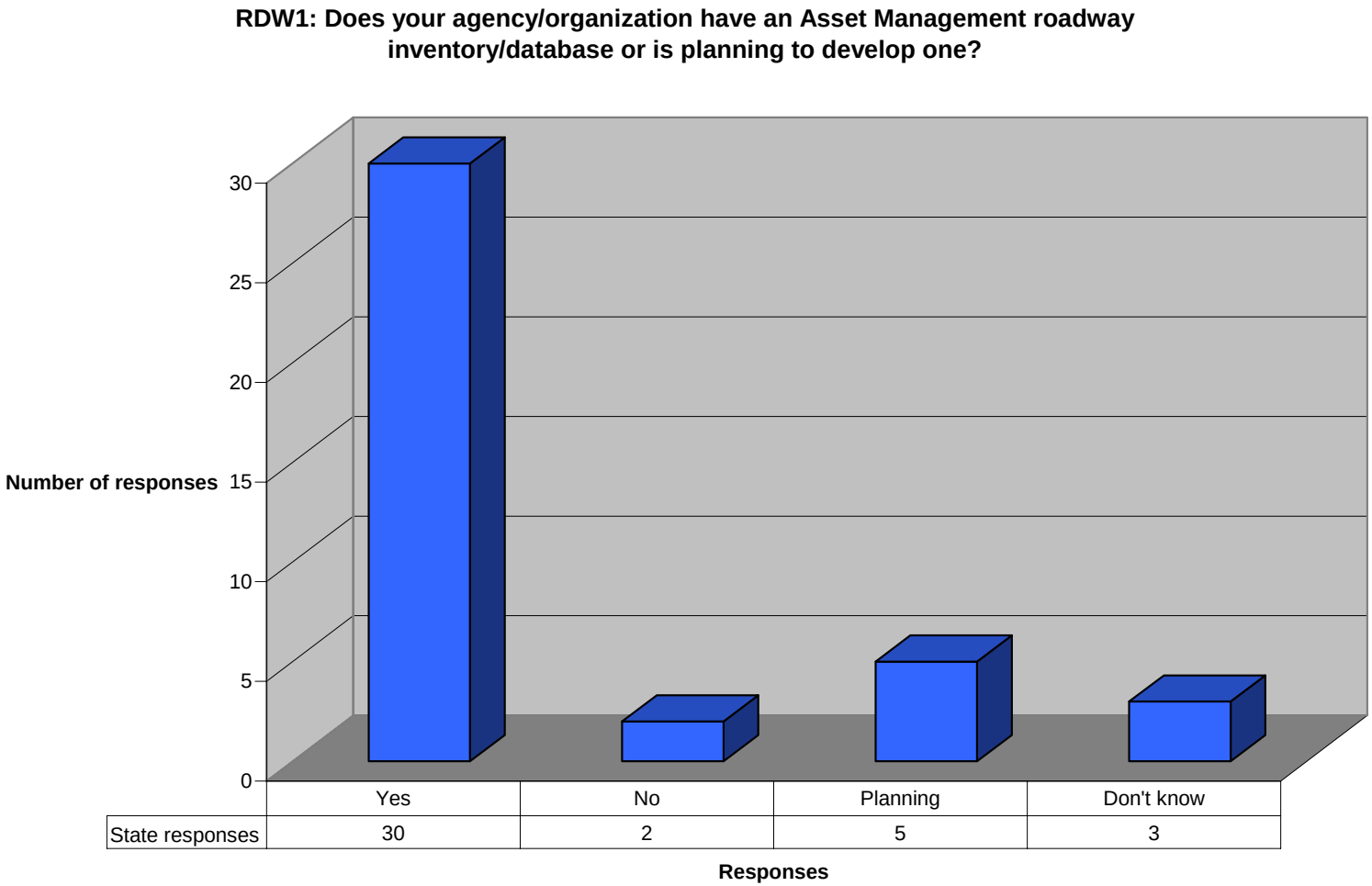
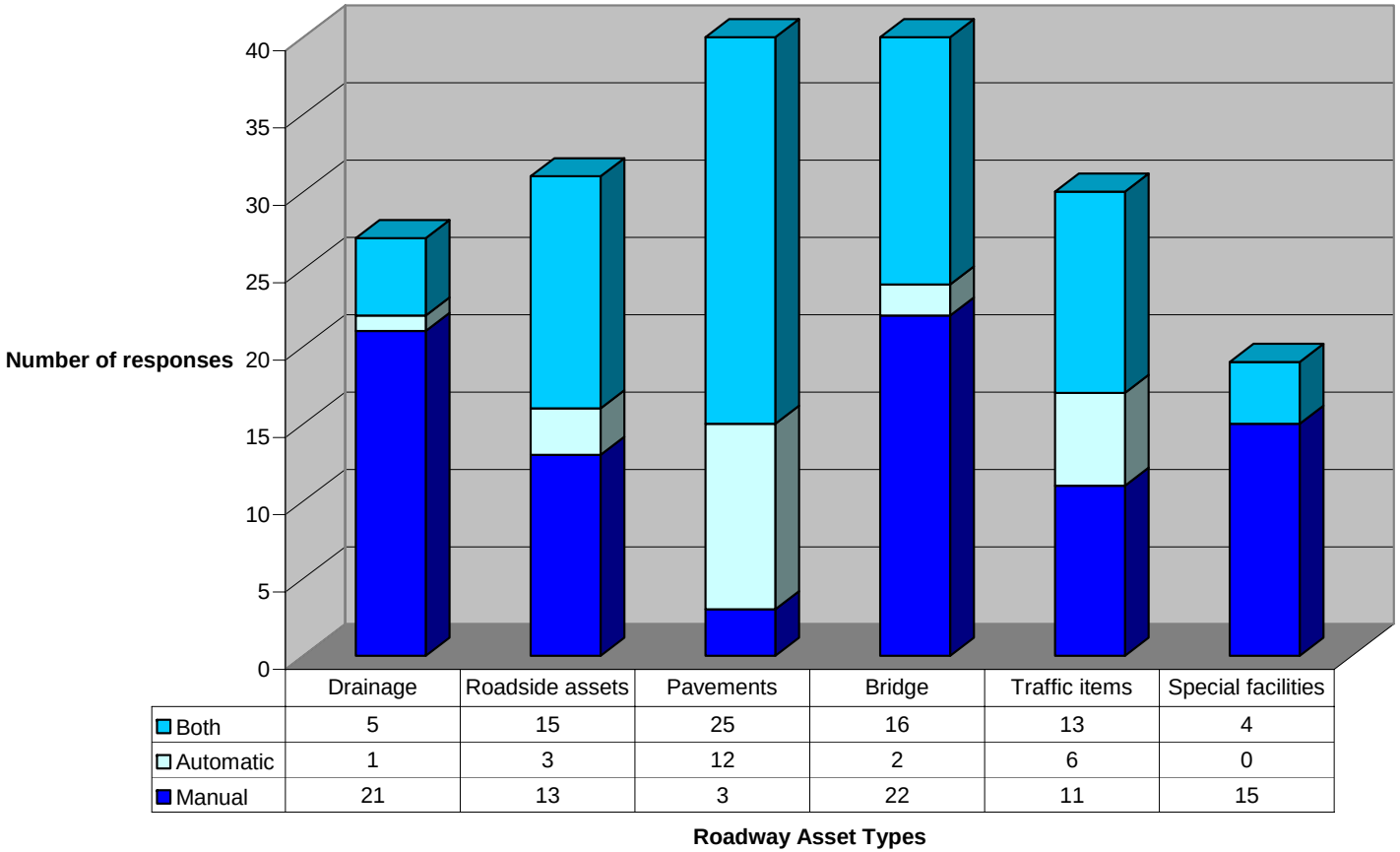


Figure 7. Existence of Asset Management inventory/database

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

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

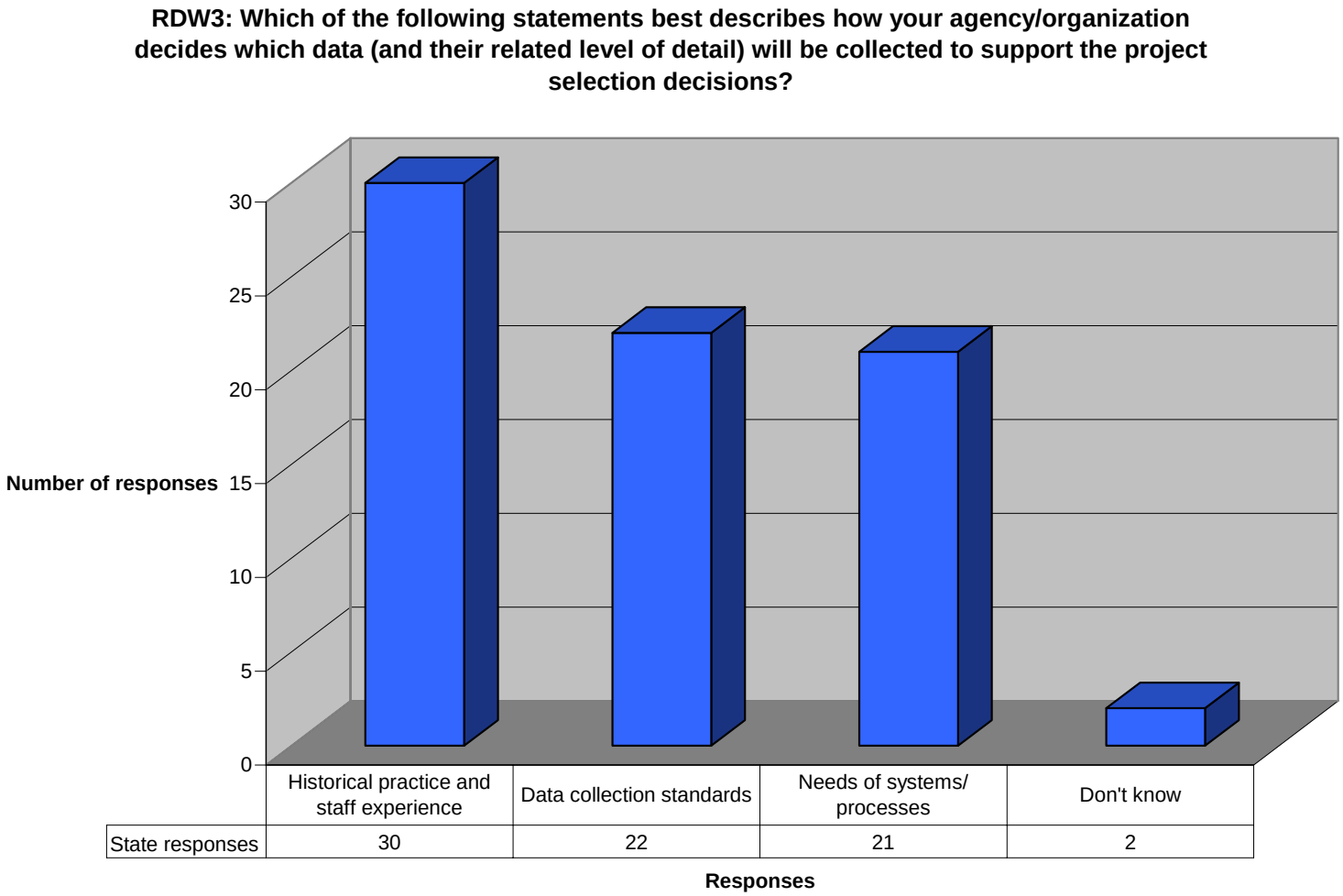


Figure 9. Agency data collection rationale

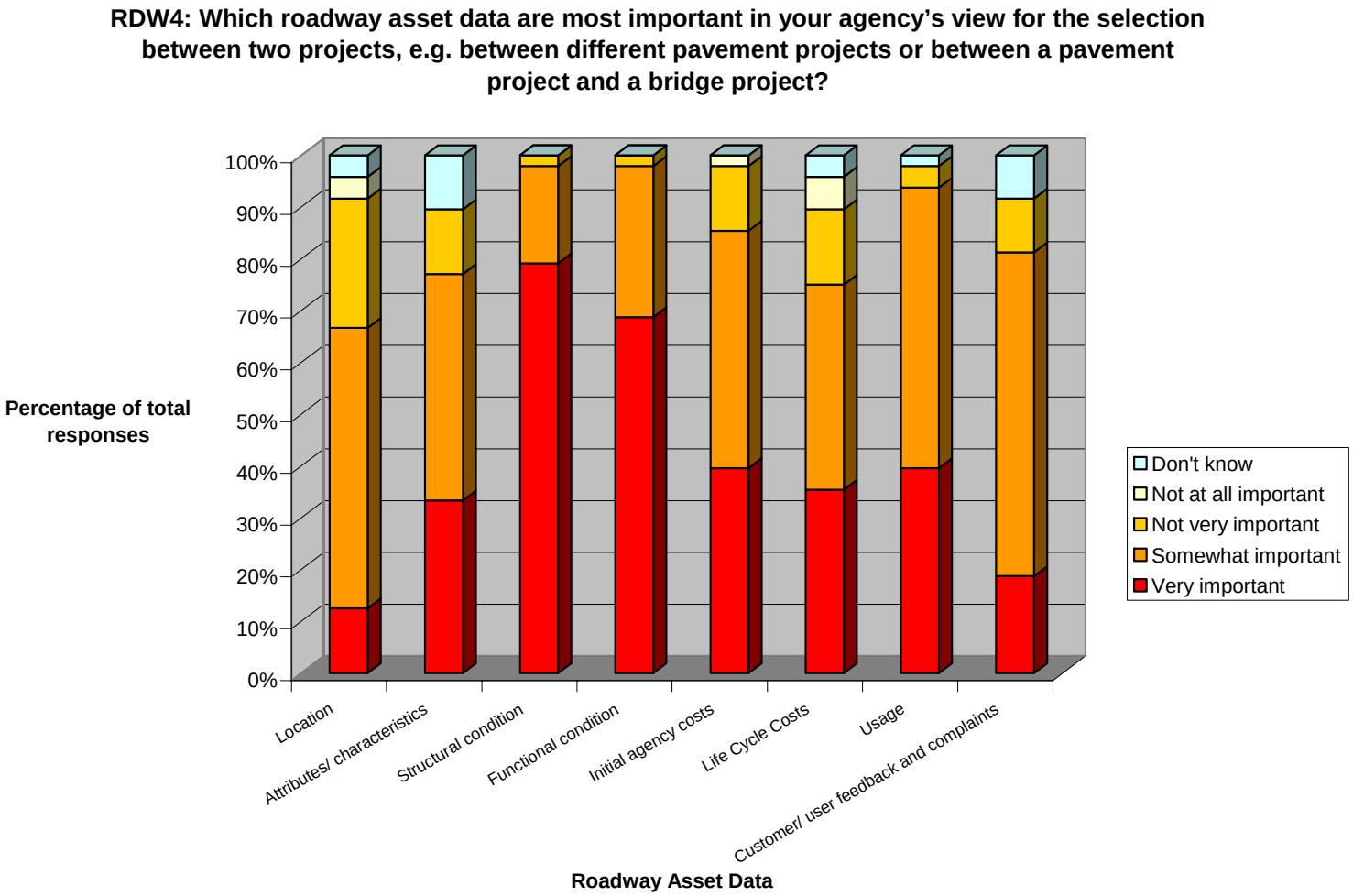


Figure 10. Roadway Asset Data and their anticipated importance for Project Selection

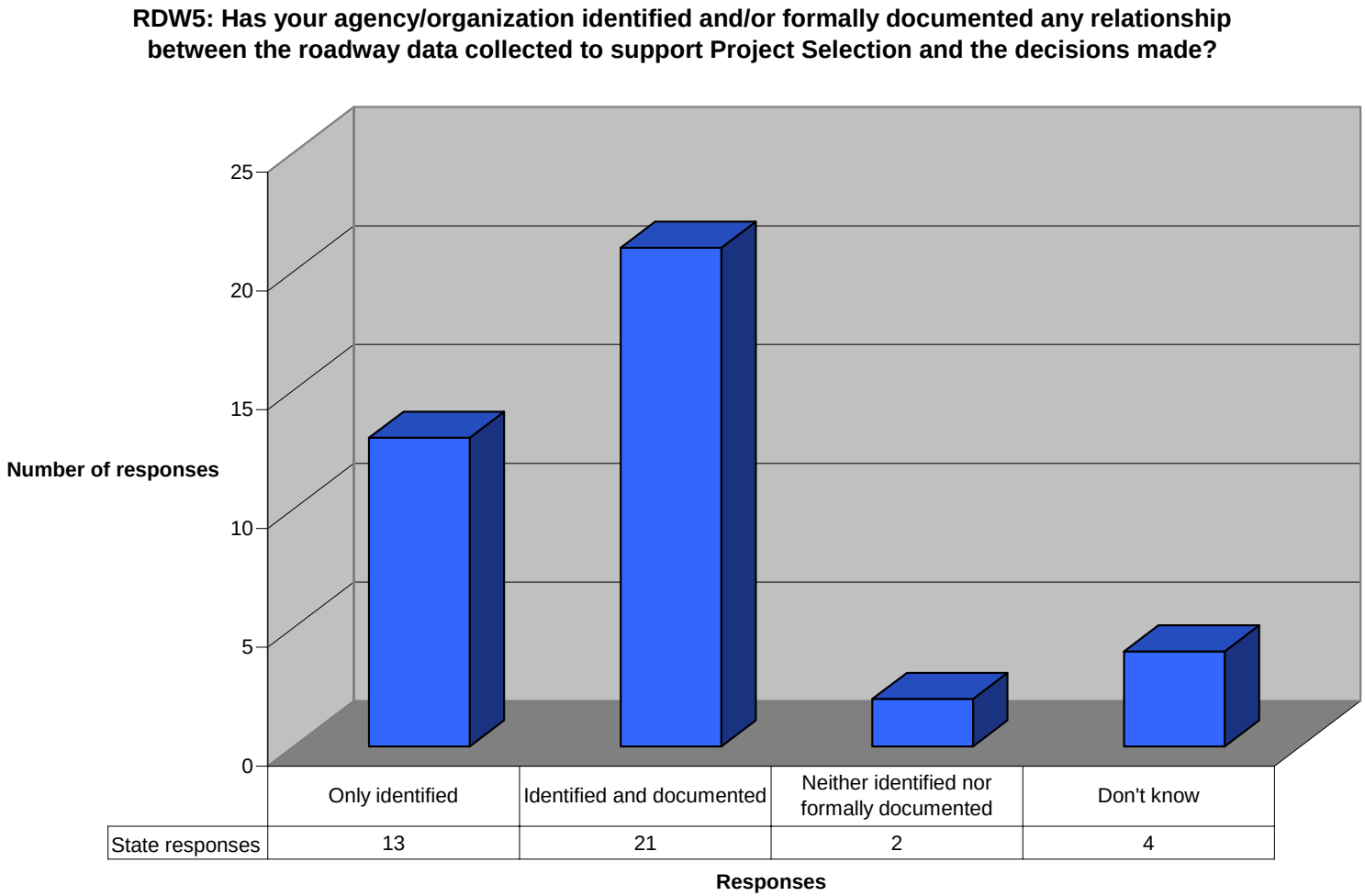


Figure 11. Identification and documentation of links between data collection and Project Selection