Since this is the initial stage of our research, the missing parts will be actively supplemented. The study also plans to build a comprehensive knowledge management system throughout the life cycle as its final objective.

Acknowledgment

This research was supported by a grant from the Gas Plant R&D Center funded by the Ministry of Land, Transportation and Maritime Affairs (MLTM) of Korea.

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AN ASSET MANAGEMENT ASSESSMENT MODEL FOR STATE DOTs

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ABSTRACT: In the past, many state Departments of Transportation (DOTs) in the U.S. managed their highway assets on a "worst first" basis and planned their highway projects in a tactical rather than strategic fashion. Due to increasingly tight highway budgets and recognition of long term benefits of asset management systems, the Federal Highway Administration (FHWA) has strongly pushed and encouraged state DOTs to implement asset management for managing their highway assets and highway projects. Currently, many DOTs have actively implemented and are in the process of applying this asset management concept for their highway infrastructure. However, different DOTs are developing different asset management systems because of their different organizational structures, data management structures, relationship with the legislature, and investment priorities. This study first identifies asset management indicators which are essential to successfully implementing asset management systems for State highway assets. The research team conducted a survey of asset management experts and reviewed the practices and policies of leading DOTs in asset management. Based on these indicators, this study develops an Asset Management Assessment Model (AM^2) for different asset management systems. This model can be used by different DOTs to evaluate their current asset management systems and identify their strong areas and also their weak areas to improve in order to fully benefit from the advanced concept of asset management.

Keywords: Asset Management, Highway assets, infrastructure management, Analytical Hierarchical Process

1. INTRODUCTION

Transportation Asset Management is often described simply as a decision-making framework. It is an all-encompassing strategy that examines all of the infrastructure pieces and manages them as one unit. As part of the effort to create a total AM system, the Federal Highway Administration (FHWA) created the Office of Asset Management in 1998. This, along with numerous other research initiatives have sought to create the framework for AM that can be applied to State DOTs.

While there is a well defined and accepted AM framework for State DOTs, there have not been any studies that have developed a model that measures the level of AM implementation within a DOT for a benchmarking purpose. This paper presents an Asset Management Assessment Model for State DOTs in the United States.

2. BACKGROUND

Transportation AM for State DOTs has several definitions. Perhaps the most complete definition of AM is contained in the research performed by the National Cooperative Highway Research Program (NCHRP). NCHRP Report 551 defines AM as a "strategic approach to managing transportation infrastructure" [1] that is based on the principles described in the "Transportation Asset Management Guide" (The "Guide") [2]: Policy Driven, Performance-Based, Analysis of Options and Tradeoffs, Decisions Based on Quality Information, Monitoring to Provide Clear Accountability and Feedback.

There have been a number of AM initiatives done by both the federal and state levels. One of the first steps towards AM at the federal level started when FHWA established the Office of Asset Management in 1998. Shortly thereafter, in 1999, FHWA produced the "Asset Management Primer." Its purpose was to educate transportation officials about AM as well as convince them that it was a better way of conducting their practice. According to the "Asset Management Primer," AM is a philosophy that "focuses on the benefits of investment, as well as its costs, and takes a comprehensive view of the entire portfolio of transportation resources. Asset Management is an improved way of doing business that responds to an environment of increasing system demands, aging infrastructure, and limited resources" [3].

Research sponsored by AASHTO and FHWA with the Transportation Research Board (TRB) produced NCHRP Project 20-24(11). Two tasks of this project were to: propose a generic framework for transportation asset management that can be adopted by member states, and develop an AASHTO "Guide for Transportation Asset Management." The "Guide," which was developed in 2002, provides agencies with guidance for implementing AM concepts and principles within their business processes [2].

Federal agencies such as FHWA and AASHTO have produced numerous reports to assist state agencies with implementing AM. Many states have taken these principles and used the given frameworks to help begin the AM process within their own organizations. Some

state agencies are using these guidelines as well as taking their own initiatives to implement AM. FHWA has published a series of comprehensive transportation AM case studies that review current practices in several states. Three comprehensive studies included: Washington State [4], Ohio [5], and North Carolina [6]. The practices identified in these case studies serve other State DOTs by providing ways to successfully implement AM.

The "Best Practices in Transportation Asset Management" produced by the FHWA represents one of the most recent reviews of AM practices in the U.S. Its purpose is to "identify best case examples of the application of asset management principles and practice in U.S. transportation agencies"[7]. It not only examined six state transportation agencies, but also a city transportation department, two metropolitan planning organizations, two county transportation departments, a tollway authority, and two statewide asset management associations. Having a variety of transportation agencies that participated in this study allowed for a large spectrum of AM expertise to contribute to the list of best practices.

3. ASSET MANAGEMENT INDICATORS

One of the main assumptions that this research rests upon is that there is an ideal AM framework that is attainable for State DOTs. This framework would contain all of the essential components of AM. For the purpose of this study, these essential components for AM implementation will be called AM indicators.

There have been several AM frameworks put together in the past several years that outline the necessary steps to implement AM. Instead of trying to come up with an entirely new framework, this study built upon the "Guide's" accepted framework and modified it to include an important component that this study deems essential to the AM process. Figure 1 represents this modified AM framework which now includes Asset Management Culture. The rest of this section describes each of the major AM indicators and their associated sub-indicators.

The first major indicator of this framework is Asset Management Culture. AM is not another new program, but in fact a "way of doing business". Everyone in the agency should understand that AM is a better way of doing things. This ultimately requires a change in culture. In order for AM to be successful, it must have the support of everyone involved.

Asset Management Champions are necessary for a successful AM system. The "Best Practices in Transportation Asset Management" Scan Report reported that "the success of the asset management process was directly linked to the actions of an asset management champion or champions within the organization" [7]. This report stated that this champion was sometimes the head of the agency or maybe just a key staff member who believed strongly in the principles of AM.

The Perception of AM within an agency is extremely important to its success. "Buy-in from all units of the agency is critical to a successful asset management effort" [2]. Not only must top management understand and buy into AM, but all staff should understand these principles as well.

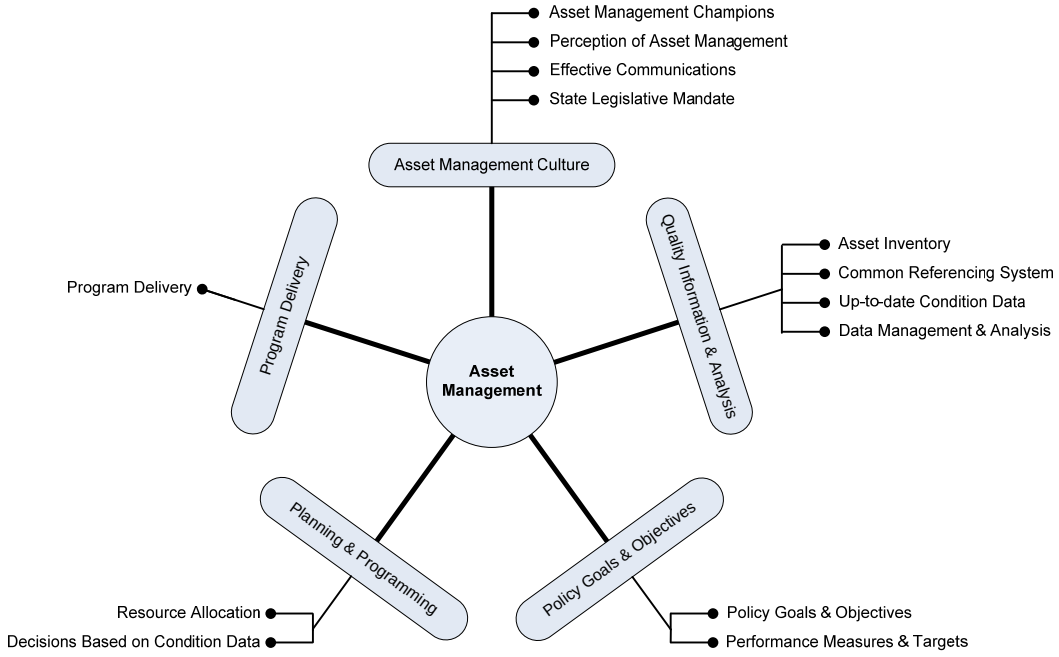

Figure 1. Asset Management Framework with Associated Indicators

Effective communication is critical to the success of AM as well. It must be present between an agency and its governing bodies, its stakeholders and its customers [2]. Strong "vertical" communication that allows staff to

understand the vision of the top management must be present within the agency. Strong "horizontal" communication between divisions within the agency that facilitates tradeoffs between investment areas is also necessary for AM success.

Several agencies, including the Michigan Department of Transportation (MDOT), have found that the existence of state legislation requiring AM is a strong catalyst to adopt AM principles [7]. In some cases this may force agencies, which may be initially uncommitted to AM, to develop an AM perspective, or at least serve as a means to begin AM within the organization.

The next major AM indicator is Quality Information and Analysis. Quality information is the backbone to any AM system. Without it, AM cannot function; it becomes meaningless. Data is necessary for agency objectives, the decision-making process, project delivery, and to monitor progress toward these agency objectives. Data affects every step in the AM framework. In order for an agency to be able to implement AM effectively, it must first know what assets it has, where these assets are located, and what condition the assets are in as well as be able to perform the necessary decision-supporting analysis.

A complete and accurate asset inventory is needed [8]; otherwise system-wide analysis is ineffective. Many times, the collection of quality data is one of the first steps that an agency takes in order to successfully implement AM.

It is imperative that accurate locations for all major assets exist through the use of a common spatial referencing system. Having assets tagged with spatial information allows the ability to integrate data from different sources in a relational database [8].

Up-to-date Condition Data is also a necessary piece. "Useful and reliable data are central to a fully functioning Asset Management process" [9]. If data is to be useful, it must be current. Data that is several years old may not be useful because it does not represent the present condition of the assets that are being examined. The "Guide" states that a benchmark for effective and efficient data collection is "complete and current asset inventory and condition data."

Asset data should be managed within a formalized data management framework [10]. There should also be a dedicated person(s) to managing data management and analysis software. A knowledgeable and experienced data integration leader and an expert data manager are needed to design a modular, robust, and maintainable architecture that can support the expanding and changing transportation decision-support requirements [9].

Policy Goals and Objectives is a major AM indicator. Its role is to establish a clear guidance for the remaining steps in the AM framework [2]. This drives the decision-making process of an agency. It allows an agency to set priority investment areas which gives direction and makes it easier to set objectives.

It is important that an agency select a priority investment area. "The asset management framework does not prescribe what priorities should come first – only that individual agencies and their policy-making bodies discuss and analyze policy options to adopt the ones that are felt to be warranted"[2].

Performance Measures and Targets provide the critical link between policy goals and planning and programming decisions. They allow agencies to measure what affect policy decisions have on programming. They are a way to monitor progress toward a result or goal and are indicators of work performed and the results achieved [1].

Planning and programming is the next major AM indicator in the framework. It is important because in this step decisions are made about what projects should be selected. Once goals and objectives along with performance measures have been established, decision-makers can now perform tradeoff analysis and allocate resources across the network as needed.

Resource Allocation is a key sub-indicator. AM "involves applying general principles smartly, effectively, and tactically to resource allocation and utilization – the heart of asset management" [2]. This process should be comprehensive, viewing the transportation system as an integrated whole which considers tradeoffs among investment areas.

Resource allocation decisions should be based on condition data. They should be made across programs and geographic regions based on expected performance rather than historical splits or formulas that do not correlate with an objective indication of system condition.

Program delivery is the last major AM indicator. It is unique because it occurs after most of the "traditional" AM decisions have been made. At this point, policies and performance measures have been established, resources have been allocated, and specific projects have been programmed. However, AM also extends into this final step by making certain agencies consider the most efficient way to deliver projects.

Alternative delivery methods should be regularly evaluated within the agency. This involves an assessment of options while considering relative costs, benefits and risks, both immediate and long term [2]. As a part of program delivery, performance-based contracts need to be regularly evaluated. Additional opportunities in program delivery exist in outsourcing maintenance and operations activities.

4. ASSESSMENT OF ASSET MANAGEMENT INDICATORS

Simply the identification of critical factors for AM is nothing new to research in this field. However, these indicators have never been weighed based on their importance in implementing an ideal AM system. If accurate weights for these indicators can be developed, a more precise assessment tool could then be presented.

The Analytic Hierarchy Process (AHP) is a methodology used in multicriteria decision making that was introduced by Saaty [11]. It is a theory of measurement that is used to quantify qualitative or subjective factors that affect a decision. AHP was chosen to quantity the AM indicators because of its well-known and widespread application as well as its relative ease of

use. The chosen methodology should be able to take the subjective opinions of AM experts and convert them into quantifiable numbers that weigh the importance of the AM indicators.

A questionnaire survey was developed to allow AM experts to assess the importance of each AM indicator. The survey consists of applying AHP to compare the five major AM indicators and subsequently the sub-indicators. This is done through a series of pairwise comparisons in order to determine which indicator is more important when implementing an ideal AM system.

Potential survey respondents were carefully selected from State DOTs that are known to be leaders in AM. The major source of identifying DOTs that are leaders in AM came from the literature review. This included case studies and recent research that referenced DOTs that are making advances in AM. Several other states were identified by recommendations from peer agencies and the director of the AM office of FHWA. Of the twenty-six surveys that were mailed, sixteen were completed and returned. This yielded a response rate of 16/26 or 61.5%. The sixteen returned surveys represented fourteen different transportation agencies (thirteen DOTs and FHWA). The number of years of experience in the transportation industry among the survey respondents was very high. The collective amount of experience was 339 years among 16 professionals which resulted in an average amount of experience of 21.2 years per person.

Each completed survey generated five reciprocal matrices whose values were composed from the responses of that participant. For each matrix, eigenvalues and eigenvectors were calculated. An eigenvector for each indicator within a given matrix was calculated and these values were normalized to create weights for each indicator.

The consistency ratio (C.R.) is a measure of how consistent a matrix is within AHP. The threshold value that indicates acceptable consistency is a C.R. equal to 0.10. If the C.R. is above this threshold, it must be reduced. This research used a method that Saaty suggests to improve consistency which revises the original judgments in an "artificial" manner. This procedure was carried out for all of the matrices that did not meet the required C.R. = 0.10.

Once each of the matrices has an acceptable C.R., the weights of each one can be included in the synthesis procedure to create a composite weight for each indicator. To synthesize the data, the average weight and standard deviation for each of the five major AM indicators and each of the thirteen sub-indicators was calculated. These results are summarized in Tables 1 and 2. Total weights for sub-indicators are obtained by multiplying the weight of each sub-indicator by its associated major AM indicator. The total weights will be directly used in the Asset Management Assessment Model because they represent the relative importance of each sub-indicator. The total weights are summarized in Table 3.

Table 1. Major AM Indicator Weights

Major Indicators	Lower Limit (-Std Dev)	Mean	Upper Limit (+Std Dev)
Asset Management Culture	0.067	0.195	0.322
Quality Information & Analysis	0.149	0.265	0.381
Policy Goals & Objectives	0.165	0.300	0.435
Planning & Programming	0.047	0.123	0.199
Program Delivery	0.012	0.118	0.224

Table 2. AM Sub-Indicator Weights

Major Indicators	Sub-Indicators	Lower Limit (-Std Dev)	Mean	Upper Limit (+Std Dev)
Asset Management Culture	Asset Management Champions	0.096	0.272	0.449
	Perception of Asset Management	0.092	0.216	0.339
	Effective Communication	0.120	0.303	0.487
	State Legislative Mandate	-0.014	0.209	0.431
Quality Information & Analysis	Asset Inventory	0.166	0.31	0.455
	Common Referencing System	0.131	0.296	0.461
	Up-to-Date Condition Data	0.092	0.204	0.316
	Data Management & Analysis	0.064	0.190	0.315
Policy Goals & Objectives	Policy Goals & Objectives	0.319	0.570	0.821
	Performance Measures & Targets	0.179	0.430	0.681
Planning & Programming	Resource Allocation	0.116	0.343	0.569
	Decisions Based on Condition Data	0.431	0.657	0.884
Program	Program	1.000	1.00	1.000

Delivery	Delivery		0	

Table 3. Total Weights for AM Sub-Indicators

Major Indicators	Sub-Indicators	Total Weight
Asset Management Culture	Asset Management Champions	0.053
	Perception of Asset Management	0.042
	Effective Communication	0.059
	State Legislative Mandate	0.041
Quality Information &	Asset Inventory	0.082
	Common Referencing	0.078
Analysis	System	
	Up-to-Date Condition Data	0.054
	Data Management & Analysis	0.050
Policy Goals & Objectives	Policy Goals & Objectives	0.171
	Performance Measures & Targets	0.129
Planning & Programming	Resource Allocation	0.042
	Decisions Based on Condition Data	0.081
Program Delivery	Program Delivery	0.118

The research team acknowledges the large standard deviations for the major AM indicators and sub-indicators. These deviations indicate that the data is scattered which may demonstrate that different AM experts have difference opinions about the criticality of AM indicators when implementing an ideal AM system. A perfect scenario for applying AHP through the use of a survey would be to conduct the survey in person with each participant. This would allow the participant to completely understand the meaning of Saaty's fundamental scale as well as how to accurately apply it for each comparison. However, this was not able to take place in this study due to travel constraints. As a result, the survey sent via email and regular mail to allow a wide distribution and a quick response time. Even though the survey contained instructions about the fundamental scale and how to apply the comparisons, the research team acknowledges that mistakes in both of these areas could have taken place, which might be attributed to large standard deviations. A better arrangement for the AHP based survey would have reduced the noises of the collected data.

5. ASSET MANAGEMENT ASSESSMENT MODEL (AM^2)

The Asset Management Assessment Model, namely, AM^2, for State DOTs represents the primary deliverable of this study. The purpose of identifying the AM indicators and assigning their weights was to create an assessment tool to more accurately measure the level of AM implementation within a State DOT. This AM^2 serves two purposes: (1) to be used as a diagnostic tool so that State DOTs may identify strengths and weaknesses within AM; and (2) to serve as an AM benchmark so that peer agencies may compare their results.

The model is available in a survey format. In the assessment model, each major AM indicator is listed with its associated sub-indicators shown beneath. For each sub-indicator, there are between one and five statements that must be evaluated. Each statement represents a benchmark level of AM implementation which help further define the given sub-indictor. The participant is to evaluate each statement on behalf of their DOT and choose whether they agree or disagree with the statement, to a varying degree (using a Likert scale). A 'don't know' option is also included as one of the responses. Based on their response, a score of 0-5 is given. This score is averaged for each sub-indicator and multiplied by that sub-indicator's weight. From these values, an overall AM assessment grade is given. This assessment grade will give the participant an idea as to how their DOT measures up to the AM benchmark from an overall perspective as well as in each major indicator and sub-indicator.

5.1 Validation of AM^2

Once the Asset Management Assessment Model was developed, it was tested and validated on five DOTs in order to validate the model's effectiveness. The model would be deemed effective if it returned grades that were in line with what could be expected from DOTs at known AM implementation levels. While currently it is not possible to know exactly what level of AM implementation a given DOT is at, it is known that certain DOTs are leaders in this area, others are in the initial stages, and some have not started any AM implementation.

Three broad AM implementation levels were chosen (high, medium, low) and DOTs for each of these three levels were selected. The top level represents DOTs that are advanced in AM and have been practicing AM principles for a number of years. The middle level represents DOTs that are familiar with AM practices and are implementing some of these practices, but still have room for growth and improvement. They understand what needs to be done, but do not currently have the capabilities to perform all of these tasks. The bottom level represents DOTs that have a limited understanding of AM principles and are currently doing very little or nothing to implement these practices. The five DOTs that were chosen are shown as anonymous, but are represented by the names and implementation levels given in Table 4. The purpose of this validation procedure was to determine if the AM Assessment Model would return grades for each of these DOTs that were within a predetermined range. It would be expected that DOTs #1 and #2 would have higher grades than DOTs #3 and #4, all of which should be higher than DOT #5.

Table 4. State DOTs Used for Validation

Implementation Level	State DOT
High	DOT #1
	DOT #2
Medium	DOT #3
	DOT #4
Low	DOT #5

Each of the five DOTs that were selected for this validation test was first contacted and an AM contact within the agency was identified. That person was informed about the study and then emailed a copy of the AM Assessment Model. The copy of the model that was sent to the participants did not include 'Results' or 'Score Breakdown' worksheets. This was an attempt to make the model as objective as possible. Without these worksheets, the participants could not check their score and then revise their answers in order to obtain a higher score. However, once the model was completed, the participants had the choice to request a copy of their results.

5.2 Results of Validation of AM^2

The results of the validation test matched the predetermined AM implementation level for each DOT. While the predetermined AM implementation level for each DOT was only a subjective value based on prior knowledge about the given agency's AM practices, it at least provided a starting point from which to compare the results from the AM Assessment Model (AM^2). The purpose of the model is to quantify the level of AM implementation within a State DOT. The results from the validation test reveal the quantified AM assessment grades for each DOT. These grades match the predetermined AM implementation level for each agency. DOTs #1 and #2 are clearly the two highest scores, followed by DOTs #3 and #4, with DOT #5 having the lowest grade (see Figure 2) Labeled next to or beneath each DOT in this graph is the predetermined AM implementation level.

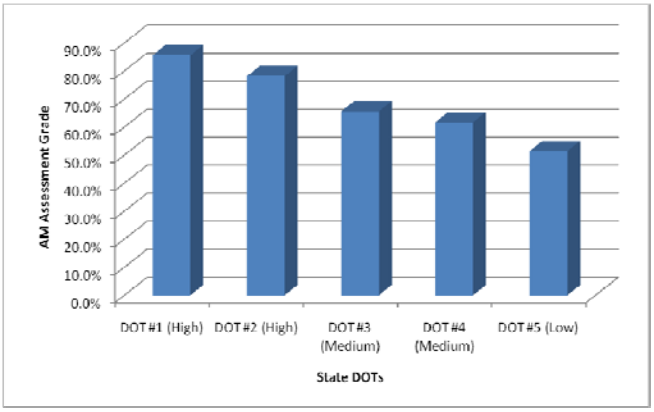

Figure 2. Validation Results

AM^2 provides a more precise measure of an AM implementation level than documented in previous AM research. AM^2 can also provide which area is lacking and which area is performing better than the other indicators. It can assist DOTs in determining areas to improve in order to implement more ideal asset management systems in state level. If nothing else, the model at least returns a grade for a given DOT within a range that should accurately describe the AM implementation level as shown by the results of the validation test.

6. CONCLUSIONS

This study developed a model (AM^2) that measures the level of AM implementation within a State DOT for a benchmarking purpose. In order to satisfy this goal, five different major indicators and thirteen different sub-indicators have been identified. The weights for the AM indicators and sub-indicators were quantified with the AHP method and sixteen AM experts in the U.S. Based on these quantified indicators, an AM assessment model (AM^2) was developed and validated with five DOTs. This model can be used by different DOTs to evaluate their current asset management systems and identify their strong areas and also their weak areas to improve in order to fully benefit from the advanced concept of asset management.

The first major contribution of this study is the identification of AM Culture as a major indicator. Throughout the literature review and interview process, it became evident that AM was more than just a set of practices and principles. It requires an understanding that AM is the "best way of doing business." Previous studies and AM officials both agree that AM should not be viewed simply as a new program or another competing management system. It should be viewed as a business practice that connects every department and manages the entire system as a whole. This requires buy-in from everyone within the agency as well as a change of culture. This concept has never been formally included as a necessary component of AM. Even though this indicator is subjective, this study identified and included AM Culture as a critical AM Indicator. AM Culture was validated as a critical indicator when it received the third highest weight of the five major AM Indicators.

The second major contribution is the weighting of the AM Indicators based on their level of importance. Conversely, this study rests on the assumption that certain AM Indicators are more important than others when implementing an ideal AM system. As a result, AHP was used to quantify the importance and develop weights for each major AM Indicator and Sub-Indicator.

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